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Introduction for Teachers

You are about to involve your students in one of the most exciting frontiers of science – the search for life elsewhere in the universe!

Central to the search for extraterrestrial life is the hunt for other Earth-like planets. Since the first extrasolar planet was discovered in the 1990s, new planets have been detected at an accelerating pace. Most of those discovered to date are fiery, uninhabitable places. However (if it hasn't happened by the time you read this!), scientists expect to find Earth-like worlds, orbiting just the right distance from their star, in the very near future. That means it is highly likely that this generation will be the first to find life beyond Earth.

Using the MicroObservatory telescopes and image processing software, students will detect actual alien worlds in other star systems. And working at the leading edge of what is known, they'll use computer models to predict what we could learn about Earth-like planets should we discover them orbiting other stars.

Students will be using the telescopes and models in the same way scientists do as they search for life beyond our home planet. Perhaps most impressive is that students can participate in this work armed only with basic scientific concepts typically taught in pre-college physics and earth science classes.

Your Tools

You'll have three primary tools to support your classes during this project. You'll have a project website that provides access to the telescopes, image-processing software and models. This website will also provide students with an opportunity to share their data with other students and scientists. They'll have a student guide that will help them understand how to use the telescope and other online resources to search for other worlds, and in which to record their ideas, calculations and findings. You will have this teacher guide, to support you as you facilitate your students' explorations.

The student guide describes a core set of activities to lead you through the data gathering and modeling process. The teacher edition supplements this with an explanation of the purpose of each activity, core concepts covered, suggestions of how to prepare, and more in depth background information. The teacher edition also provides suggestions for how to facilitate the activities, as well as why students are doing specific steps, common misconceptions, strategies for success, and possible student responses to discussion and assessment questions. The Supporting Resources page of the website also includes suggestions from teachers who have tried these activities in a variety of classrooms, from middle-school Earth Science to Advanced Placement Physics. The ideas from these teacher co-developers will help you adapt and supplement the core activities to address your own content goals and student needs.

Core Learning Objectives

This project is designed to work in a variety of physics, earth science and astronomy classrooms. To a significant extent, you will decide your students' learning objectives based on the content you intend to teach. However, all students will develop their understanding of the following core concepts during this project:

- Our Sun is a star, and the stars are suns. Even

the nearest star lies enormously far beyond our own solar system. Stars are orbited by planets, which may be very different worlds from ours.
- Light carries information. Scientists use light to learn about the universe.
- Some objects emit visible light of their own, while others merely reflect that light.
- The light we receive from a star system is composed of different wavelengths. There are wavelengths of light beyond what we can see.
- There are potential sources of error in all scientific measurements. Awareness of these potential errors and efforts to minimize them are essential to the identification of important data and ultimately to the advancement of science.
- Models are important tools used by scientists working at the frontiers of science. A model – physical, visual, or theoretical – captures important features of the world, and helps us analyze and predict its behavior.

Your students will also engage in other practices and skills central to scientific work:
- Using appropriate tools and techniques to gather, analyze and interpret data.
- Using graphing- and database programs to assist in quantitative analysis.
- Developing descriptions, explanations, predictions and models using evidence.
- Communicating procedures and explanations to others.
- Exhibiting curiosity about a topic as a motivation to ask additional questions or further investigate.
- Being open to new ideas yet able to question and test their own ideas and those of others.

Assessment

There are a number of opportunities throughout this project for you to use to assess students' progress. At certain points during the activities, students are asked, "What are your thoughts?" While some of these questions have no right or wrong answers, they can provide insight into the thought processes of your students. Also embedded in the project are several products, which can be assessed. Students are asked to make and test predictions using models and transit data they have collected. Students are also asked to do mathematical calculations, the accuracy of which can be assessed. In a final performance assessment, students apply what they learn about light curves to develop and support hypotheses about the conditions on mystery alien worlds. This final product will require students to apply all of the core concepts of the Other Worlds/ Other Earths project.

Scheduling This Project

This project is likely different from others you are doing in your classroom, because it needs to be scheduled to coincide with a real phenomenon in the natural world – a planetary eclipse of a star. The students will also be using a real telescope and dealing with variable weather conditions. That means they may have to make several attempts to obtain images successfully. Therefore, you will need to schedule your project to coincide with known planetary transits, which do not occur every night. It is very important that you familiarize yourself with the information in the Teacher Tutorial that follows before you schedule and begin your classes. This will make sure you are able to design your students' first experience on the telescope to ensure that they are successful in capturing a planetary transit.

Before you start the project!

Teacher Tutorial

Teachers who have done the Other Worlds project with their students have found that it sometimes takes multiple attempts to successfully obtain images students can use to detect alien planets. Therefore, it is important to start trying to get good transit images as early as possible in the project. The star images students take the very first time they use the telescope (on the first day or soon thereafter) will be the transit images they analyze throughout the first part of this project.

"The star images students take the very first time they use the telescope (on the first day or soon thereafter) will be the transit images they analyze throughout the first part of this project."

Transits do not happen every night. When scheduling this project and the night students will use the MicroObservatory telescope, you should consult the calendar of transits provided in Appendix A to make sure your students' images will be taken of the right star and at the right time to capture a transit. It is also recommended that you make sure that there will be several opportunities to take images of a transit during the first few weeks of your project. This is in case the first set of images isn't usable due to weather conditions (such as clouds), problems with the instrumentation in the telescope, errors in data entry when the images are ordered, etc.

It isn't necessary for students to understand the transit detection method before they use the telescope the first time, as long as you understand how to correctly schedule the images. To make sure these first images capture a transit, please read the following tutorial before the first day to make sure you understand :

"To make sure these first images capture a transit, please read the following tutorial before the first day to make sure you understand."

- what a planetary transit is, and how it can be used to detect planets orbiting other stars,
- how to read the calendar of transits,
- how to have students time their image-taking so that when they pool their images they will span an appropriate length of time to capture transit and baseline data,
- why it is important to also take an image with the opaque filter each night your students take images.

What is a Planetary Transit?

Astronomers have been hunting for planets that orbit stars similar to our own Sun. To date, they have detected more than 1000 of these new worlds. Current telescopes are not sensitive enough to see these planets directly. Instead, astronomers use indirect methods. One involves detecting a planetary transit.

What is a planetary transit? In a few cases, the orbit of an alien planet happens to be oriented so that the planet passes through our line of sight with the star. That is, the planet eclipses, or blocks, part of the star's light; once during each orbit. These are called transiting planets, because if we were closer we would see the planet transit

Before you start the project!

across the face of its star, just as Venus is transiting across the face of the Sun in this image.

< *Fig. T-1: The 2004 transit of Venus across the face of the Sun. Credit: Jan Herold. Source: http://en.wikipedia.org/wiki/File:Venustransit_2004-06-08_07-49.jpg*

How can a telescope be used to detect planetary transits?

Telescopes do more than take pictures – they gather light; and the images contain valuable information about the amount of light reaching the telescope from each star. It turns out that even a small telescope, such as the MicroObservatory telescope students will be using, is sensitive enough to detect a 2-3% drop in the amount of light reaching the telescope when the image is taken. To detect a transiting planet, you must take a series of images that span the timeframe of the entire transit; measure the brightness of the star in each of those images; plot it on a graph of time versus brightness; and look for the telltale dip in brightness that is the signal of the alien world.

How should I have students schedule their image so that they will capture adequate transit and baseline data?

It may take multiple attempts for you to successfully obtain transit images. Although these struggles to collect good data can provide good teachable moments for your students, it is important to maximize your opportunities for success within the timeframe you have to complete the project.

To meet the challenge of successfully detecting an alien world, the activities in this project have been laid out assuming that the images the students take at the very beginning of the project will capture a transiting exoplanet. It is not necessary for students to understand what a transit is when they take these images – they will use models to learn about this later. However, it is important that you schedule the specific night and times these first images are taken carefully so that the images can be used throughout the project.

To make sure your students order images on a night that a transit is occurring, you will need to consult the Calendar of Transits in Appendix A of the student guide. Your students should access the telescope on the day listed, to take images for transits that evening or early the next morning. The times listed are the predicted start and end of the transit, in Arizona time. On the pull-down menu, select times that span this range, plus an hour on either side if possible, for the baseline.

To capture a complete transit, you should make sure students order images at different times during the transit period, as well as for a period of time (an hour, if possible) before and after the transit is expected to occur, for the baseline data. The telescope can take an image every three minutes. Collectively your class should take a minimum of 25-30 images, at regularly-spaced time intervals, to make sure you have enough to see the dip in brightness. If you can double this number of images (two per student) that is even better.

Before you start the project!

(The more measurements you take, the more likely it is you will be able to discern a transit!)To make sure students' images are ordered at the right times, you may want to create a sign-up sheet like the sample one below. You can either have students sign up for a time slot before they order their images or you can assign them to students ahead of time.

Sample classroom worksheet

Date: 9/7/10

Name of Target: TRES3

Start Time *(time first image is taken – include baseline!):* 7:54 pm

End Time *(time last image is taken – include baseline!):* 11:12 pm

Time..... Student name

7:54........ Harry S

8:00........ Sally W

8:06........ Liam H

8:12........ Jonah B

Continue through transit and baseline….

Why is it important for me to take an image with an opaque filter to go along with the students' images (which are taken with a clear filter)?

Each night that transit images are taken, it is important to take one extra image with an opaque filter. This filter doesn't let any light into the telescope from the night sky. This image does, however, typically show that there is some light "pollution" from the telescope instrumentation. Students will subtract this image from each of their star images before they do their brightness measurements in Part 1 of this project, to minimize this source of error.

Overview of Activities

The Student Guide and Teacher Edition describe a core set of activities for this project. Depending on your students' prior knowledge and the nature of your course, you may want to supplement these with additional lessons.

The core activities are outlined as follows:

INTRODUCTION:

Students are welcomed to the community of planet hunters. They review their "cosmic address": Earth's place in the solar system, Milky Way Galaxy, and universe. They discuss their prior ideas about the search for extraterrestrial life on other worlds, drawing on popular culture as well as their own scientific knowledge, including books, articles, television shows, and movies they have seen.

PART 1: DETECT AN ALIEN WORLD AND FIND OUT WHAT IT'S LIKE.

Students use the MicroObservatory telescope to detect an alien world.

- *Activity 1.1: Use the telescope to take images of an "alien" solar system.* Students take, process and study telescope images They think about what they are telling them about what's out there.

- *Activity 1.2: Detecting an alien planet I: Modeling a transit.* Students use physical and computer models to predict how a planet would block the light of its star.

- *Activity 1.3: Detecting an alien planet II: Making the observations.* Students use images they have taken with the MicroObservatory telescope to detect an alien world orbiting around another star.

- *Activity 1.4: Creating a first portrait of your alien world.* Students analyze the light from the star to figure out the size of the planet; the nature of its orbit; its closeness to its star; and its distance from Earth.

PART 2: LOOKING FOR A HABITABLE PLANET... AND LIFE.

Students use models to decode a set of light signals from a mystery world, exploring what we might be able to learn in the near future about the potential for life on an alien planet.

- *Activity 2.1: Mystery Signal #1: Transit Graph.* Students apply what they learned in Part 1, analyzing a transit graph of their mystery world.

- *Activity 2.2: Searching for oceans, ice, and land. Decoding the light reflected from a planet.* Students study light curves that show the change in light reflected from a planet over time. They use computer models to analyze their graphs of reflected light versus time hypothesize about the nature of their mystery planet's surface.

- *Activity 2.3: Detecting plant life using infrared light.* Students explore wavelengths of light beyond what we can see. They use the MicroObservatory telescope to take infrared images of Earth's surface and look for signs of life in the infrared signal from their mystery world.

- ***Activity 2.4: Taking a planet's temperature using infrared light.*** Students use models to decipher the mid-range signature of their mystery world, determining its temperature and whether it is likely to have an atmosphere.
- ***Activity 2.5: Looking for an atmosphere and signs of life…using an absorption spectrum.*** Students use models to decode the absorption spectrum of their mystery planet, determining whether it has an atmosphere, and if so, its composition. They consider whether their spectral signal is consistent with a planet that might have life.

- ***Final Activity: What have you done? What have you learned?*** Students synthesize what they learned from the light curves of their mystery planet, and develop a portrait of what they think their planet might be like and whether it might have life. They share their hypotheses with their classmates, along with their supporting evidence. Then, they use what they have learned to evaluate and further develop each other's ideas.

INTRODUCTION

Your place in the Universe

Purpose

The goal of this portion of the project is to welcome students to the community of planet hunters; to discuss students' prior ideas, conceptions, and questions about other worlds and other life in the universe; to review, as needed, the basic concepts of planet, star, and galaxy; and to engage students in the search for alien worlds.

What Students Will Do:

- Learn about the Other Worlds project and the tools available on the project website.
- Discuss Earth's "cosmic address" — our place in the solar system, galaxy, and universe.
- Discuss their own ideas about the search for life elsewhere in the universe, and what conditions might be like on other worlds.

Core Concepts:

Our Sun is a star, and the stars are suns. Even the nearest star lies enormously far beyond our own solar system. Stars are orbited by planets, which may be very different worlds from ours.

Background:

To introduce students to the project, it is important to give them time to consider their own personal relationship with the universe beyond Earth, and think about why it might be interesting to look for other worlds. The introduction to the student manual and the welcome page on the website are designed to engage students and draw them in to the search for other worlds. Even more important are the discussions you will have with your students as they consider the hunt for life elsewhere in the universe and its personal meaning. Take your time with this!

Preparation and Materials for the Introduction

TECHNOLOGY REQUIREMENTS:

- None.

MATERIALS:

No materials required for the activities described in the introductory part of this guide. However, you may want to check the Supporting Resources page of the Other Worlds website for additional images, videos, and ideas about introductory activities you could do with your students to engage them in the search for other worlds.

INTRODUCTION

Your place in the Universe

Join the Search for Other Worlds...

Welcome to the community of planet-hunters! You are about to become involved in one of the most exciting frontiers of science—the search for other worlds, for other Earths, for other life.

Were you able to find Earth in the cover image of Saturn? It's just a tiny dot, behind the rings of Saturn near the left of the photo. Can you spot yourself? Of course not! In fact, there is no way to tell from this image whether there is any life on that dot we call Earth.

If the Earth is just a single dot of light in the picture taken from Saturn – a neighbor within our own solar system — imagine how extraordinarily tiny distant planets in other solar systems would appear.

Because other star systems are so extremely far away, until very recently, humans only knew the familiar planets of their own solar system – Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.

Then things changed.

> "You are about to become involved in the search for other worlds... for other Earths... for other life."

In the last few years, astronomers have found planets orbiting stars far beyond our own Sun. These "alien" solar systems appear to be very different from our own. More than a thousand other planets are now known, and many more are being discovered as you read this.

What are other worlds like? Are there other Earths out there? Other life forms we can't begin to imagine? Other civilizations? People have asked these questions for as long as there has been a night sky to wonder about. However, it is your generation that is poised to find the answer.

A door is opening to the rest of the universe. Come on in!

Figure 1: What would it be like to have two stars in your solar system?
Credit: David Aguilar, Harvard-Smithsonian Center for Astrophysics

What You Will Do in This Project

IN PART 1 OF THIS PROJECT... you will search for an alien world in another star system. You're going to try to figure out as much as you can about this world, using just your understanding of science and nature, and the telescope images you take yourself. How far away is this world? How big is it? How close to its star? What does its orbit look like? Could it harbor life?

"You will search for an alien world in another star system."

IN PART 2 OF THIS PROJECT... you will use your imagination—and your understanding of science—to envision planets not yet discovered. You'll learn how to decode the faint signals of light from another world—signals that would tell us that life has company in the universe.

At Your Service

You'll have a suite of tools to support you as you attempt to detect and decipher signals from other worlds:

- This guide will tell you what you need to do and will give you a place to record your ideas, calculations, and results.
- Through the Other Worlds website (http://www.cfa.harvard.edu/otherworlds) you'll have access to a telescope and the tools you'll need to process your sky images and share your findings.
- You'll also have an array of computer models to help you visualize and decipher light signals from other worlds.

Your Cosmic Address

You'll be looking out into space vast distances to look for another planet. As a starting point, it's important to think about where you are right now, right here on your home planet.

If there are any creatures on the worlds you'll be exploring, they won't be writing to you anytime soon. But if they did, where would they send the letter? What's your cosmic address?

Here's a quick reminder for your galactic post office:

Your Name: ____

Your Street: ____

Your Town or City: ______________________________________

Your State: ____

Your Country: ____

Your Planet: ____

Your Solar System: ______________________________________

Your Galaxy: ____

WHY ARE THEY DOING THIS?

It is important for students to take a "big picture" view of the universe before focusing in on their target star. This is an opportunity to review the difference between a star, planet, solar system, and galaxy.

COMMON MISCONCEPTIONS

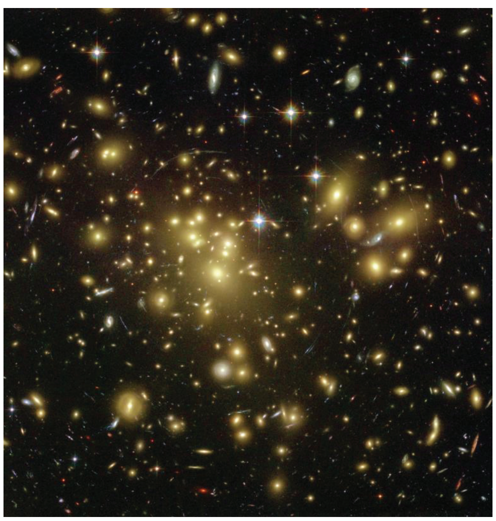
Students often show confusion about the relative location of objects they see in the night sky. For example, many students believe that there are other stars and even galaxies within our solar system.

STRATEGIES FOR SUCCESS

Suggestions of other activities you could do to engage students in the search for alien worlds are included on the Supporting Resources page of the Other Worlds project website.

< *Figure 2: A solar system is a star (e.g. our Sun) orbited by its planets (e.g. Earth). Credit: NASA http://www.nasa.gov/centers/goddard/images/content/226335main_earthsun_200803XX_HI.jpg*

< *Figure 3: Our Milky Way Galaxy is a giant swirl of billions of stars and their planets. Only the nearest stars can be seen individually with the unaided eye. Credit: NASA http://apod.nasa.gov/apod/ap051004.html*



< *Figure 4: Our universe is home to billions of galaxies, each containing billions of stars and their planets. Abell 1689: http://hubblesite.org/newscenter/archive/releases/2003/01/image/a/ Credit: NASA, N. Benitez (JHU), T. Broadhurst (Racah Institute of Physics/The Hebrew University), H. Ford (JHU), M. Clampin (STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA*

As you can see from the images above, there are a huge number of stars and their planets in our universe—so many that we have little experience dealing with numbers that large.

In this project, you'll be exploring only the solar systems nearest to Earth. These are the ones that can be observed most easily, and where astronomers have the greatest chance of actually detecting habitable planets.

As you'll see for yourself, even these "nearby" worlds are incredibly far away. The universe is vast, beautiful, and mysterious.

WHAT ARE YOUR THOUGHTS?

Throughout this module, you'll be asked to ponder certain questions, share your ideas, and generate questions of your own. You are a part of a planet-hunting community, but you are also on your own personal journey into the universe beyond Earth—so engage your mind and heart!

Consider the following questions. Remember not to worry about whether you are "right" or "wrong" — just write your ideas.

1. Telescopes have helped humans see far beyond our own planet, solar system, and galaxy. Do you think your life would be different if telescopes had never been invented?

2. Why do you think we Earthlings are so curious about whether there is life out there?

WHY ARE THEY DOING THIS?

The class discussion about these questions will give students a chance to articulate their personal ideas about the possibility of life beyond Earth, and what life might look like on other worlds. It will also help to broaden their thinking to consider the incredible array of possible planets and planetary orbits that may exist in the cosmos.

QUESTION 1: *Students' answers should reveal their personal feelings about Earth's place in the universe. You might ask them if knowing what's out there makes them feel less significant, or, conversely, more significant because they are connected to the vast cosmos. Students should recognize how amazing it is that humans can know so much about stars and galaxies that are billions of miles away.*

QUESTION 2: *Students' answers to this should reveal their own curiosity about other worlds and the possibility of life beyond Earth. To probe students' thinking, you might ask "How would it change things if we did find signs of life? What would you do? Would you be scared? What would it mean for Earth's future?".*

3. Most of the other solar systems discovered so far are not like our own. For a moment, travel in your imagination to an alien world. Describe what you think life might be like on:
   a. A planet with one side that always faces its star.

   b. A rocky planet much bigger than Earth, where there's more space on the surface and where gravity is stronger.

STRATEGIES FOR SUCCESS

Some students will be uncomfortable not knowing the "right" answers to these questions. Make it clear to students that you are not looking for a particular answer – only their ideas. It's important early on in this project to create an atmosphere that allows students to safely articulate their thoughts, and what they don't know, as well as what they do. Probe them gently to encourage them to explain the basis of their thinking.

QUESTION 3a: *Students should realize that this would make one side very hot all the time, and the other side very cold. They should also realize that it would be permanent day on one side of the planet and permanent night on the other. Have them think about whether there might be any parts of this planet that might have conditions conducive to life.*

QUESTION 3b: *Students might think about this question from a personal/human perspective, and imagine what it would be like to have more space for people to live, or for them to be heavier and for movements to be more difficult. They might also take a broader perspective and think about how life evolving on a planet with more gravity might look different from life on Earth.*

c. A much smaller rocky planet, where you'd have less space on the surface and weigh very little.

QUESTION 3c: *As with (c), students' answers will vary depending on whether they are thinking about this from a human perspective or from the broader perspective of potential impacts on the evolution of life. They might think about the ease with which they could move about, or about increased competition for space on this smaller world.*

d. A planet that is always cloudy, and there is never a clear day or night.

QUESTION 3d: *Students might wonder if there would there be enough light on the surface to support life. From a human perspective, people on the surface would never have seen the stars…*

e. A planet with a very eccentric orbit, so that for part of the year it is extremely close to the sun and part of the year it is very far away.

QUESTION 3e: *Your class discussion of this question is a good opportunity to review students' understanding of the cause of Earth's seasons. Earth's seasons are caused by the planet's tilt (the orbit around the Sun is nearly round). In this example, the very eccentric orbit would cause extreme temperature differences from one part of the year to another.*

4. What movies, books, articles, or television programs have you seen that helped shape your view of "what's out there"?

QUESTION 4: *Students' ideas about the universe are likely to be highly influenced by representations in the media. Although the information in science fiction movies and books may be far from real, these fictional stories serve to spur the imagination and help you envision possibilities. In fact, many professional astronomers originally became interested in their field through exposure to science fiction in their youth.*

5. What are some of your questions about other worlds and other life in the universe?

QUESTION 5: *Students' questions will vary, depending on their personal interests. They should understand that all scientific exploration begins with questions.*

PART ONE

Detect an alien world and find out what it's like

Purpose

To give students an opportunity to detect actual alien planets in distant star systems.

What Students Will Do:

- Take images of a star system and a galaxy with the MicroObservatory telescope.
- Retrieve and process their star and galaxy images using the MOImage software.
- Reflect on their personal ideas about the nature of a galaxy and the vast scale of the universe. Consider whether they might be looking at other Earth-like worlds and even other life in their star and galaxy images.
- Use physical- and computer-based models to predict how the star's brightness will change as a planet transits.
- Detect a planet orbiting the star.
- Figure out the size of the alien planet; what its orbit is like; how close the planet is to its star; and how far the planet is from Earth.
- As a class, publish these results to the planet-hunting community.

Core Concepts:

- Our Sun is a star, and the stars are suns. Even the nearest star lies enormously far beyond our own solar system. Stars are orbited by planets, which may be very different worlds from ours.
- Light carries information. Scientists use light to learn about the universe.
- There are potential sources of error in all scientific measurements. Awareness of these potential errors and efforts to minimize them are essential throughout science.

- Models are important tools used by scientists working at the frontiers of science. A model – physical, visual, or theoretical – captures important features of the world, and helps us analyze and predict its behavior.

Background:

Just a few decades ago, astronomers could only speculate about the existence of planets beyond our solar system. This is because current telescopes are not sensitive enough to see planets directly. Then, the first planets were found by looking for the telltale sign of an orbiting planet: the star wobbles slightly as the orbiting planet's gravity tugs on the star. (For example, even though the Earth is a million times less massive than the Sun, its gravity moves the Sun by about one yard every second – a leisurely walk.) Since then, astronomers have detected more than 1000 of these new worlds.

In a few cases, the orbit of these planets happens to be oriented so that the planet passes through our line of sight with the star. These planets transit across the face of their star and block part of the star's light, once during each orbit. The planets that we will investigate are transiting planets. These are of special interest to astronomers because, as you will see, we can tell a great deal about what these planets are like.

By carrying out the investigations in Part 1, you and your students will become part of this historic search.

Preparation and Materials for Part One

TECHNOLOGY REQUIREMENTS:

- A computer and web access for each pair of students.
- A copy of MOImage should be on each computer. (Download from the Getting Started page on http://www.cfa.harvard.edu/otherworlds)
- Other Worlds Orbits model [accessible on Modeling Lab page of the project website]
- LCD projector or other video projection capabilities, for showing video clips of Venus transit (provided on website page, Getting Started)
- [Optional] Printer to print telescope images

MATERIALS:

- Desk lamp, tennis balls, shower curtain or similar objects to use for physical modeling of planetary transits.
- Calendar of transits (see Teacher Guide Appendix A)

PART ONE

Detect an alien world and find out what it's like

If all you had were your eyes to work with, your ability to explore the universe would be limited. However, with the telescope under your control you will have superhuman capabilities! That is because the telescope gathers much more light than human eyes do.

In this portion of the project, you'll take images of a galaxy and star and then think about what they are showing. Then, you'll begin your search for an alien world. You'll take measurements of your star images and analyze them to search for the signal that will tell you there's an orbiting planet. Your measurements will even tell you what that planet is like, and how far you have to travel to get there.

TEACHERS NOTES

ACTIVITY 1.1

Use the telescope to take images of an "alien" solar system.

PURPOSE

To take, retrieve, and process images of the star that students will be investigating, along with an image of a distant galaxy of stars.

WHAT STUDENTS NEED TO KNOW/APPLY: A galaxy is made up of billions of stars. Many stars, like our Sun, have orbiting planets.

BACKGROUND

Students will have an opportunity in this activity to take images of a galaxy and star and then to think about what they mean. This will also give you an opportunity to assess their preconceptions about the night sky.

MicroObservatory telescopes, although relatively small compared to those used by large observatories, are valuable tools for exploring the night sky. MicroObservatory magnifies only about 30 times, but it gathers about 500,000 times more light than human eyes can.

Students' images have captured light from a vast expanse of the cosmos, even though the telescope was pointed at only one twenty-thousandth of the night sky. The galaxy in their image is likely to span a distance of 100,000 light years, and each star in the galaxy is an average of 5 light years (30 trillion miles) apart. The stars within the galaxy glow so brightly that we can see the galaxy's graceful form from Earth. Yet, at the scale of students' images, each star is smaller than an atom!

ACTIVITY 1.1

Use the telescope to take images of an "alien" solar system.

What You Will Do: Take an image of an "alien" solar system and a distant galaxy using the telescope.

You'll start your search for other worlds by using the telescope to take images of a star thought to be orbited by planets — an "alien" solar system, perhaps not so different from ours. And to help you get a "big picture" view of the universe, you'll also take images of a distant galaxy of stars.

In this activity, you'll learn how to:

- use the telescope to take images
- enhance your images to bring out details
- interpret the "big picture" of what's in your images
- jot down any questions that these images might inspire

GET A USERNAME AND PASSWORD

Your teacher will help you choose a username and password in a standard format. These will allow you to access the telescope, take images, and publish your findings on the Web. Record your username and password in Table 1.1 (on page 16), so you won't forget them.

MEET YOUR INSTRUMENT

Your instrument for exploring is the MicroObservatory telescope. The telescope is located at the Smithsonian Institution's Whipple Observatory near Tucson, Arizona. But you'll control it remotely from your classroom or from home.

MicroObservatory is just a small telescope — its mirror is barely six-inches wide — but it can see a billion light-years into space. It has a camera inside, so you can take your own images of what the telescope is looking at. It is ideal for searching for other worlds.

Figure 5: A MicroObservatory telescope near Tucson, Arizona. "I'll be your telescope tonight... May I take your order, please?" Credit: Smithsonian Astrophysical Observatory

CHOOSE A STAR TO EXPLORE

You may not have much of a choice! Although astronomers have detected hundreds of planets beyond our solar system, only one or two may be detectable on the day you take your images. Your teacher will help you and your team choose a star to explore, based on a calendar that predicts when a planet orbiting your star will be detectable.

CHOOSE A GALAXY TO OBSERVE

You'll also take an image of a distant galaxy of stars. We live in the Milky Way Galaxy, a giant swirl of hundreds of billions of stars, including the one we call our Sun. But we can't see our own galaxy as it would look from the outside. So taking an image of another galaxy will give you some perspective on what a galaxy looks like and how huge the universe really is. The telescope menu will offer you a choice of galaxies to observe.

ACCESS THE TELESCOPE AND TAKE IMAGES

Control the telescope using Protocol 1.

PROTOCOL I

How to take images with the telescope

1. Access the telescope from the Other Worlds Web site: http://www.cfa.harvard.edu/otherworlds.
2. From the home page menu, click on "Telescope Access."
3. On the Telescope page, choose your target star or galaxy from the pull down menu.
4. Enter the time you would like to take the image. (Note: The time on the pull-down menu refers to the Arizona time zone at the telescope.)
5. Select your camera settings: Set an exposure time of 60 seconds. Select the clear filter.
6. RECORD the date and time your image will be taken in Table 1.1. You will need this information to find the image after it has been taken.
7. Enter your username and password.
8. When all of the required information is entered, click "take image tonight." You will receive a message that the image will be taken at the requested time. If any information needs to reentered, the computer will prompt you.
9. Repeat the above process to take more images.

TABLE 1.1: IMAGE INFORMATION

Your username and password	
Name of your target star	
Date your star image will be taken	
Time your star image will be taken	
Name of your target galaxy	

What You Will Do: Download and view your images of a galaxy and a star.

Keep in mind that students' images will be deleted from the MicroObservatory image archive after two weeks. It is important to save the images so that students will be able to use them later in the project to detect a transiting planet.

RETRIEVE THE IMAGES YOU TOOK WITH THE TELESCOPE (THE NEXT DAY)

Like most night-sky explorers, you may be eager to see if your images were taken successfully. Did a sudden rainstorm spoil your plans, or were the skies clear? Did the telescope work as it should? It's time to find out.

To download and save your images, follow the steps below in Protocol 2: Retrieving and Saving Your Images.

Remember

You're taking real images using a real telescope. If the sky is cloudy, you might have to try again.

IMPORTANT: Be sure to download the version of your image that is in FITS format. The FITS image contains much more information than the version you see in your Web browser (which is in GIF format). You'll need these FITS images for later work. To see your FITS image, you'll have to open it in special software, described below.

PROTOCOL 2

How to retrieve and save images

1. You can get your images by clicking on "Get Images" on the home page of the project website.
2. Your requests will be listed including their status (pending or complete). Click on "GIF" link to take a quick look at your image.
3. Click on the "FIT" link for your image to download and process your image.

PROCESSING YOUR IMAGES

To see fine details in your images — especially your galaxy image — you may want to adjust the contrast and brightness. You can do this using the image-processing program, MicroObservatory Image. Follow Protocol 3.

PROTOCOL 3

How to process your images

1. Open the image processing software MOImage. When a blank blue screen appears, open your FITS image by dragging it to the blue screen.

ADJUST IMAGE

2. To process the image, click on "Process" at the top of the MOImage window and select "Adjust Image" from the pull-down menu. A new box will appear on the screen. Click "auto" in the image processing box. This will automatically adjust the image so that it is easier to see. The image can be further adjusted by dragging the arrows on the bar up and down to change the contrast in the image.

CHECK IMAGE QUALITY

3. Are you wondering if you have a good image? Do you think there might be clouds? Is it too dark? Are there streaks of light

STRATEGIES FOR SUCCESS

If these images don't work out and students need to try again, but there isn't a transit predicted for a number of days, don't despair. Students could take star and galaxy images the very next night and work with them on Activities 1.1 and 1.2. Then, have them take images for Activity 1.3 on a predicted transit night.

Students could work with archived images if they have a cloudy night and the images aren't successful (Archived images are available on the Get Images page of the Other Worlds website).

PROTOCOL 3 CONTINUED

that you think might be a problem? Go to the Process Image page on the Other Worlds website for tips on how to recognize a good or bad image.

PRINT IMAGE

4. If you would like to print your image, it will save ink and make it easier to see if you first invert the image so that the stars look black and the background looks white. To do this, select "invert color" from the Process drop down menu.

Are you wondering if you have a good image? Go to the Process Image page on the Other Worlds website for tips on how to recognize a good or bad image.

GALAXY GAZING

Take a few moments to study your images. Consider the "What Are Your Thoughts?" questions that follow and write down your ideas.

Figure 6: This is a composite image of the M81 galaxy taken using NASA telescopes. The blue areas are younger, hotter stars. The orange/ yellow area toward the center contains older stars. Image credit: NASA/JPL-Caltech/ESA/Harvard-Smithsonian CfA

COMMON MISCONCEPTIONS

Students often show confusion about the nature of galaxies, stars and solar systems, and have difficulty comprehending the vast distances between celestial bodies. Many students believe that stars are all the same size and are evenly distributed through a galaxy or universe. Conversely, some believe distant galaxies are very "crowded" (objects within the galaxy are relatively close together). Many are likely to have difficulty grasping the scale of our solar system relative to the cosmos.

WHAT ARE YOUR THOUGHTS?

Record your ideas about your galaxy and star images below.

1. Describe (if you can!) how big the area is that you are looking at in your galaxy image.

QUESTION 1: *Students are likely to have a variety of answers to this – some who have prior experience with the MOImage processing software may even try to measure the number of pixels covered by the galaxy in the image. What is important is that they should recognize the actual area they are looking at is immense – many times larger than our solar system.*

2. What are you actually seeing when you look at the galaxy? If you could go to that galaxy, what would it be like?

QUESTION 2: *Students should understand that they are in a galaxy called the Milky Way. Although the stars in a galaxy look close together when viewed from far away, they are actually quite far apart. The number of stars you would see in the night sky would vary according to where you were in the galaxy, with more stars toward the center.*

Amazing fact

It would take 30,000 pictures like yours to cover the entire night sky!

3. Now look at your star image. Use the star chart provided on the Getting Started page of the project website to find your target star. Do you think you are seeing another solar system? Another Earth? Another you?

QUESTION 3: Students answers will vary, and will reveal their initial ideas about whether there are planets like Earth orbiting other stars, and whether there is likely to be life elsewhere in the universe.

Did you know?

Are you having trouble finding your star in your image? There is help for you on the Other Worlds website! Go to the Process Image page to hone your skills in recognizing stars!

4. Make a prediction: Do you think it is really possible to tell — just from your images — if your star is orbited by a planet? Do you think you could tell anything about the planet itself, if there is one? Why or why not?

QUESTION 4: It does seem unlikely that the images they took can provide any clues about the presence of a planet, let alone what the planet is like. Have them keep an open mind. They will revisit their prediction at the end of Part 1, after they have accomplished the seemingly impossible.

5. W hat kinds of questions do you have about the images you've taken or about "what's out there?"

QUESTION 5: Students may be hesitant at first, but accept all questions. Getting in the habit of asking one's own questions is an important part of scientific inquiry. And it is a good opportunity to note of students' interests and refer to them as appropriate during the activities.

Teachers Notes

Activity 1.2

Detecting an alien planet 1: Modeling a transit.

PURPOSE:
To predict how the observed brightness of a star would change with time, as a planet orbits the star.

Students will use their prediction to help interpret their results in the next activity, when they use their star images to look for a transiting planet.

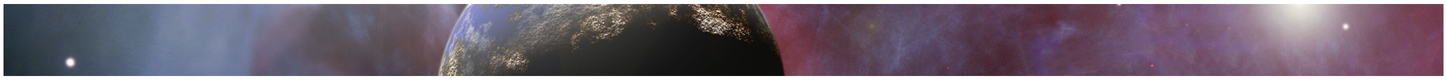
What Students Need to Know / Apply: Objects casts shadows. The bigger the object, the more light it blocks.

BACKGROUND:
Models are essential tools for all of the sciences. A model captures some, but not all, of the feature of a real system. Scientists use models in order to make predictions about what they might find during an experiment; and they use models to help them interpret what they find. A model can be a physical object, a computer program, or even a set of mathematical equations.

In this activity, student will use both physical- and computer-based models of a solar system to predict how the brightness of their star varies as a planet transits across (eclipses) the star. Later, after they have made their actual observations, they will use the same models to begin to visualize what their alien solar system might look like.

Graphs are also essential tools used throughout the sciences. In this and the next activities, students will use simple graphs to predict what they will find; then to represent the data they do find; and finally, to interpret what they have found.

In this activity, the focus is on using a graph as a representation of an idea; in this case, the idea is that the orbiting planet blocks out a portion of the star's light as it transits across the face of the star. By graphing the star's brightness over time, we can visually see the time period when the planet transits: the star will be less bright then. (Try not to let the details of graphing obscure the simplicity of this idea.) The process you'll use in this activity is used by scientists everywhere, in their hunt for other worlds.



ACTIVITY 1.2

Detecting an alien planet I: Modeling a Transit.

What you will do: Use physical and computer models to visualize a planet eclipsing its star.

So far, your star is just a dot of light. There seems to be no hope of actually detecting a planet orbiting that star. Or is there?

You're going to try to detect a faint signal that tells us the planet is there. Here's the signal: Every time the planet orbits the star, it blocks out some of the star's light as it passes between the star and our line of sight. So the star should appear dimmer as the planet "eclipses" it.

Before you can look for the signal in your images, you'll need to work with models that will help you predict what the signal should look like. Scientific models help us predict what we might find — and help us interpret what we do find.

BACKGROUND:

As the planet orbits its star, it periodically blocks out some of the light from its star. (This is similar to an eclipse of the Sun, where the Moon blocks out the light from the Sun.)

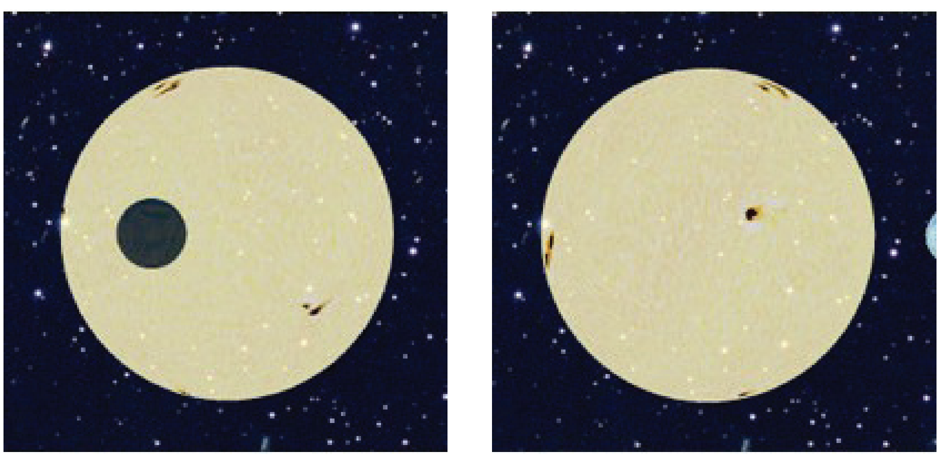


Figure 7: Left: As seen from Earth, a planet that passes in front of its star blocks some of the star's light. This is called a "transit." Right: After the transit, more of the star's light is visible (plus a little bit of light reflected from the planet.) [Note that "sunspots" on the star might be confused with a planet.]

Do the physical modeling as a demonstration. Simple physical models using a ball for the planet and a desk lamp for the star work well for this activity. Have students observe the model as you orbit the ball around the star. Discuss the questions in their student guide as they observe, and then have them record their thinking.

Students may have difficulty imagining that stars are so far away that we are not able to see the orbiting planet directly, as they can with the model. You might want to hold a piece of wax paper, or fluorescent light cover between the physical model and their eyes to help them focus strictly on the light.

A planetary eclipse of a star is known as a transit. The transit detection method is one of the most important ways to find planets in other star systems — and it's the one you will use. However, it only works when the orbit of the alien planet happens to be aligned just right, with respect to our line of sight.

WORKING WITH A PHYSICAL MODEL

You will observe a simple physical model of an alien solar system, using materials such as a desk lamp and a ball. View your model as you would view an alien solar system from Earth. Remember to imagine that you would be so far away that you would not be able to directly "see" the planet with your eyes or the telescope. All you would see is the starlight.

Discuss the following questions as you observe the model, and record your thinking.

STRATEGIES FOR SUCCESS

For more ideas about the types of physical models you might use, see the Supporting Resources page of the project website.

STRATEGIES FOR SUCCESS

If you have the time and think your students would benefit, you might want to have students do the modeling themselves. Students could even design their own model, selecting from a variety of materials.

1. What happens to the brightness of the light reaching your eyes from the light bulb when the model planet passes in front of the model star?

QUESTION 1: *Students should notice that the light dims briefly when the planet passes directly between their eyes and the light.*

2. What happens to the brightness of the light reaching your eyes during other parts of the planet's orbit (when it isn't blocking the model star's light?)

QUESTION 2: *Students should notice that for a long time (relative to the transit time) the light isn't dimmed. They may notice that for a short time when the planet is about to orbit "behind" the star, they see the light from the star plus light reflecting off of the planet and toward their eyes. They will not be able to discern this additional reflected light when they do their measurements. However, scientists are developing technologies to separate out the light reflected from a planet. They will model what they would be able to learn from the planet's light in part 2.*

3. Try changing the orbit so that the planet no longer passes directly in front of your eyes. How does that affect the light reaching your eyes?

4. Try using a larger planet. How does that affect the light reaching your eyes?

QUESTION 3: *Students should notice that the light only dims from their perspective if and when the planet passes between their eyes and the star. If the planet's orbit is tilted so that it does not eclipse the star from the viewer's perspective, they will not see the dimming that is the telltale sign of an orbiting planet. We are only able to detect (using the transit method) the planets with orbits that are oriented just right from Earth's perspective.*

COMMON MISCONCEPTIONS

Students may become confused when they notice that moving the ball closer to their eyes relative to the light bulb seems to block out more of the light. This doesn't happen with transiting planets, because we are so far away from both the star and planet. The amount of light blocked out is affected only by the size of the planet, not its distance from the star.

QUESTION 4: *Students should notice that a larger planet blocks out more of the light.*

5. Models are useful for helping you visualize what you aren't able to observe directly. Write your ideas about the following:

   a. How would the alien solar system you modeled look different if you viewed it from millions of miles away?

QUESTION 5a: *This question is posed now to remind students that they would not be able to see the planet – only a tiny pixel of light from the star. With sensitive-enough instruments, they would see the brightness of the star's light decrease as the planet passes between their eyes and the star.*

   b. The MicroObservatory telescope can't see continuous motion, the way your eyes can. It can only take one image every three minutes. How would you use the telescope to detect changes in the light from the star over time?

QUESTION 5b: A series of images taken by the telescope, over a time period encompassing the transit and a bit beyond, would allow them to detect the transit.

You might want to ask students to think about what would happen if the images were taken at times that were too far apart to detect the orbit. How many images during, before and after a transit do they think it would take?

WORKING WITH A COMPUTER MODEL

Now you'll use a computer model to help you predict what a graph of your star's brightness over time might look like, as a planet orbits your star. You will use the results to guide you when you try to detect a planet using the images you have taken of your star.

Access the Orbits Lab on the Other Worlds Web site: Go to http://www.cfa.harvard.edu/otherworlds and choose Modeling Labs on the menu. Click on the Orbits Lab link.

The model shows a planet orbiting around its star. In this model, time is speeded up: In reality, it would take days, months, or years for a planet to orbit once around its star. Also, the planet would be farther away from its star.

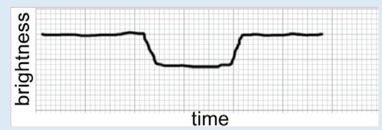
Step 1. Observe the model and a sample graph.

In this first view, the planet transits directly across the center of the star. Push the Show Graph button to have the model generate a sample graph. This graph shows how the star's observed brightness changes with time. Watch carefully what happens on the graph when the planet transits in front of its star. Does the graph make sense to you?

Draw the graph generated by the model (use the margin to the right). Label the graph so that it is clear the x-axis represents time and the y-axis represents brightness. Explain in your own words what the graph is showing. How does this graph relate to what was happening with the planet and star?

Your explanation:

Before students begin using the Orbits Lab, you might want to talk as a class about what a graph of brightness vs time during a planetary transit would look like. Students should recognize that if we could observe the star's brightness during the course of a transit, and graph our results, we might expect a graph like this:



This graph shows that the star's brightness appears the same for a while, but as soon as the planet blocks some of the star's light, the star appears a little dimmer. When the transit is over, the planet is no longer blocking the starlight. The star then appears as bright as it was originally. (Note: For now, ignore light coming from the planet, and focus only on the star's light. The star is very much brighter than the planet!)

Step 2: Predict what the graph will look like if...

Here comes the challenge. Hit the Next button on the Orbits model to access the model's control panel. Now you can change the planet's size and orbit. But it will be up to you to draw the graph.

Use the model to help you predict what a graph of the star's brightness versus time would look like for three cases:

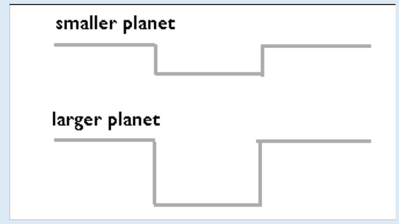
a) The planet is larger than the one shown in the sample. (Try increasing the size of the planet. How does that change the amount of light you see from the star?) Draw the graph you predict in the right margin:

How is this graph different from the sample graph?

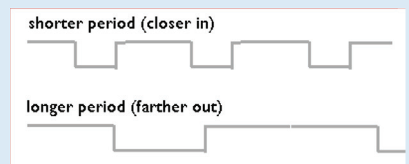
b) The planet orbits faster than the one in the sample. (Try making the planet orbit faster. Note: In real life, faster planets orbit closer to their star.) Draw the graph you predict.

How is this graph different from the sample graph?

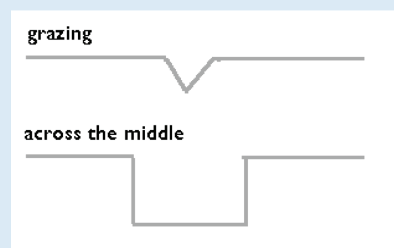
Students should recognize that a bigger planet would block out a larger percentage of the star's light, making a graph that looks like this



If a planet has a shorter orbital period, less time will elapse between successive dips in the brightness curve. Students might also know that a planet with a longer orbital period is further away from its star, and will travel more slowly, so will block the light for longer time:



A grazing planet will block out less light and for a shorter time.



c) The planet's orbit just grazes the star... (Try tilting the plane of the orbit to change your point of view.) Draw your predicted graph.

How is this graph different from the sample graph?

Step 3. Check your predictions with the model

Now that you've made your predictions, hit the Next button on the model. Adjust the model and use the graphing feature to see what graph the model predicts for a larger planet, faster planet, or tilted orbit.

Did your predictions match the predictions of the model? If the model's predicted graph looked different explain how it was different.

Summary: Using your predictions

Good work! You've found that just by following the brightness of the star, you will be able to:

- detect a planet in orbit around the star
- tell something about the size of the planet
- tell something about the orbit (whether it is tilted or not, as seen from Earth).

You'll use these results when you work with your telescope images in Activity 1.3.

WHAT ARE YOUR THOUGHTS?

Pull together what you've learned from your modeling by discussing the following questions with the class. To help you think about these questions, your teacher will show you videos of a transiting planet in our own solar system — the transit of Venus across the face of the Sun in 2004.

1. The videos show a real transit, whereas the models are just a simulation. So what was the point in working with the models? In what way did they help you prepare to detect a planet?

Show the videos of a Venus transit (provided on the Getting Started page of the Other Worlds website) and go through the Orbits Model on the Getting Started page of the Other Worlds website, as you hold a class discussion of the What Are Your Thoughts questions.

QUESTION 1: The computer models are interactive and allow you to simulate the variety of planets and orbits that are possible. Models such as this help you make predictions about what you might observe, and to develop explanations for observed phenomena.

TEACHERS NOTES

ACTIVITY 1.3

Detecting an alien planet II: Making the observations

What Students Need To Know / Apply: To find patterns in data, it is important to minimize sources of error in measurements.

PURPOSE:

To detect an alien world.

BACKGROUND:

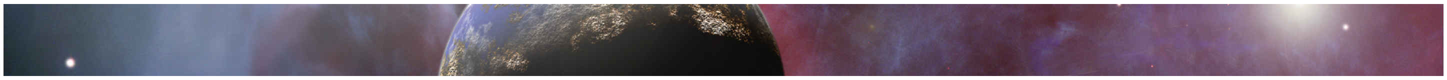
Of the billions of stars in our Milky Way galaxy that are expected to have planets orbiting them, only a few dozen of the closest stars have actually been observed to have planets transiting across them. You are going to explore one of them.

You might think this would be easy: The star is bright for a while, and then dimmer when the planet blocks some of its light. What could be easier to detect?

One problem is that planets are much smaller than stars, so they block out only a few percent — at most — of the star's light. The giant planets you'll detect block out about 2% of their star's light. (The Earth would block out a mere 0.01% of the Sun's light during a transit!) Another problem is that there are many competing factors and sources of error. To cite a few:

- clouds or haze may drift across the telescope's field of view
- our atmosphere blocks out increasing amounts of starlight as the star sets on the horizon
- not every pixel on the telescope's chip is equally sensitive to light
- electronic noise in the telescope's chip may create a signal when none is there
- the star may have starspots (i.e., sunspots) that change its brightness

In view of this, your quest to detect an alien planet is a heroic effort. It is also a wonderful "teachable moment" to address an issue fundamental to all of science: How do we detect a signal in the midst of noise? This activity will lead you and your students through an analysis of the data you collect and will point out some important features of data analysis.



ACTIVITY 1.3

Detecting an alien planet II: Making the observations

What you will do: Try to detect a planet orbiting your star, using your MicroObservatory images.

You are about to become one of the few human beings to actually detect an alien world orbiting a distant star.

Remember that the planet itself is too small, too far away, and too faint to see directly with the MicroObservatory telescope — or even with the Hubble Space Telescope! Instead, you will look for the planet indirectly. You'll use the pictures you've taken to look for the dimming of the star's light, as the planet passes between the star and our line of sight. From your previous work with models, you know how the brightness of the star would change if a planet transits across its face.

You and your classmates have already taken a series of images of your star, over the course of several hours. Here's your challenge: Measure the brightness of your star. Then plot it on a graph of brightness versus time of night. When all of your classmates have plotted their data on the graph, see if you can…

- detect the telltale dip in brightness that signals a transiting planet
- tell when the transit begins — that is, when the planet just begins passing in front of the star
- tell how long the transit lasts
- tell what percentage of starlight the planet blocks

In order to carry out this investigation, you'll learn how to:

- measure the brightness of objects in your image
- display and assess your data

You'll also learn how to minimize various sources of error in your experiment. This is very important, because you are looking for a faint signal — a change of no more than 1 to 2% of the star's brightness. (Planets are much smaller than stars, so they block only a tiny amount of the star's light during a transit.)

STRATEGIES FOR SUCCESS

If students' first set of transit images didn't work out, they could take another set at this point. Since they modeled and therefore understand the concept of a transit, involve them in planning when they will take images. Have them use the calendar of transits to determine the night and time interval over which they will take images (make sure they remember to take baseline images before and after the transit). Also, have them plan how often during the transit they want to take images.

Before you begin

PREPARING YOUR WORKSPACE

Here's what you'll have to work with as you attempt to detect a planet orbiting your star. Have these ready on your computer before you begin:

- Your image of your star, and access to your classmates' images
- A "dark image," taken with the opaque filter.
- The image-processing software called MicroObservatory Image.
- A star-finder chart, for locating your star.
- Access to the Other Worlds website, including the Graphing Tools in the Process Data section.

WHICH IMAGES WILL I WORK ON?

You'll work on at least two images:

- The image you already took with the telescope.
- The image that your partner took with the telescope. That way, you and your partner can each check each other's work.

You can also work on more images, if you have time.

CHECK THE QUALITY OF YOUR IMAGES

Before you start taking measurements, check to make sure you are using images of good quality. Smeared or unclear images can give you bad measurements and make it hard to see a dip in your transit graph. If you have doubts about your image, look at the "What's Wrong With My Image?" page on the Process Image page on the Other Worlds website. Double check your own image. Then, get together with some of your classmates and view each other's images. Are there any you think should be deleted from your experiment?

If you eliminated any images, explain why:

If the stars are not clearly visible in your image — e.g. if it was cloudy — then your teacher will identify a new image for you to use.

To help students compile information about their images, you could put a sign- up sheet on the board or an overhead projector, with times spanning the first and last image taken. Then, have each student come to the board and write down the date and time their image was taken.

What are the factors that might affect whether or not you would detect a transit on a particular night? The longer the orbital period, the less likely it is that you would detect a transit on a particular night (e.g. if an alien world was looking at Earth, they would only see one transit each 365 days); the transit has to occur at night for it to be visible to us from Earth. Of course also, you need to be looking at a star that has an orbiting planet, and the orbital plane of the planet has to be oriented so that the transit would be visible from Earth; the alien planet needs to be large enough so that the dip in brightness is large enough for the MicroObservatory telescope to detect.

HOW THE TELESCOPE RECORDS BRIGHTNESS

The telescope contains a digital camera that captures your image of the night sky. The digital camera divides your image into thousands of tiny little squares, called pixels (short for "picture elements"). The brightness of each pixel is converted to a number. (The brighter the light falling on the camera, the higher the number. The numbers run from 0 = no light all the way to 4095 = the maximum light the camera can handle.)

These numbers are stored in the FITS file of your image. They contain all the information about the brightness of different parts of your image.

6	7	7	7	7				7	7	7	7	7
7	7	7	6	2	2	2			7	7	7	7
7	7					2	1			7	7	7
7				8	8	7					7	7
7				7	7	7	7				7	7
7				6	7	7	7	6	6		7	7
				6	4	2					7	7
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					1							7
					1							

Figure 8: A digital image (left) is made of tiny squares or dots. The brightness of each square is represented by a number in the imagefile (right) that is stored in the computer. This image is made from only 8 shades of gray: the numbers run from 1 (black) to 8 (white). The numbers for only a few pixels are shown. Your eye can distinguish about 256 shades of gray — compared to 4096 for the MicroObservatory telescope!

HOW YOU'LL MEASURE BRIGHTNESS

The MicroObservatory Image software program uses the numbers in the FITS image file to recreate your telescope image. You'll draw a small circle around your star, and then measure the brightness of the pixels inside that star. In a way, a digital image is like a "paint-by-number" picture: The numbers tell the computer how bright to draw each pixel. Here, you'll be going the other way: You'll start with the image, and measure the underlying numbers in your FITS file. The brighter the star, the higher the number.

MINIMIZING ERRORS IN YOUR WORK

To detect an alien planet you will have to make very precise measurements. This is because the planet is likely to be tiny compared to its star, blocking out only 1-2% of the light. That means you are trying to detect a very slight dip in your graph.

COMMON MISCONCEPTIONS

Many students believe that the main purpose of a telescope is to magnify. In reality, telescopes are designed primarily to gather light.

STRATEGIES FOR SUCCESS

To help students understand how a telescope gathers light, you might want to do an additional activity. See the Supporting Resources page of the Other Worlds website for ideas.

STRATEGIES FOR SUCCESS

Students might think that the processing of their image would change the brightness of the stars. However, this just changes how it looks to our eyes. The brightness information stored in the image stays the same. You could have students experiment with this to prove to themselves that this is true.

An orbiting planet is likely to be tiny compared to its star, blocking out only 1–2% of its light.

Detecting such a small dimming is challenging because there are a number of possible sources of error in star brightness measurements. Read about each of these possible measurement errors and how you will correct for them.

Errors from the telescope hardware:

Electronic "noise" in the telescope registers a faint brightness even when no light enters the telescope. (It's the same with you: When you close your eyes at night, you can "see" spots of light, even when there is no light. No one's perfect!)

To correct for noise from the electronic chips, you will subtract a "dark image" — taken with an opaque filter — from your star image before you take any measurements. This is called "calibrating your instrument" or "zeroing your instrument."

Errors from nature

Lots of things in nature—other than an orbiting planet—could cause a star's brightness to appear to dim. For example, a thin cloud could drift across the telescope's field of view, or it could get hazy. And as a star gets lower in the sky over the course of a night, it will appear dimmer because its light must pass through more and more of the Earth's atmosphere. (That's why the Sun appears dimmer on the horizon at sunset.) You could confuse this with a transit.

Learn More

Just as the light-sensing portion of your eye is made of millions of tiny cells—so is the light-sensing chip on the telescope made of millions of tiny silicon cells. Each cell corresponds to one dot ("pixel") in the final image.

Each cell measures the amount of light that falls on it. The cell can distinguish 4096 grey levels, from 0 (black) to 4095 (white). This is far more than your own eyes, which can detect only about 250 different shades of grey.

Figure 9: All stars — including our Sun — appear dimmer as they get lower in the sky. Using a comparison star cancels this effect out.

You will compare your star's brightness to the brightness of two comparison stars in the same field of view as your target star. Thus if haze suddenly blocks out half the light from your star, it should do the same to the comparison stars. By plotting the ratio of your star's brightness to the comparison star's brightness, you will eliminate the effect of clouds, haze, air mass, etc.

There is another error from nature that can make your star appear too bright: the sky between the stars is not completely black. This background light can be present for a number of reasons. In the wee hours of the morning (or at dusk before the sky is completely dark), the sky will be brighter. If you don't correct for this, you might think your star is getting brighter over time, when it's actually the entire sky. The background sky may also contain light because of close-by sources such as the glare of city lights and the faint glow of Earth's atmosphere. This means that when you measure your star's brightness, in reality you'll be measuring the brightness of your star PLUS this background sky.

To correct for brightness in the background sky, you'll have to measure the background sky brightness and then subtract it from your star measurement. That way you'll have the brightness due just to the target star, and not to the star PLUS background sky.

Human errors

Human errors can happen for many reasons – measuring the wrong star, using a different circle size, recording the measurements incorrectly, etc.

To increase your chances of detecting an alien world, be sure that you:

- Use the star finder chart to be certain that you are measuring the correct target star and comparison stars.
- Make sure everyone in your class is using the same circle size for their measurements.
- Always make your measurements in the same order (target star, comparison star(s), background sky patches).
- Record your results carefully.

- Measure your image AND the image of one of your classmates. That way, you can compare your measurements and redo them if they come out very different.
- Record your results carefully.

Don't worry. You can do it! When you're ready to start, just follow the instructions step by step. Good luck.

Measuring your star's brightness

OPEN AND VIEW YOUR IMAGES

1. Open the "dark image" — the image taken with an opaque filter — in MOImage (look for "Dk" in the file name). Shortcut: You can drag the file into the MOImage window.

2. Open the FITS image of your star in MicroObservatory Image (MOImage).

3. Adjust your image: Under the Process menu, select Adjust Image. In the small window that opens, select Auto. This will make the stars in your image easier to see.

When you move the cursor over an image, you can see the brightness of each pixel displayed as a number: The number is shown in the small Image Info window and is labeled "Pixel Value." (If the Image Info window is not open, you can open it from the menu, Window/Image Info.)

You might think that the Dark Image — taken with no light entering the telescope — would have pixel values that are 0, corresponding to completely black. But instead, the pixel values are typically around 300. This comes from electronic "noise" in the digital camera. It affects every image you take, and it would interfere with your brightness measurements.

To get rid of this electronic noise, you'll simply subtract the Dark Image from your star image. That way, you'll be left only with the brightness from objects in your image.

SUBTRACT "NOISE" FROM YOUR IMAGE

4. Under the Process pull-down menu, select Image Calculator.

5. Subtract the Dark Image from your star image. (Make sure Image1 is your star image, the Operation is Subtract, and Image2 is the Dark Image.) Click OK. The resulting image appears in a new window. This is the image you will work with.

6. To see your stars more clearly, select the small Adjust Image window again and click Auto.

About Time...
Astronomers often use "Universal Time" (UT), which is the time at the Greenwich Observatory in England. It is 7 hours later than the time at the telescope in Arizona.

For example, a transit that begins at 4 AM Universal Time will be seen in Arizona to begin at 9 PM.

When you control the telescope, be sure to use the local time at the telescope.

FIND YOUR STAR AND COMPARISON STARS

7. Using your star chart (from the Getting Started page of the website), find your star and the two comparison stars. Important: Take all the time you need to be certain that you have found your star and the two comparison stars. Check with your partner to be sure you have independently found the same stars.

8. Click on the magnifying glass icon at the top of your image. Move the cursor that it is centered between your star and the two reference stars. Click several times to enlarge the image. Your star and reference stars should remain in the field of view. (If not, double-click the magnifying glass icon and try again.)

CREATE CIRCLE

9. Click on the circle icon at the top of your image. Move the cursor so that it is near your star and drag it to make a circle that is exactly 4.5 in radius. (Notice that the radius is shown at the top of the image.) It is important that your circle radius remain 4.5 for all of your measurements!

10. Adjust the location of your circle so that it is centered on your star as best as you can. You can move the circle by dragging it — or by using the i, j, k, and l keys to move up, left, down, and right.

MEASURE YOUR STAR'S BRIGHTNESS

11. To measure the brightness of all the pixels in this circle: Hold down "command" "m" on a Mac and hold down "control" "m" on a PC. (Or instead you can select the Process menu and choose Measure.)

12. The number in the Total column is the total brightness measurement for your star. Record this measurement in Table 1.2.

13. Drag the circle to the first comparison star, moving in a clockwise direction. Position the circle, take another measurement, and record the total brightness of this comparison star in Table 1.2.

14. Repeat the process for your second comparison star: Drag the circle to the comparison star, take the meaurement, and record it in Table 1.2.

MEASURE THE BACKGROUND SKY BRIGHTNESS

Notice that the background sky — the sky between the stars, for example — is not completely black. This faint light comes from many different sources: stray light near the telescope; haze in Earth's atmosphere; and dust in outer space.

This background light would interfere with our experiment. We'll have to measure it and subtract it from our star measurements.

15. Take two brightness measurements of the background sky: Select locations near the stars, but not on top of any stars. Make certain the radius of your circle is still 4.5. Record your measurements of the background sky brightness in Table 1.2.

Check that you have 5 measurements in all:

- The target star
- Comparison star 1
- Comparison star 2
- Patch of background sky 1
- Patch of background sky 2

MEASURE YOUR PARTNER'S IMAGE

When doing an experiment, it is often important to have another person check your measurements. If your partner can reproduce your results, that gives you more confidence that you have not made any errors. And if you have made an error, you can correct it.

Now measure the brightness of the star in your partner's image. Also measure the two comparison stars, and the two background sky samples. Use the same procedure as you did for your star (steps 1 to 15 above). Again, you should have 5 measurements in all:

- The target star
- Comparison star 1
- Comparison star 2
- Patch of background sky 1
- Patch of background sky 2

Record your results for your partner's image in Table 1.2.

Note: Your partner's measurements of your star image may not be exactly the same as the measurements you made. That's because you and your partner may place the circles slightly differently around the stars — and you will probably sample different parts of the background sky. But both sets of measurements on the same image should be very close to each other. If not, discuss it with your partner and see where the difference might come in. Then correct whichever measurement you think might be in error. (For example, one of you might have measured the wrong star, or used a circle that was not the standard radius, 4.5.)

TABLE 1.2

Image #1 (your image) Date and time taken:	Total brightness inside your circle
Target star	
Comparison Star 1	
Comparison Star 2	
Background 1	
Background 2	
Image #2 (your partner's image) Date and time taken:	Total brightness inside your circle
Target star	
Comparison Star 1	
Comparison Star 1	
Background 1	
Background 2	

Record the measurements for your image and that of your classmate's in Table 1.2. If you took more than one image, add a table and carefully record the information.

FINDING YOUR STAR'S RELATIVE BRIGHTNESS

As you discussed earlier, your star brightness must be very precise to allow you to detect the slight dimming of your star during a transit. Follow the steps below to calculate a corrected brightness ratio and increase your chance of success!

From your Table 1.2: What is the average brightness of a background sky patch? (Take the average of your two measurements.)

Average background brightness: ____________________

Subtract this background brightness from each of the three star brightness measurements (target star, two comparison stars).

Corrected target star brightness = __________________

Corrected comparison star 1 brightness = ___________

Corrected comparison star 2 brightness = ___________

Now calculate the average corrected brightness of the two comparison stars. (Take the average of your two comparison star brightnesses above):

Average (corrected) comparison star brightness:

____

Compare your target star with the average of the comparison stars. What is the ratio of their brightnesses? (Divide your corrected target star brightness by your corrected average comparison star brightness):

Ratio of brightnesses: __________________________________

UNDERSTANDING YOUR MEASUREMENT

Take a moment to reflect on what you've just done. You have determined the relative brightness of your star, compared to other stars in your image. If anything other than a transiting planet affects your star's brightness, it should affect the comparison stars the same way. For example, if the sky gets hazy, that could block out some of your star's light — but it would affect the comparison stars equally, so their relative brightness would remain the same.

The next step is to follow your star's relative brightness over time. To do this, everyone in your class will plot the relative brightness of their star on a graph, to see if you can see the dip in brightness caused by an orbiting alien world.

DISPLAYING YOUR RESULTS

Now you are ready to graph your results, and your classmates' results, to see whether you can detect an alien world.

Your teacher may use an overhead projector to project graph paper on the board. You and your classmates can then each plot your results. You can create a graph showing the relative brightness of your star, versus the time of night. Each point on the graph represents the measurements from a single image.

You can also graph your results online. This enables you to combine or compare your work with the results of other observers. And it enables you to publish your findings to the world!

To create a graph online, carefully follow the next steps.

CREATING A GRAPH ONLINE

Access the Other Worlds website at http://www.cfa.harvard.edu/otherworlds and select Process Data from the menu. Choose Enter and Display Data from the submenu.

Note: If you are entering data for just a few images, use the following steps. But if you have worked on dozens of images, then select the Multiple Images box on the website, and for instructions skip to the section below, How to Enter Data for Multiple Images.

ENTER THE FILENAME OF YOUR IMAGE

Enter the complete filename of the FITS image that you worked on. Do this by copying the filename and pasting it into the "Name of image" box provided. (An example filename: WASP10-100713080805.FITS)

ENTER YOUR STAR'S RELATIVE BRIGHTNESS

Enter your star's relative brightness, in the appropriate input box.

ENTER A START AND END TIME FOR YOUR GRAPH

Using the pull-down menu, select a start time and end time for your graph using the time you recorded in Table 1.1. Be sure to choose a start and end time that includes the first and last images taken by your classmates. You can change the start and end time, and redraw the graph as often as you like.

ENTER YOUR EXPLORER NAME AND PASSWORD

By entering your explorer name and password, your data will automatically be labeled with your name. When you graph your data, you can see which points are yours and which are your classmates'.

Click the Graph Your Data button to generate your graph.

To enter additional data, repeat the above steps.

WATCH YOUR GRAPH GROW

As more and more of your classmates enter their data, you graph will start to take shape. To see new data as they are added, refresh your browser window.

HOW TO ENTER DATA FOR MULTIPLE IMAGES

You can enter data directly from MicroObservatory Image and have the computer do the calculations for you. Click the appropriate button on the Enter Data web page. Paste the full name of your FITS imagefile in the data entry box. Then, carry out your measurements on the image, using MicroObservatory Image. For each image, make five brightness measurements, including target star, two comparison stars, and two background sky patches. Then select and copy the whole measurement table from MicroObservatory Image, and paste it starting on the next line down. (Note: to select all of the data, hit either Command-A for Macintosh or Control-A for WindowsPC. Copy the data by hitting either: Command-C for Macintosh or Control-C for WindowsPC). Then skip a line, and repeat the process. When you hit enter, the computer will do all calculations and graph your data.

FINDING A SIGNAL IN YOUR GRAPH

Now you have a graph showing the brightness of your star over several hours. You are looking for a decrease in the star's brightness — the telltale sign that an alien world is transiting across the face of your star. The transit should last for an hour or more.

Are you surprised at how "messy" the graph looks? Compare your graph with the predictions you made when you modeled a transit. Welcome to the real world!

What do you think of your graph? Do you see a dip in brightness similar to your predictions? Now that you have your data, it's time to think about what it means.

What's all the noise about?

Your graph may be messier than the nice smooth curve you predicted you would see. Don't despair! Even transit curves measured by professionals using large telescopes have a large amount of scatter.

"How many measurements do I need to see a transit?"

You will not be able to detect a transit from just four or five measurements. That's because the measurements you take will not always fall "where they are supposed to." Any single measurement is subject to error; it may fall above or below the expected value.

With more measurements, you can start to see whether there is a pattern in your data—a "signal" emerging from what looks like noise. Combine your measurements with those of your classmates to see a pattern emerge.

Whether you are trying to determine whether a new medical treatment is effective, or whether a sports star is better this year than last, or whether there is an alien world orbiting your star, the problem is the same: You need enough data to see a pattern emerging from the "noise."

"What do I do about measurements that are very different from the others?"

Some of your measurements may be wildly different from the rest—by 10-20% or more. One of the beautiful things about science is that you are not allowed to simply ignore data that don't fit your prior beliefs or expectations. But that shouldn't stop you from re-examining a measurement when something seems amiss. Did you measure the correct target star and companion stars? Go back through the measurements to see where the problem might lie. If you need to, re-measure your image to see if you get the same result. If you are convinced that something is wrong with a particular measurement, make a note in your records and leave the measurement out. Otherwise, include it among your results.

"A beautiful thing about science is that you are not allowed to ignore data that don't fit your prior beliefs. But that shouldn't stop you from re-examining a measurement when something seems wrong."

Have you found a planet?

Record your thinking about your measurements in the spaces that follow.

Do you think you have detected a planet?

How confident are you of the detection? Why?

Why do you think there is so much scatter in the data?

Are there any data points that seem way out of line? Did you go back to any points that looked questionable and measure the images again?

TEACHERS NOTES

ACTIVITY 1.4

Create a first portrait of your alien world.

What Students Need To Know/Apply: The farther away a light source, the dimmer the light it casts.

PURPOSE

To determine the size of the planet that students detected; the possible tilt of its orbit; the planet's distance from its star; and the planet's distance from Earth; and to discuss the significance of these results.

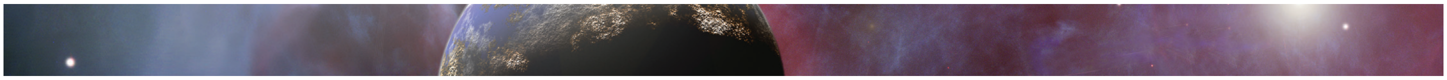
BACKGROUND

In this activity, students analyze the results of their transit measurements to build a first portrait of what their planet is like. They use their graph to determine the fraction of starlight blocked by the planet, and draw conclusions about the planet's size. To determine whether the planet's orbit is tilted, students compare the shape of their transit graph to the model graph done in Activity 1.2. To determine the planet's distance from its star, students can use their estimate of how long the transit takes.

To determine the distance from Earth to the target star and its planet, students use the principle that the farther away a star is, the dimmer it appears: Students will compare the light reaching us from two nearly identical sources: the Sun, and their chosen Sun-like star. By comparing the relative brightness of the Sun and star, they can estimate their relative distance, using the inverse-square law. And taking the distance to the Sun as a given (93 million miles), they can determine the distance to the star, by setting up a simple proportion.

This is summarized in the following proportion:
(measured brightness of the star) = (distance to the Sun)
(measured brightness of the Sun) (distance to the star)

In this activity, students measure the brightness of the Sun from an MicroObservatory telescope image taken previously. They compare this brightness with their star's brightness, which they measured in Activity 1.3. Since they also know the distance to the Sun, they can use the proportion to determine the distance to the star. For example, if the star were a million times dimmer than the Sun, then the star would be a thousand times farther.



ACTIVITY 1.4

Create a first portrait of your planet

What you will do: Use your results to create a simple portrait of what your planet is like.

Congratulations! You have detected a planet orbiting another star. But what is that planet like? It is truly remarkable that you can tell some basic properties of your planet — from the measurements you've already made.

In this section, you'll apply some basic science and math concepts to your data in order to tell:

- How big is your planet?
- Is the planet's orbit tilted, as seen from Earth?
- How close is your planet to its star?
- How far is your planet from Earth?

With these answers, you'll create a "first portrait" of your planet.

HOW BIG IS YOUR PLANET?

Study the dip in your transit graph. What fraction of the star's light is blocked when the planet transits? To figure out this fraction, you'll need to estimate two numbers, using your graph:

- the star's brightness when there is no transit__________
- the star's brightness during a transit_________________

The difference between these two numbers, divided by the star's normal brightness (when there is no transit), equals the fraction of starlight blocked by the planet.

Figure 10: How much of the star's light do you think is blocked by this transiting planet?

To determine the size of the planet, relative to its star, students read their graphs to determine the fraction of starlight blocked by the planet. For example, a 1% dip in brightness means that the disk of the planet must be 1% the area of the disk of the star. The diameter of the planet is found from the square root of this, in this example, the planet is 0.1 times the diameter of its star. That's about the size of the giant planet Jupiter, compared to the Sun. By contrast, the Earth is only 0.01 times the diameter of the Sun, so it would block out only 0.0001 of the Sun's light (i.e. 0.01%) during a transit. To detect an Earth-sized planet would require 100 times more precision than the MicroObservatory telescope. NASA's Kepler mission, now in space, is capable of detecting Earth-sized planets, and may well have discovered the first one by 2011. Astronomers using ground-based telescopes are also looking at smaller, cooler stars. Earth-like planets orbiting these stars would be easier to detect, and in principle could even be detected with MicroObservatory telescopes. Stay tuned!

The area of the planet's disk is only ___________________ of the area of the star's disk. (This is the same fraction as above)

From this number, what is the relative size (e.g., diameter) of the planet, compared to its host star? (This is the square root of the above.)

____

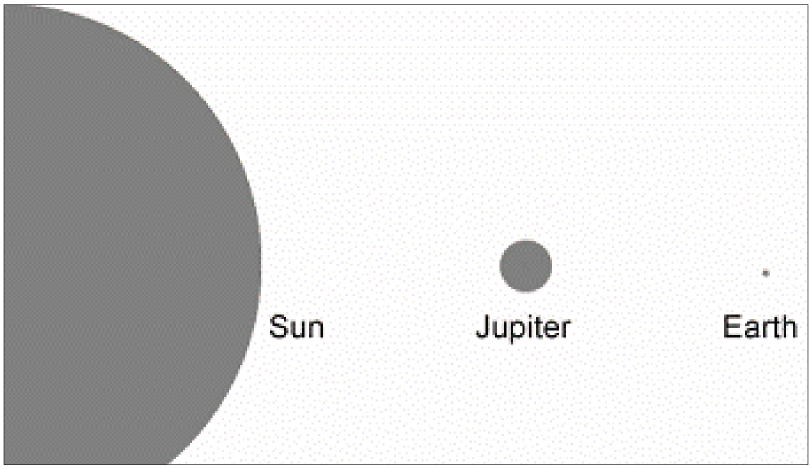


Figure 11: Earth's diameter is about 0.01 times the Sun's diameter. Jupiter is about 0.1 times the Sun's diameter.

How does the size of your planet compare to Jupiter or Earth (see Figure 11)?

If you visited this planet, do you think you would weigh more or less than you do on Earth?

WHAT IS THE ORIENTATION OF YOUR PLANET'S ORBIT?

Does your planet transit across the middle of its star? Does the transit just graze the star (tilted orbit)? (Compare your class' graph with the early predictions you made, using models.)

Transits for most of the stars have a flat "trough", indicating that the planet transits across the main face of the star. But for the star TRES3, the planet's orbit just grazes the star. The transit graph looks like the state of Texas: As soon as there is a dip, the brightness returns to the baseline level.

HOW CLOSE IS YOUR PLANET TO ITS STAR?

You'll use a concept from physics and astronomy: The closer a planet is to its star, the faster it moves — and so the shorter the transit time. (For example, Venus transits our Sun in about 6 hours, while Mercury, which is closer to the Sun, takes only 4 hours.)
First, use your graph to estimate how long your planet takes to transit across the face of its star:

Duration of a transit, in hours: ___________________________________

From this duration, do you think your planet is closer or farther from its star than Earth is from our Sun?

You can get a better estimate of how close your planet is to its star, by using the following graph. This graph shows the duration of a transit, for different distances from a Sun-like star.

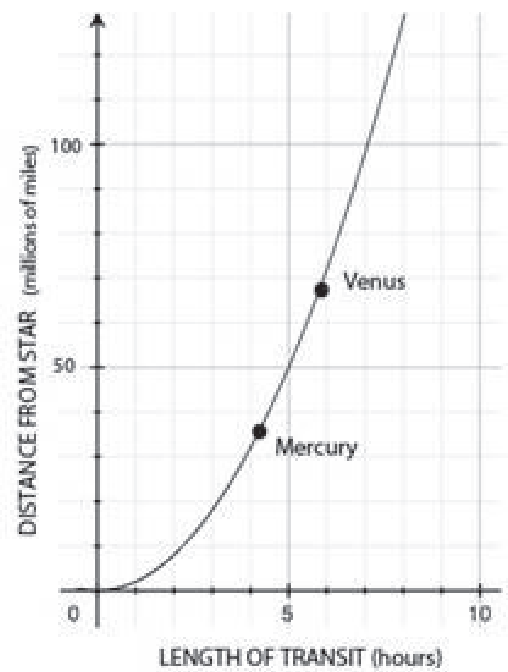


Figure 12: GRAPH OF TRANSIT DURATION vs DISTANCE FROM PLANET TO ITS STAR. Once you know how long your planet's transit takes, you can read off its distance from its star. This graph is only approximate, and applies to stars similar to our Sun.

Is your planet closer to its star than Mercury is to the Sun? How hot do you think your planet must be?

For physics students: Distance between host star and planet:

You may want to ask physics students to use either Kepler's Law, or Newton's laws or tables found on the Internet to calculate the following:

How long is the period of your planet's orbit? (Time to go once around.)

From the period, what distance is the planet from the star? (Assume that the star has the same mass as our Sun.)

How close is your planet to its star, compared to the Earth-Sun distance? Much closer? Much farther?

The closer a planet is to its star, the faster it moves (and therefore the shorter its transit time). Earth science students will know this from our own solar system, in which the outer planets like Jupiter are observed move slowly (12 years for an orbit), while close-in Mercury whips around the Sun in a few months. Students can compare their measured transit time with Venus and Mercury (about 6 hrs and 4 hrs, respectively). Figure 1.8 lets students read off an estimate of their planet's distance from its star. The importance of this distance is that it bears on whether the planet might be habitable. The planets detected in this project are all very close to their stars. Liquid water would not exist on these planets, and neither would life. As of this writing, astronomers have not yet detected a habitable planet, but that is expected to happen in the next few years.

Distance from Earth to your planet

Your star and its planet are just a dot in your telescope image. Obviously, they must be very far away. But how far is far? How long would it take you to travel to this alien place? And how long would it take any creatures that live there to reach Earth — or at least send a message?

BACKGROUND

You might think it's impossible to tell anything about that dot. Fortunately, all light contains information about the object that it came from. In this investigation, you'll use the brightness of the star's light to help you estimate how far away the star is.

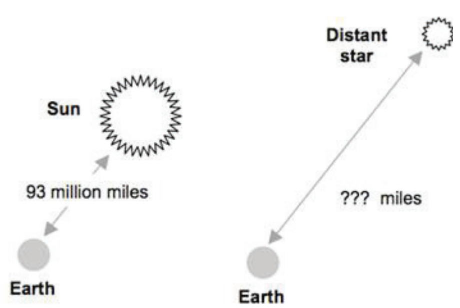
You'll use a simple concept: The farther away a light source, the dimmer the light it casts.

Big Idea: "The farther away a light source, the dimmer the light it casts."

THE PLAN

You have already measured the brightness of your star. (It's in your Table 1.2) Now you'll measure the brightness of a similar star: our own Sun. You'll ask, "How many times dimmer is my star, compared to the Sun?"

Using this ratio, you'll estimate, "How many times farther away is my star, compared to the Sun?" (You'll use a simple rule that lets you compare distances if you have already compared brightnesses.)



For some of the target stars, the star and the Sun are different sizes. However, the distance estimated by students will still be amazingly close to the actual distance.

STRATEGIES FOR SUCCESS

If your students don't have prior experience with the inverse square law, you might want to do an extra activity or demonstration to show how it works. See the Supporting Resources page of the Other Worlds website for ideas.

MEASURING OUR SUN'S BRIGHTNESS

You'll use an image of the Sun that was also taken with the MicroObservatory telescope. (If the image is not already on your computer, you can download it by going to the project Web site, http://www.cfa.harvard.edu/otherworlds. From the home page menu, select Getting Started, and download from the link, Sun Image.)

Note: An easy shortcut is to drag the Sun Image link from the Web site right into MicroObservatory Image. It will open automatically, and you don't need to download the image to your computer.

You will not need to subtract a "dark image" as you did with your star, nor will you need to measure the background sky brightness. The Sun is so bright that the other sources of error are insignificant by comparison.

Create a large circle that just fits around the sun. As before, hit "command" "m" on the Mac or "control" "m" on a PC to take a measurement. IMPORTANT: Make sure the measurement window is wide enough to see the whole number. The Sun's brightness will be eight or nine or more digits long!

Record your Sun measurement in the right-hand column in Table 1.3 Record your star's brightness in the left column of Table 1.3. (Use your "corrected target star brightness" measurement from page 40).

TABLE 1.3

Star Name:	**OUR SUN**
Measured total brightness:	Measured total brightness:
Exposure time: 60 seconds	Exposure time: 0.1 seconds
Filter (if any): none (clear)	Filter (if any): Sun filter Dims image by 100,000,000 times

To determine the distance to your star, just follow the steps below. Keep a record of your measurements and calculations in the spaces provided.

COMPARING THE BRIGHTNESS OF THE SUN AND YOUR STAR

Simply comparing the brightnesses you measured for your star and the Sun wouldn't be a fair comparison: As you can see from Table 1.3, the exposure times of the two images were different. Also, the Sun image was taken with a filter, but the star image was not.

- The star's exposure time was 60 seconds and the Sun's exposure time was 0.1 second.
- The Sun filter allows through only 1 part in 100 million of the Sun's light (otherwise, the telescope mirror would melt!)

To make a fair comparison, you'll have to adjust for these differences.

HOW WILL YOU MAKE A FAIR COMPARISON?

With your team or your class, discuss how you would answer the following question:

"If the exposure time for the Sun image had been 60 seconds instead of only 0.1 seconds, how many times more light would have reached the telescope's sensor? How many times larger do you think your brightness measurement would be?"

(Record your calculations below and in the margin, in case you need to come back and check your work later.)

For a 60-second exposure, I think the Sun's measured brightness would be:____________________________ times greater than what I measured.

Now discuss how you would answer the following question:

"If the Sun's image had been taken without the Sun filter, how many times more light would have reached the telescope's sensor? How many times larger do you think your brightness measurement would be?" (The telescope's Sun filter lets through only 1 part in 100 million of the light falling on it.)

(Record your calculations below and in the margin, in case you need to come back and check your work later.)

Without a filter, I think the Sun's measured brightness would be ______________________________ times larger than what I measured.

Compare the Sun with your star: How many times brighter than your star is the Sun?

Calculations:

The Sun appears ___________________________times brighter than my star. (c)

Or to put it another way, how many times dimmer than the Sun is your star?

My star appears ___________________________times dimmer than the Sun. (c)

CALCULATE YOUR STAR'S DISTANCE FROM EARTH

You might think that if a light appears a million times dimmer than its twin, it must be a million times farther away. But the rule is a little more complicated:

As a light gets farther away, it becomes dimmer in proportion to the square of the distance.

For example, if the Sun were 1000 times farther away, it would appear 1,000,000 times dimmer. So you can square the relative distance to get the relative dimness. Or you can take the square root of the relative dimness (or brightness) to get the relative distance.

This method was first developed in the 1800s, and led to the discovery that even the nearest stars in our galaxy are very far away. It is important to discuss with students the implications of the great distance between stars. One point is to emphasize is that, since we have no idea how to travel to another star system, if we want a good idea of what these other worlds are like, we need to learn how to decode the light traveling to us from out there. That is the focus of Part 2 of the Other Worlds project.

Discuss with your team:

"Given your finding for the relative brightness of your star and Sun, what is their relative distance? That is, how much farther than the Sun is your star, in order to appear as dim as it does?"

As a source of light gets further from Earth, the light dims in a predictable way, according to the inverse square law. According to this law, a star that appears 100 times dimmer than its twin will be only 10 times farther away. Now, use the inverse-square law to calculate the star's distance from Earth:

- Compare your star's distance from Earth with the Sun's distance from Earth: How many times farther must your star be, in order to be as much dimmer as you just found? (This is the square root of (c) above).

Calculations:

My star is ________________________ times farther than the Sun. (d)

If the Sun is 93 million miles (150 million kilometers) from Earth, how far is your star?

Calculations:

The distance to my star is ________________________________ miles.

Some students may feel compelled to compare their calculated distance with those calculated by the scientific community. They may find differences, but they should not feel concerned. The distances calculated by scientists, using the best available technology and techniques for minimizing error, are considered to be within 20% of the actual distances, and in some cases the likely error is even larger. This level of accuracy is adequate for scientific purposes. On the other hand, if we were planning a trip to a star system, we would want to improve the accuracy of our distance calculation!

CONVERT YOUR DISTANCE TO LIGHT-YEARS.

The universe is vast, and the distances between stars and between galaxies are huge. To reduce large numbers to a more manageable size, astronomers describe distances in terms of light-years. A light-year is the distance light would travel in a year, which is about 6 trillion miles! (This is 6×10^{12} miles.)

How far is your star in light-years, if one light-year is 6 trillion miles?

Calculations:

The distance to my star in light-years is ______________________.

This means it would take ________________________ years for light to travel to Earth from the star.

WHAT ARE YOUR THOUGHTS?

Now that you've figured out the distance to your star, what does that number mean? Here are some questions to get you thinking. There's space to jot down your thoughts below.

1. In the science fiction series, Star Trek, the starship Enterprise can travel at ten times the speed of light ("Warp 10").

   a) Roughly how long would it take the fictional USS Enterprise to get to your star, from Earth?

QUESTION 1a: For a star that is 150 light years away, it would take 15 years to get their if you are traveling at 10 times the speed of light. The Star Trek characters would be aged and bored by the time they had visited even a few solar systems. So the galaxy is much bigger than even the producers supposed.

b) Suppose you are the science advisor to the Star Trek series. Do you mind that the show is not scientifically accurate? Or do you think the "artistic license" in the show is fine? What do you advise the producers of the show, and why? When do feel it is important to be scientifically accurate, and when not?

QUESTION 1b: Students should feel comfortable moving back and forth between the accuracy required in science, and the poetic license artists enjoy. But they should be aware of the difference.

2. You've been asked by the President to communicate with any beings in your star system. You'll use pulses of laser light and also radio waves (which are a form of light).

   a) How long will it take a message to get there? How long would the President be waiting for a reply?

QUESTION 2a: For a planet that is 150 light years away, it would take 150 years for a message to get there, and the same time to get back.

b) What kind of conversation would you have, given the time spans involved? What kinds of questions would you ask?

QUESTION 2b: Ask students what kinds of questions they might ask today that might be relevant and important 300 years from now!

c) Would it make sense to have a galactic news show? If you sent out a news bulletin today, and your counterpart in your star system sent out their news today, when would you receive each other's news? Would it still be news? Does it make sense to talk about "now" — the present — for the Milky Way galaxy as a whole?

QUESTION 2c: There are nearly 30,000 light years from the center of our Milky Way galaxy. A newscast sent out today will be very old news by the time it reaches the galaxy's center. From a practical point of view, any other inhabitants of our galaxy don't share the idea of "now" with us!

3. What do you make of the fact that nature has isolated solar systems from each other by such vast distances?! Is this a bad thing, or a good thing — or both?

QUESTION 3: The huge distances make it very difficult to communicate with or travel to one of these solar systems. It also makes it difficult to study them, since the light from them is so faint. But it also protects young civilizations (like ours) from possible marauding aliens (think of the history of Earth's civilzations.) The great distances make it all the more important that we learn how to decipher the information that light can carry—since light is the fastest and currently only messenger between solar systems.

4. Did you compare your result to the published scientific value for the distance to your star? Remember, in science there are no answers, only results. How much confidence do you have in your findings?

QUESTION 4: Nature doesn't come with a manual or even an answer book. So we have to learn to accept tentative results. By looking at the possible sources of error in our work, we can continually improve our results.

Students may cite errors that they encountered previously in their brightness measurements, including weather, defects in their images, etc. The assumption that the target star is just like our Sun is probably the biggest source of error. In reality, most of the stars in this project differ slightly in size and temperature, and therefore in brightness, from our Sun.

Why do you think your result might differ from professional astronomers' results? What are some of the possible sources of error in your measurements? Also consider whether the assumptions you made might not be completely accurate.

CREATE A PORTRAIT OF YOUR PLANET

1. Based on your notes on the previous pages, write a paragraph describing what you learned about your planet size compared to Earth, and what you've concluded about its orbit. Support your conclusions with evidence from your light curve.

2. Go back to the Orbit Model software and create a portrait of your alien solar system that matches your findings. Create a planet that is the right size compared to its star. Adjust the tilt of the orbit based on your curve. (It doesn't have to be exact). Distances in the model are not to scale (your planet would be farther from its star). Now, either draw your planet here, or take a screen shot, print it, and paste it here.

Congratulations!

You are now among the few people on Earth to have detected an alien world!

There are billions of planets out there, waiting to be discovered. As planet-hunters discover more and more planets — especially worlds that more closely resemble Earth — the big question is, "What are these worlds like?"

To prepare for these upcoming discoveries, planet-hunters are working with computer-based "model" planets, to help them figure out how to decipher the faint light from distant solar systems and learn much more.

That is the next step in this project.

Credit: David Aguilar, Harvard-Smithsonian Center for Astrophysics

PART TWO

Looking for a Habitable Planet...and life

Purpose

To learn and apply basic concepts about the behavior of light and matter, central to earth science and physics.

What students will do:

In these activities, student teams will investigate one of several different “mystery” planets. For each mystery planet, they will be given a set of “light-signals” representing hypothetical observations of this planet. Their challenge is to use the data for their mystery planet — along with computer-based models and telescope activities — to build up a profile of what the planet is like, and to assess whether the planet might have suitable conditions for life. In each case, the planet will be compared to what we know about our own Earth.

In carrying out these activities, students will:

- Analyze a transit graph to estimate the size of their mystery planet.
- Look for the presence of oceans, ice, and continents on their mystery planet, by assessing the amount of visible light reflected from the planet.
- Look for the presence of alien plant life, by assessing the amount of infrared light reflected from the planet.
- Determine the temperature of the planet, by looking at the amount of infrared light emitted by the planet.
- Determine the composition of the planet’s atmosphere, if any, by looking at the planet’s absorption of infrared light.
- Pull together a profile of their mystery planet, and assess the planet’s suitability for life.
- Create a portrait of their mystery world, and share their ideas with their classmates.

Core Concepts:

- Light carries information. Scientists use light to learn about the universe.
- Some objects emit visible light of their own, while others merely reflect that light.
- The light we receive from a star system is composed of different wavelengths. There are wavelengths of light beyond what we can see.
  - A spectrum, which displays all of the different wavelengths of light received from a star system, can tell us the molecules that are present in an alien planet's atmosphere. Indicators of life include oxygen, carbon dioxide, methane and water.
- Models are important tools used by scientists working at the frontiers of science. A model – physical, visual, or theoretical – captures important features of the world, and helps us analyze and predict its behavior.

Background

In previous activities, we explored the light coming from the star. From this light, we were able to infer the presence of an orbiting planet and find a few of its properties. However, we could learn much more about the planet if we could detect and decode the light reflected or emitted from the planet itself.

This is the frontier: measuring and interpreting light coming to us directly from an alien planet's surface. A star is as much as a billion times brighter than its orbiting planets; light from a planet is simply drowned out by the glare of the star. Only recently, for very large, bright, and hot planets, have astronomers been able to tease out the planetary light from that of the star. Several plans are being considered to block out the light from a star and measure only the light coming from its planets. The technology is not yet available to block out the light from a star, but scientists are already gearing up to interpret the first light from a planet. When we get the first signals of light from the planet, how will we know how to interpret them? What can light tell us about the planet itself?

In this section, we're going to imagine that astronomers have gathered the light from different "mystery" planets. It is our task to interpret this light.

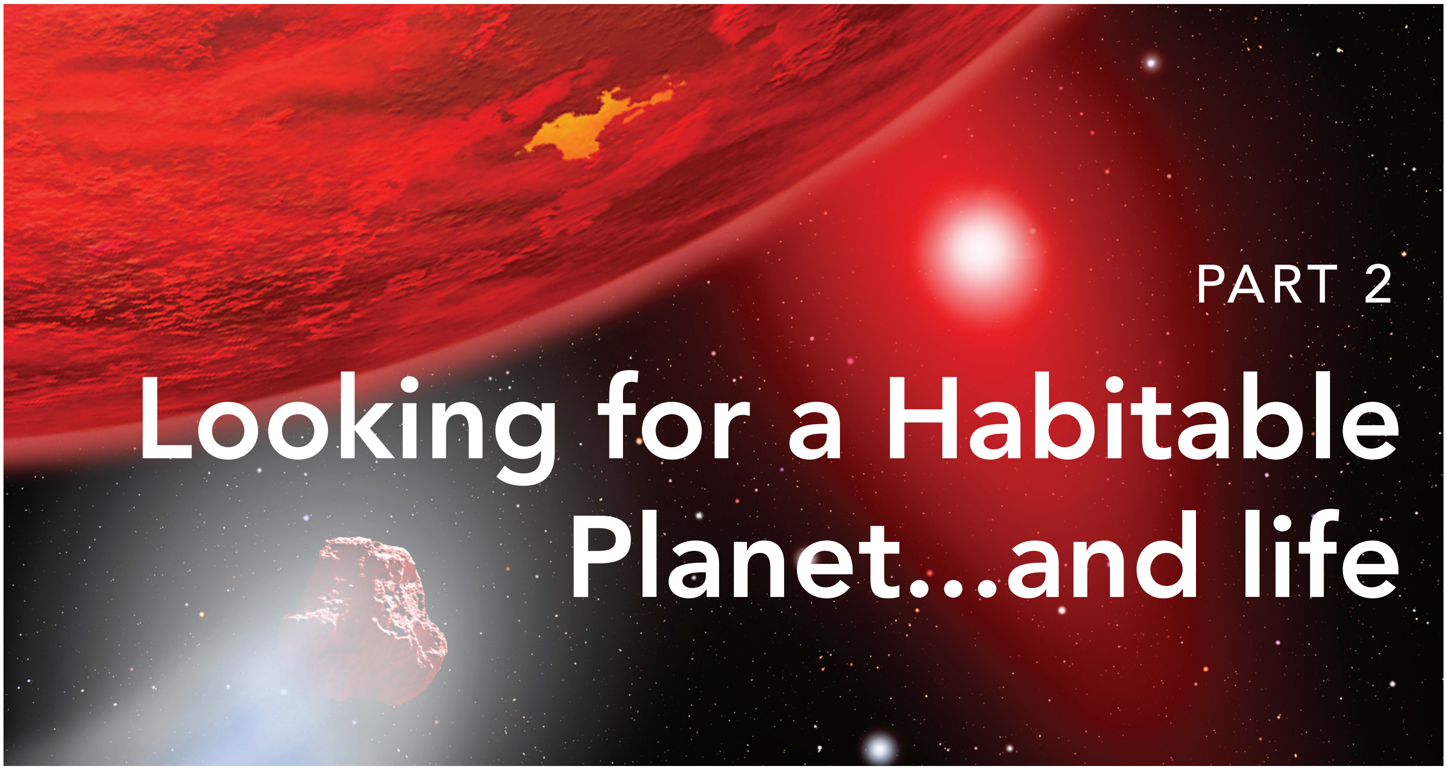
Preparation and Materials for Part 2

Technology Requirements

- A computer and web access for each pair of students.
- The software for the Other Worlds Modeling Labs should be on each computer. The software for each activity is downloadable from the Other Worlds website on the Modeling Labs page.
- LCD projector

Materials

- One set of mystery graphs for each 3-4 students or pairs of students (Appendix B)
- Interpretation of Mystery Signals for Teachers in Appendix B
- Activity 2.3 - TV remote control device(s)
- Activity 2.3 - Cell phone camera(s)



PART 2

Looking for a Habitable Planet...and life

No one has found life on another planet... yet.

At this point in time, we are able to detect planets around other stars. By studying the light that reaches us from the star we can learn about the planet's size and orbit. But what we REALLY want to know is whether there's life on these alien worlds. And for that we need more information.

Planets and life evolve together

Earth's properties have helped to shape the kind of life that can grow here. In turn, life has altered the entire planet!

So in looking for life, we need to look first at what the planet is like. Does it have oceans and continents? Does it have an atmosphere? Is it warm enough for life, but not too warm? Can we see signs of life directly?

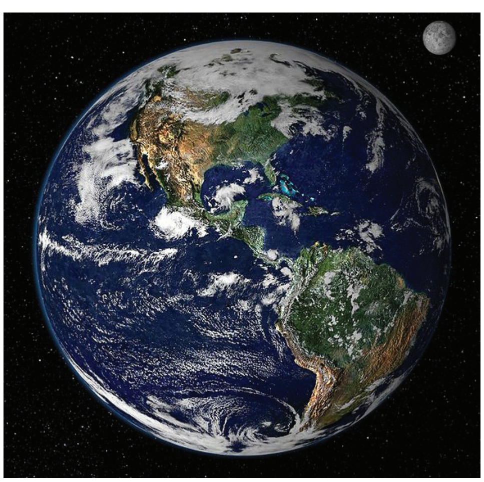


Figure 13: Earth from Space.
http://earthobservatory.nasa.gov/IOTD/view.php?id=885
Credit: NASA

How can we learn more about an alien world's surface and atmosphere?

Scientists believe that we will be able to learn much more about alien planets once we learn how to decode the light coming from the planet itself, not just from the star that it orbits. That is a huge challenge: Stars are billions of times brighter than their planets, so the planet is lost in the star's glare.

Note: In these activities, we are ignoring the effect of clouds on the reflected light. Astronomers are developing ways to take clouds into account, but for clarity and simplicity, we ignore the effect of clouds.

Some astronomers are working on ways to block out a star's light, making it easier to see light from orbiting planets. Meanwhile, other scientists are attempting to model what the light from an alien world might be like—and what we will be able to learn from it.

How do we decipher light from an alien world that no one has seen before? In this next part of the Other Worlds project, you'll continue to work at the cutting edge of science. You'll use models to analyze the types of light signals we will soon be able to receive directly from a planet's surface.

Your challenge

Imagine that the world's greatest astronomers have finally captured light from an alien planet that might harbor life.

They have come to you to figure out what their observations could indicate about the alien planet. They want to know:

- "How big is the planet?"
- "Does the planet have oceans? Continents? Ice?"
- "Could there be any (alien) plant life on the planet?"
- "How cold or warm is the planet?"
- "What is the atmosphere like?"

They also want you to use your findings to assess:

- "Could the planet's environment support life as we know it?"

Finally, they want you to create a portrait of the alien world based on your results, and be ready to explain your findings to others. What do the light signals reveal about the planet? How do you know? What does it mean?

The catch:

Like all alien planets, the one you'll investigate is so far away that it provides just a single pixel's worth of light.

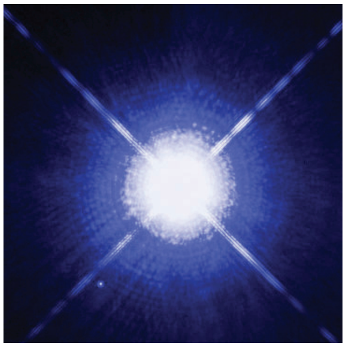


Figure 14: The light from a star is so bright it is very difficult to see the tiny bit of light from an orbiting planet.
Credit: NASA, H.E. Bond & E. Nelan(STScl); M. Barstow & M. Burleigh(Univ. of Leicester); & J.B. Holberg(UAz)

And you'll have only two properties of the light to go on: the brightness of the light, and the color of the light.

Think it can't be done? See if you're up to the challenge.

The data:

Your teacher will give you a packet containing the observations of the mystery planet. The astronomers have measured the brightness of the planet, over time. And they've also measured the brightness of the planet at a single time, but at different colors (wavelengths) of light. That's all you'll have to go on...

You have a lot of questions to answer about your planet, and only your graphs to use. As you work through each graph and begin to develop a picture of your mystery world, it is important to keep track of your ideas and supporting evidence in this student book. Take time to record your ideas completely - this information will be the basis for your profile presentation at the end of this project.

So let's begin! You'll start by looking at a type of graph that you've seen before. This is a chance to use what you learned in Part 1.

Record here which mystery planet you are investigating:

---

1. You will find sets of mystery signals to go with Part 2 in Appendix B.
2. Distribute one set of mystery signals for each 3 or 4 students.
3. Explain to students that these signals, or light graphs, represent hypothetical observations of alien worlds, made by astronomers sometime in the (near) future. Their challenge is to interpret these observations to build up a profile of the alien world, and to determine whether the planet might support life.
4. Explain that most of the graphs will not make sense now, but will become clear after students have carried out the activities and have learned how to interpret the data.

ACTIVITY 2.1

Mystery Signal #1: Transit Graph

What you will do: Begin developing a profile of your mystery world by analyzing a graph of the planet's transit.

Your set of mystery planet signals includes a transit graph for your mystery world. What does it tell you?

STEP 1: WHAT IS THE SIZE OF YOUR PLANET?

Using what you learned in Part 1, analyze the graph to estimate the size of your planet (assume it is orbiting a star the same size as our Sun). Record your planet's size in Table 2.1 on the next page. Note: if you're having trouble remembering how to do this, look back at Activity 1.4, in Part 1.)

STEP 2: WHAT ELSE CAN YOU SAY ABOUT YOUR PLANET'S ORBIT?

In Table 2.1, describe any other conclusions you can draw from the transit graph (for example, how long does one orbit take? Is the planet closer to its star than Earth is to its Sun? Note: again, look back at Activity 1.4 in Part 1 if you don't remember how to do this.)

Also in Table 2.1, describe the calculations and evidence you've used.

STEP 3: BASED ON WHAT YOU KNOW SO FAR, DO YOU THINK YOUR PLANET COULD HARBOR LIFE?

In Table 2.1, write your ideas about whether your planet could potentially harbor life, based on what you've learned from your mystery transit graph. If so, do you have any thoughts about what life might be like?

At this point, you don't have a lot to work with to assess whether there is life. However, you should consider how close your planet is to its star, compared to Earth. Is it too close (and therefore too hot for life as we know it)? Too far away/cold? The size of the planet is likely to affect any life that exists, as well. You already did some thinking about this in the What Are Your Thoughts? questions at the end of the Introduction.

WHAT ARE YOUR THOUGHTS?

Begin to build a profile of your mystery world by recording what you've learned from Signal #1 in Table 2.1. Also say what you think (so far!) about whether your planet could harbor life. Write down your ideas and evidence as clearly and completely as you can – you will use what you've written at the end of the project to pull together a profile of your mystery world and create a portrait to share with others.

See Appendix B for teacher notes about the interpretation of Signal #1 for each of the mystery planets.

TABLE 2.1

	What does the signal tell you about your mystery planet?
Planetary Conditions (your ideas/ conclusions about the size of the planet and its orbit)	
Evidence - Describe the evidence you found in Mystery Signal #1.	
What Does it Mean? - Is this evidence consistent with a planet that might harbor life? - What more do you need to know?	

TEACHERS NOTES

ACTIVITY 2.2

Searching for oceans, ice and land. Decoding the light reflected from a planet.

PURPOSE:

To investigate the kinds of materials that reflect more light and those which reflect less light; and to use the results to determine whether the students' mystery planet might have oceans, ice, and continents.

What Students Need to Know / Apply: The amount of light reflected from an object depends on what the object is made of.

BACKGROUND:

We all have the experience of squinting on a bright day at the beach or while walking on snow: Sand and snow reflect most of the sunlight falling on them. By contrast, asphalt is dark; it absorbs, rather than reflects, most of the light falling on it.

The fraction of light reflected from an object is sometimes called the object's albedo, from the Latin for "white." Albedo runs from 0 (reflects no light) to 1.0 (reflects all light falling on it). Snow has high albedo (0.6 to 0.9), while soil has low albedo (0.05 to 0.3).

The concept of albedo is important in earth science and astronomy, because a planet's albedo affects its climate. For example, the more ice that forms on Earth, the more it reflects light into space, and therefore the cooler it gets and the more ice forms, and so on. This process was in part responsible for the Earth's ice ages. Conversely, as the Earth's polar ice melts, its albedo falls, and Earth absorbs rather than reflects more light energy. This process accelerates the problem of global warming.

By measuring the albedo — the fraction of reflected light — from our mystery planet, we can deduce something about the nature of the planet's surface.

Note: The concept of albedo implies that we know how much light is falling on the planet to begin with. To determine the albedo of a planet, astronomers first calculate the amount of starlight falling on the planet. Then they calculate how much light would be reflected if the planet were completely white. The amount of light actually reflected is compared with this theoretical value to estimate the albedo.

ACTIVITY 2.2

Searching for oceans, ice, and land. Decoding the light reflected from a planet.

Figure 15: Earth and Moon. Credit: NASA

What You Will Do: analyze a graph of reflected light from your planet that contains clues about the planet's surface.

When you look at a photo of Earth from space, you are really looking at light from the Sun reflected off of the surface of our planet. This light contains a wealth of information. We can easily see with our eyes in this "close up" image of Earth that there are oceans and continents, deserts and areas with rich vegetation, and clouds swirling around a blanketing atmosphere.

However, images of distant solar systems are taken from very far away (much further than the picture of Earth from Saturn on the cover of this guide). Even when scientists are able to block out the blinding light from the star and focus on the planet, it will still be only a tiny single speck of light.

With the Oceans, Ice, and Land modeling lab, students will explore the varying reflectivity of surfaces on Earth. They will:

- make predictions about which surfaces (oceans, forest, ice, etc.) reflect the most light and which reflect the least.
- explore how the brightness of light received from a distant planet can vary as the planet rotates, indicating (for example) the presence of continents and oceans.
- practice matching brightness versus time graphs to planets.

With this information, students should be able to interpret Signal #2 from their mystery world: the albedo graph.

STRATEGIES FOR SUCCESS

You might want to compare students' predictions about the relative brightness of Earth's surfaces with the measured albedo values. (Values below are from Ruddiman, 2001)

Surface Reflectance (albedo) range	
Fresh snow or ice	0.6-0.9
Old, melting snow	0.4-0.7
Clouds	0.4-0.9
Desert sand	0.3-0.5
Soil	0.05-0.3
Tundra	0.15-0.35
Grasslands	0.18-0.25
Forest	0.05-0.2
Water	0.05-0.1

So how will you know from such a small bit of light what is on the surface of the alien world? You'd be surprised what you can learn using a simple idea.

Look back at the image of Earth in Figure 2.3 and notice that if you compare the oceans, clouds, deserts and forests, they vary in brightness. You'll use this fact as a powerful tool to learn more about the surface of your mystery planet from Graph #2.

Interpreting Signal #2: The Albedo Graph

The second light graph from your mystery planet shows what we would see if we could look at the light reflected directly off a planet's surface over a period of time.

STEP 1: USE EARTH AS A MODEL.

Open the Oceans, Ice, and Land lab on your computer. Follow the instructions to complete the activity, which will teach you what you need to know to understand light signal #2, the reflected light (albedo) graph from your mystery planet.

STEP 2: APPLY YOUR RESULTS TO YOUR MYSTERY PLANET GRAPH.

Based on the observations of reflected light from the planet, what are your ideas about the planet's surface: Does the light-graph you have support a planet with an ocean? With a continent? With ice? With a combination of these? Is there more than one possible kind of planet that would fit the evidence you have at hand?

In Table 2.2 , enter your ideas about the mystery planet's surface. (Keep an open mind. You can refine your ideas when you get more evidence.)

COMMON MISCONCEPTIONS

Studies have shown that many students have difficulty with the concept of reflection. Rather than understanding that light travels from a source, is reflected off of an object, and then travels to their eyes, they believe that light from a source brightens objects so that we can see them. Some students believe they can see objects because light travels from their eyes to the object.

WHAT ARE YOUR THOUGHTS?

Build a profile of your mystery world by recording your ideas and evidence in Table 2.2

TABLE 2.2: SIGNAL #2 ALBEDO	
	What does the signal tell you about your mystery planet?
Planetary Conditions (your ideas/ conclusions about the surface of your planet)	
Evidence - Describe the evidence you found in Mystery Signal #2.	
What Does it Mean? - Is this evidence consistent with a planet that might harbor life? - What more do you need to know?	

See Appendix B for teacher notes about the interpretation of Signal #2 for each of the mystery planets.

You might want to point out to students that if they have a repeating pattern in their Albedo graph, that will tell them the length of a day on their alien world. For example, a feature that is very bright, such as a desert, might rotate into view once a day, causing a peak in their brightness graph. They could tell the day length by measuring the time between these peaks whenever they show up.

TEACHERS NOTES

ACTIVITY 2.3

Detecting plant life using infrared light

PURPOSE:

To investigate the behavior of infrared light and its interaction with plants; and to use the results to predict whether the mystery planets might harbor plant life similar to that on Earth.

What Students Need to Know / Apply: There are colors (wavelenghts) of light beyond those we can see with the unaided eye.

BACKGROUND:

There is another property of light that we can measure, besides brightness: color. Our eyes can see only a tiny fraction of the many colors, or wavelengths, of light. Just beyond the red end of the spectrum is the range of wavelengths known as infrared. When you create a spectrum, using a prism, the infrared colors are there beyond red—they are just not visible to the unaided eye! (Note: Color refers to our perception of light, not to a well-defined physical quantity. However, since we perceive the spectrum as colors, rather than as numbers, it is useful to use the notion of "colors" we can't see, when referring to infrared and other forms of light.)

Plants appear bright white, when viewed with an infrared-sensitive telescope or camera. That is because plants reflect almost all the near-infrared light that falls on them; in fact, they are among the most reflective objects in nature. This appears to be true of all known plants. No one knows why this should be; perhaps infrared light interferes with photosynthesis in some way that is not understood. As a result, plants are relatively dark in the visible part of the spectrum, below 700 nanometers (nm), but are very bright between 700-800 nanometers. This leap in brightness is called the "red edge," and may be a useful tool for detecting plants on alien worlds — provided that alien plants behave similarly to those here on Earth.

Please note that students will no longer be working with brightness versus time graphs. Rather, their graphs will show brightness versus wavelength. Students commonly struggle to make this transition, but it is an important one because they will be working with this new kind of graph for the rest of this project.

ACTIVITY 2.3
Detecting plant life using infrared light

What You Will Do: use infrared light reflected from your planet to look for possible plant life.

To learn more about our alien planet – what its temperature is, whether it has an atmosphere, whether it has life, we need to start exploring the colors of light, including colors humans can't see!

You'll use infrared light – which is invisible to our eyes, but not to a telescope – to look for plant life on our own planet, and on a model alien world.

When you've completed this activity, you'll use what you've learned to decode Signal #3 and look for evidence of plant life on your mystery world.

STEP 1: MODELING COLORS WITH THE SPECTRUM LAB
The light we see around us is a mixture of different colors of light.

So far, you've been looking at the brightness of the white starlight you can see in telescope images. However, the light only looks white to your eyes. It actually contains many colors of light mixed together. If you separate the light into the different colors and study them, you can learn much more.

Go to the Other Worlds website at:
http://www.cfa.harvard.edu/otherworlds/

Go to the Modeling Lab. Open the Spectrum Lab online and follow the steps to explore a new kind of graph. Rather than looking at brightness versus time, you'll now look at brightness versus wavelength.

The emissions graph in Figure 16 shows the brightness of light at each wavelength. The colored bar in the top part of the figure shows what each wavelength looks like to our eyes. (The infrared part of the spectrum is drawn back and white because no one knows what this light would look like).

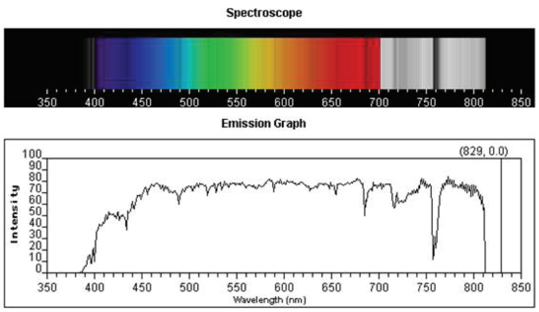


Figure 16: The spectrograph shows a rainbow of light — the wavelengths of light we can see with our eyes — and a bit further into the infrared.

STEP 2: USING A DIGITAL CAMERA TO SEE INFRARED LIGHT

The light around us includes colors ("wavelengths") of light that we can't see.

The wavelengths of light just longer than red are called infrared. These "colors" of light are invisible to the human eye, but are just as real as the colors of light we do see.

You use infrared light all the time! It's the light that comes out of the remote control device for your television.

Figure 17: Although you can't see it with your eyes, your television remote emits infrared light. Credit: Ed Poor http://en.wikipedia.org/wiki/File:Blue_infrared_light.jpg

> **ACTIVITY 2.3, STEP 2**
>
> The light from a TV remote control is invisible to the eye, but should appear as a bright spot on the cell-phone screen or digital camera screen!

Try looking at the light coming out of a remote control device, using a digital camera, or a cell-phone's digital camera. The camera can see the light, but your eyes can't! The MicroObservatory telescope is also sensitive to infrared light.

STEP 3: LOOKING FOR PLANT LIFE USING INFRARED LIGHT

All stars, including our own Sun, are sources of infrared light. Though we can't see the infrared with our eyes, everything on the planet is bathed in this infrared light.

What do live plants look like when viewed in the infrared portion of the spectrum? Use the MicroObservatory telescope to find out.

Go to the Get Images page of the Other Worlds website. Retrieve and save the GIF image (this time you do not have to save it as a FITS file). The GIF image is the one that appears on the Web.

Reflecting on reflection:
Do you notice anything unusual about the plants in your image?

In visible light, plants appear dark green. (That's because they absorb most of the visible light that falls on them, and reflect very little.) But plants reflect almost all the infrared light that falls on them. The infrared comes from the Sun, and bounces off the plants.

In fact, plants are among the most reflective things on the planet – but only at infrared wavelengths. If you could see infrared light, plants would look bright white!

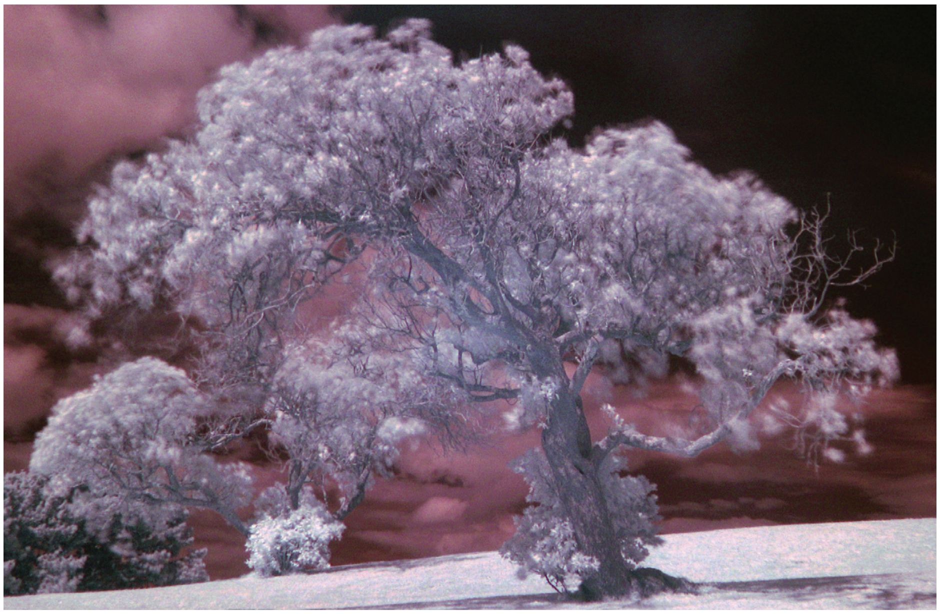


Figure 18: These two images show a tree photographed in the near-infrared range (top) and visible light (bottom).Plants reflect so much infrared light that they appear bright white— as though covered with snow. Credit: Daniel Schwen

ACTIVITY 2.3, STEP 3

Hold a class discussion about the plant images. Students should notice that vegetation shows up as extremely bright, almost white. Plants absorb much of the visible light falling on them (in order to photosynthesize!), but they reflect most of the infrared light falling on them.

Explain that plants reflect strongly between 700 and 800 nanometers (nm). (This feature is called the "red edge" and is thought to be diagnostic of plant life.)

The signal of plant life shows up on a spectrograph as a bright peak between 700 and 800 nanometers (nm). Because this brightness peak is just beyond visible red light, astronomers call it the "red edge."

We don't know if other worlds will have plants similar to ours. But if they do, we could tell they're there by detecting the infrared light they reflect.

STEP 4: APPLY YOUR RESULTS TO YOUR MYSTERY PLANET.

Look at the light graph for your mystery planet. Do you see a feature that shows bright reflected light between 700 and 800 nanometers that could be the signature of plants? Note: This feature might be faint, if there are just a few plants on your planet. Use your judgment.

Record your ideas in Table 2.3.

WHAT ARE YOUR THOUGHTS?

Build a profile of your mystery world by recording your ideas and evidence in Table 2.3.

See Appendix B for teacher notes about the interpretation of Signal #3 for each of the mystery planets.

TABLE 2.3: SIGNAL #3 PLANT LIFE

	What does the signal tell you about your mystery planet?
Planetary Conditions (your ideas/ conclusions about possible plant life)	
Evidence - Describe the evidence you found in Mystery Signal #3.	
What Does it Mean? - Is this evidence consistent with a planet that might harbor life? - What more do you need to know?	

TEACHERS NOTES

ACTIVITY 2.4

Taking a planet's temperature using infrared light

PURPOSE:

The purpose of this activity is to investigate the connection between the temperature of an object and the light it emits; and to use the results to estimate the temperature of the mystery planets.

What Students Need to Know/Apply: All objects emit light in some range of wavelengths. The hotter the object, the shorter the wavelengths of light emitted.

BACKGROUND:

All warm objects emit light. The warmer the object, the higher the peak wavelength of light emitted. Hot objects emit light at visible wavelengths. Warm objects, such as people and planets, emit light in the infrared range. By measuring the peak wavelength of light emitted, the temperature of an object can be determined.

The graphs presented in students' Mystery Signal #4 and the temperature model are simplified. In reality, we would also be seeing absorption by the planet's atmosphere. These would be dips in the light such, such as those in Signal #5. To make it easier to calculate the temperature, we omitted those dips and troughs in these graphs. So these are an idealized graph—or if you prefer,low-resolution graphs that don't show all the features that the next graph shows.

ACTIVITY 2.4

Taking a planet's temperature using infrared light.

What You Will Do: Use infrared light from your mystery planet to determine its average temperature.

In this activity, you're going to take your mystery planet's temperature.

To do this, you need to explore the mid-infrared range of wavelengths. These are longer wavelengths of light than you used in the previous plant activity.

You'll also begin to look at light that is emitted, rather than reflected from objects. This is light all objects give off even in a dark room, just like a star gives off light in space.

STEP 1: WHAT DOES INFRARED LIGHT HAVE TO DO WITH TEMPERATURE?

- Name as many sources of light as you can:

Examples of sources of light students might name: the Sun, volcanoes, candles, glowing embers, incandescent bulbs, hot ovens and kilns. A few sources of light are produced chemically rather than through heat, such as fireflies, phosphorescent animals, fluorescent bulbs, light-emitting diodes, etc.

Most of the objects you've named are likely to be objects that are so hot that they glow with visible light. Examples are the Sun, fire, hot embers, etc.

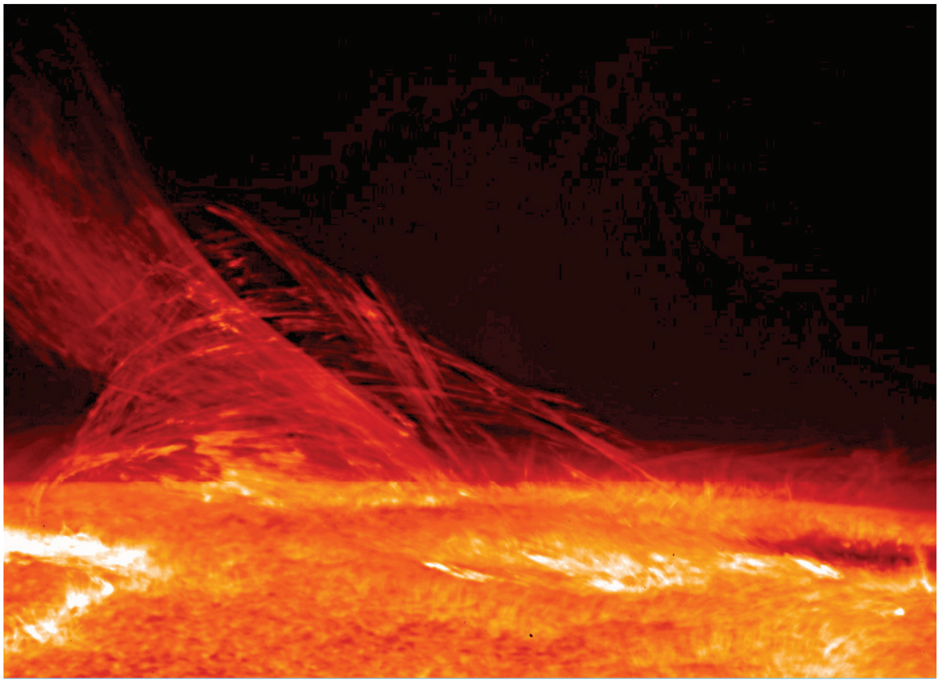


Figure 19: The surface of the Sun is so hot it glows with visible light. Credit: NASA

Warm objects give off infrared light, even in a dark room. Strange as it seems, all objects emit some wavelengths of light. For warm objects — e.g. you — these wavelengths fall in the infrared part of the spectrum. Every object around you, right now, is glowing with infrared light that your eyes can't detect. The entire planet Earth is emitting infrared light as well.

Figure 20: This is an image of a rescue vessel in the Red Sea taken from a US Navy patrol aircraft. The aircraft was using an infrared camera to search for survivors of a ferry accident. Notice that the people are bright white because they are warmer than the boat and water.

COMMON MISCONCEPTIONS

Infrared images are commonly shown in false-color, i.e., black-and-white images that have been colorized. Many students are confused by what these colors represent. For consistency, we use black-and-white images and videos to emphasize that we are looking at infrared light, not visible light.

This light comes from the motion of the molecules that make up an object. If the molecules move very fast (high temperature), they emit visible light. If the molecules move more slowly (lower temperature), they emit infrared light.

Your skin has nerve cells that detect infrared light. That is why you can feel the warmth of an object without actually touching it. (Think of the warmth of sunshine, coming to you across the vacuum of outer space; or the warmth of a hot iron when you get too close.)

STEP 2: USE THE MODELING LAB TO TAKE THE TEMPERATURE OF AN ALIEN WORLD

Open the Other Worlds Temperature Lab, on your computer. Follow the steps in this activity to learn more about how infrared light is emitted from objects in the world (and universe!) around you. Then, use the model to learn how to take the temperature of a distant planet.

The Temperature Modeling Lab shows infrared videos illustrating that warmer objects are brighter (emit more) infrared, while cooler objects appear darker. Students apply these ideas by determining the temperature of a few model planets.

Students should understand that every object with the same temperature emits light that peaks (is brightest) at a characteristic wavelength. Therefore, we can use this peak wavelength to determine the temperature of a distant world.

Measuring a planet's temperature

The wavelength at which a planet emits the most infrared light—the highest point in the spectrum—is a measure of the object's temperature. The lower the temperature, the longer this peak wavelength. In fact, you can use a simple relationship to find the planet's temperature from the peak wavelength:

$$\text{Temperature} = 2900 / \text{Wavelength}$$

where Temperature is in degrees Kelvin and Wavelength is in microns.

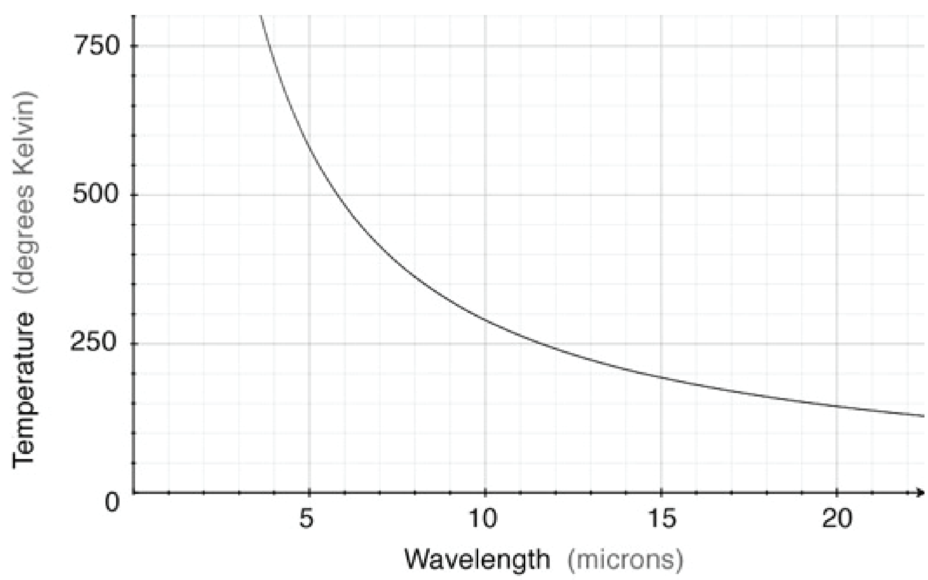


Figure 21: The cooler an object, the longer the peak wavelength of light it emits.

STEP 4: FIGURE OUT THE TEMPERATURE OF YOUR MYSTERY WORLD.

- Using Signal #4, an infrared light-curve for your mystery planet, what can you say about the temperature of the planet?
- Record your ideas in Table 2.4. Include your calculations in the margin to the right.

WHAT ARE YOUR THOUGHTS?

Build a profile of your mystery world by recording your ideas and evidence in Table 2.4

TABLE 2.4: SIGNAL #4 TEMPERATURE

	What does the signal tell you about your mystery planet?
Planetary Conditions (your ideas/ conclusions about your planet's temperature)	
Evidence - Describe the evidence you found in the light curve(s). Include calculations and diagrams as appropriate in the right column of this page.	
What Does it Mean? - Is this evidence consistent with a planet that might harbor life? - What more do you need to know?	

Signal #4 shows the brightness of the mystery planet in the mid-infrared range of the spectrum, between 5 and 15 microns. This is (infrared) light that is emitted by the planet itself.

See Appendix B for teacher notes about the interpretation of Signal #4 for each of the mystery planets.

To make things more interesting, we have assumed that the temperature indicated by the graph corresponds to the temperature of the planet's surface. In reality, we would be seeing the top of the planet's atmosphere, which is much colder. For example, the Earth looks to be very cold from space, because the top of its atmosphere is way below freezing. In practice, scientists have to use a model of how temperature changes with altitude, in order to tell anything about the planet's surface. But they would start with the same kind of graph we are using here.

TEACHERS NOTES

ACTIVITY 2.5

Looking for an atmosphere and signs of life...using an absorption spectrum

PURPOSE:

To investigate the absorption spectra of several model planets; and to use the results to deduce what the atmospheres of the mystery planets contain.

What Students Need to Know/Apply: Each kind of molecule absorbs light at specific wavelengths. The wavelengths that an object absorbs — its "absorption spectrum" — is a kind of fingerprint that helps us identify what the object is made of.

BACKGROUND:

Not all of the light reflected or emitted from a planet's surface makes it out into space. Some of the light may be absorbed by substances in the planet's atmosphere. The composition of the atmosphere determines which wavelengths are absorbed. By observing which wavelengths are absorbed (the "absorption spectrum"), we can deduce what substances must be present in the atmosphere.

The composition of a planet's atmosphere yields important clues about the possible presence of life. Oxygen gas detected in the form of ozone is considered a sign of life, since oxygen is produced by plants, just as carbon dioxide is produced by animals. Methane, also produced by living organisms, cannot co-exist for long in the atmosphere in the presence of oxygen unless it is being continually replenished. Life as we know it requires water, so water vapor is another important indicator that conditions on a planet could support life. These atmospheric signatures – oxygen, methane, carbon dioxide and water - are likely to be the signals that tell us there is life beyond Earth.

ACTIVITY 2.5

Looking for an atmosphere and signs of life... using an absorption spectrum

What You Will Do: decode the absorption spectrum of your mystery planet, determining whether it has an atmosphere, and if so, its composition.

If there is life on an alien planet, our best chance to find it is to look for its effect on the atmosphere of the planet. For example, the oxygen in our atmosphere comes from living plants. The methane comes from living things too.

But how in the world can we tell what an alien atmosphere is made of—from so far away? Once again, light holds the answer!

Here's the secret: Different substances absorb light at different wavelengths. As a result, light passing through an atmosphere is absorbed at certain wavelengths. The brightness of light at that wavelength is diminished. The pattern of absorption can tell us what the atmosphere is made of.

Figure 22: Earth's atmosphere absorbs light at a variety of wavelengths beyond the visible range we can see. Credit: NASA

Our Sun is so bright that you might think all of its light makes it through the atmosphere. But if you look closely at the emission graph (also referred to as an absorption spectrum), in Figure 2.11, you'll see that's not so.

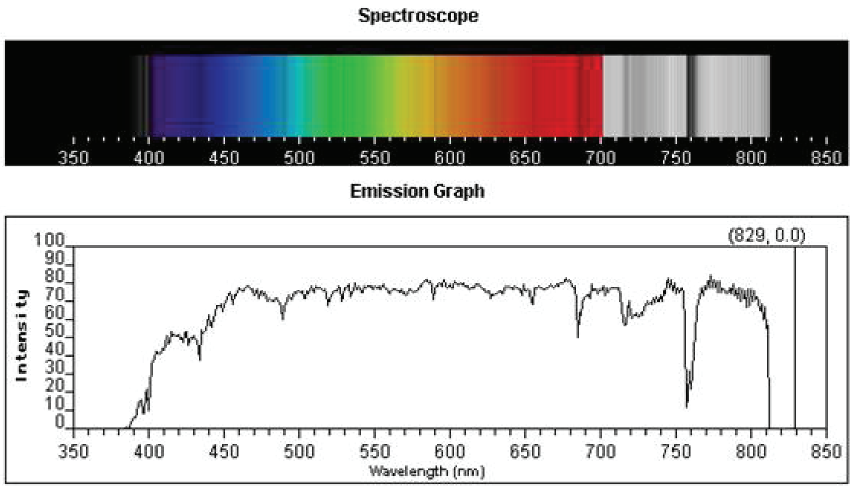


Figure 23: The spectrum of sunlight.

Can you see places where some of the Sun's light is blocked? Each kind of molecule in the Earth's atmosphere — oxygen, nitrogen, carbon dioxide, etc. — absorbs at a specific set of wavelengths. For example, the dip at 750 nanometers is where oxygen gas in the atmosphere absorbs sunlight. (Some of the very faint lines in the spectrum are where the Sun's own atmosphere blocks some of the Sun's light!)

Note that the spectra in Figure 24 are just like the one you worked with in the temperature activity. These graphs show the infrared light emitted by the planet at various wavelengths of light. (The scale is expanded to see it more easily.)

Each type of molecule absorbs specific wavelengths of light. The pattern of absorption is a 'fingerprint' that helps identify the substance.

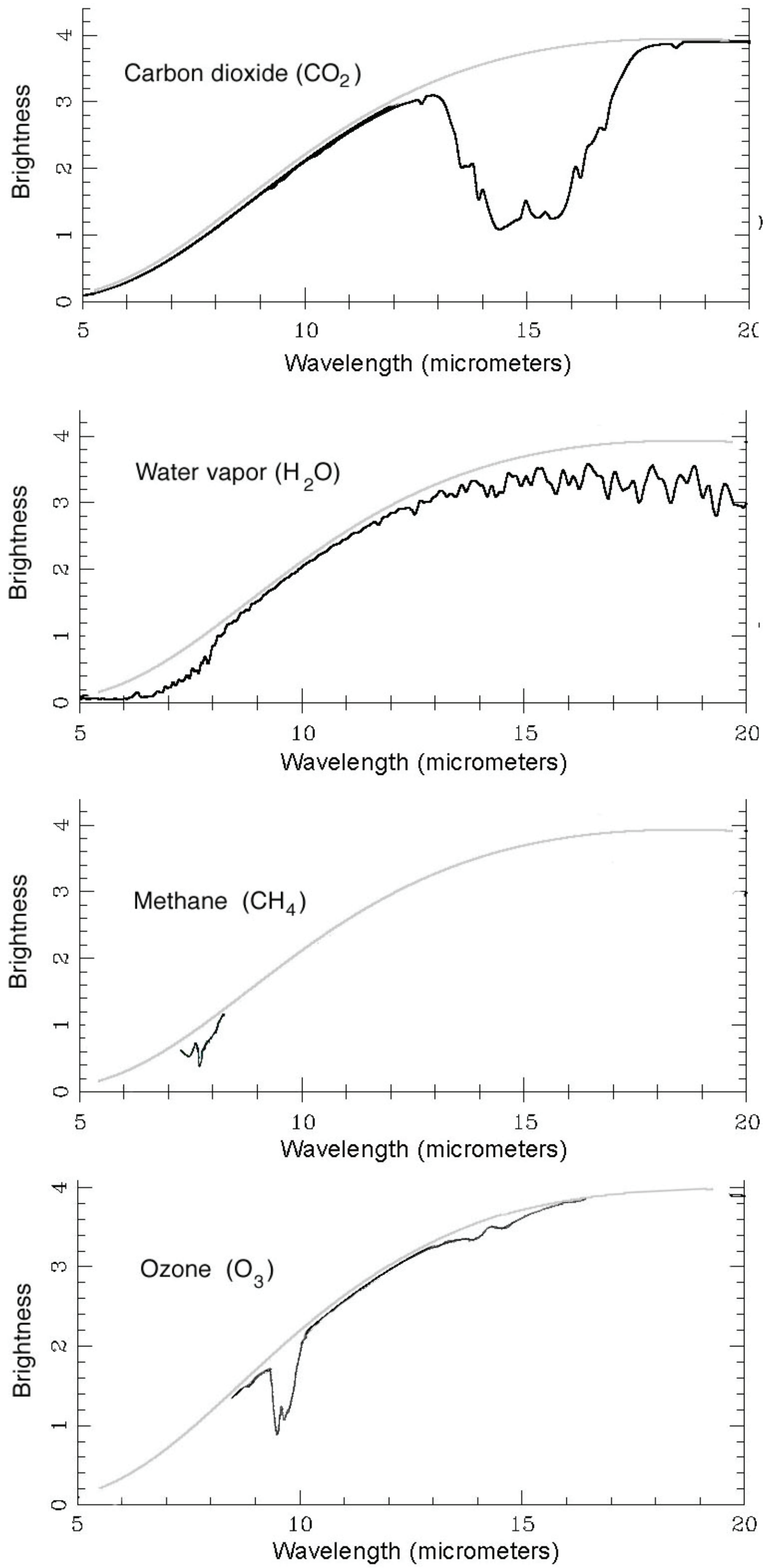


Figure 24: The wavelengths of light absorbed by molecules that are present in Earth's atmosphere.

The scale of the x-axis of the mystery planet graphs has been expanded, compared to Graph 4, in order to show the absorption features more clearly.

The planet is not as bright at certain wavelengths of light. These are wavelengths where the atmosphere of the planet absorbs some of the outgoing light from the planet. The pattern of absorption depends on what's in the atmosphere.

The absorption spectra of several different gases are shown in Figure 24. The smooth black curve indicates the infrared light emitted by the planet in the absence of any absorbing gases.

Learn More

A planet's atmosphere affects its entire climate. If you've ever wondered what the "greenhouse effect" is all about, take another look at the spectra in Figure 24. Recall from the previous activity that the infrared light in this portion of the spectrum is emitted by the planet itself, and comes from the heat stored in the planet. The gases that absorb light in this part of the spectrum — carbon dioxide, water vapor, methane — are preventing some of that infrared light from escaping, trapping the heat on the planet. As a result, the planet becomes warmer.

In the Atmospheres Modeling Lab, students see how the presence or absence of an atmosphere, as well as the composition of an atmosphere, affects the spectrum of several model planets. They apply the results to analyzing their mystery planet's atmosphere.

Looking for life.
The composition of your mystery planet's atmosphere contains important clues about whether life might be present:

If the planet's atmosphere contains abundant water vapor, that's an encouraging sign that life might be present. Life as we know it requires water.

If the planet also has methane gas, that might be a sign of bacterial life. Most of the methane in Earth's atmosphere is produced by bacteria. (Methane is the gas in a gas stove.)

If the planet's atmosphere contains ozone, that indicates that oxygen gas is present. Oxygen in Earth's atmosphere comes from plants, so oxygen is considered a sign of life. If the planet's atmosphere contains both methane and oxygen (or ozone), that is a strong indicator of life. The reason is that methane reacts with oxygen, so the two gases can't co-exist for long. Finding both means that they are continually being replenished, and life forms would be the likely source, as is the case on Earth.

Amazing fact

Without some carbon dioxide or similar "greenhouse gas" in our atmosphere, Earth's oceans would likely freeze. But too much carbon dioxide can overheat a planet. (Think of Earth's neighbor, Venus, whose thick carbon dioxide atmosphere has produced a climate so hot that it would melt lead!)

STEP 1: MODELING ALIEN ATMOSPHERES.

Open the Other Worlds modeling lab on your computer and select the Atmosphere Lab. Follow the steps in this activity and model the absorption spectra of different planets.

STEP 2: APPLY YOUR RESULTS TO YOUR MYSTERY PLANET.

What conclusions can you draw about the composition of your planet's atmosphere? Use your results with the model planets. You can also use the spectra of different gases, reproduced in Figure 24 to help you. Record your conclusions and evidence in Table 2.5.

WHAT ARE YOUR THOUGHTS?

Build a profile of your mystery world by recording your ideas and evidence in Table 2.5

TABLE 2.5: SIGNAL #5 ATMOSPHERE

	What does the signal tell you about your mystery planet?
Planetary Conditions (your ideas/ conclusions Does your planet have an atmosphere? What is its composition?)	
Evidence - Describe the evidence you found in light signal #5.	
What Does it Mean? - Is this evidence consistent with a planet that might harbor life? - What more do you need to know?	

See Appendix B for teacher notes about the interpretation of Signal #5 for each of the mystery planets.

The absorption spectra given to students have an "envelope" that looks like the blackbody curve in Graph 4. However, students may notice that the curve peaks at a different place (longer wavelength, therefore colder temperature). To simplify these activities, we have used a single set of absorption spectra corresponding to a single temperature, which happens to be colder than the blackbody curves shown in Graph 4 for the mystery planets. Have students ignore this envelope, and look only at the absorption features themselves.

Final Activity: What have you done? What have you learned?

At this point, students have gathered evidence about their "mystery planets" and developed hypotheses about what their planet might be like. They create a model of their planet using the Portrait Lab from the Other Worlds website. As a final step, students should pull together what they have learned and prepare to present their planetary profile to the world.

A note to field test teachers:

Planetary Profile Presentations – the assignment

This assignment in the student guide is intentionally somewhat general – you will certainly need to do more scaffolding for your students and be more specific about your requirements. However, we realize that the amount and type of scaffolding needed, as well as the specific content requirements, will vary depending on the level and nature of your class. Please document how you do this and send us this information.

We suggest that you might want to offer students a choice of format for their final presentation: for example, they could present their findings in a written or videotaped news report, in a live presentation, a poster presentation, or even a website. The format isn't important, as long as they clearly present their answers to the questions posed about the mystery planet, along with supporting evidence. If students present in a variety of ways, please send us samples that represent the different modes of communication. We'd love to see them!

You can choose to have students do this presentation individually or as a group project. If you do it as a group project and have an associated individual assignment to help you develop a grade, please send us an example of what you've done.

It's important for students to understand that the light signals represent incomplete clues, and therefore they cannot know for sure what their planet is like. The curves will only take them so far – beyond that, they will have to use their imagination. You will have multiple student groups who have analyzed the same set of light curves, and they may have developed different hypotheses. Encourage them to share and debate their ideas, just as scientists would.

Final Thoughts

When students have finished the project, and their profile presentations, have them individually take time to look back through their work, including the reflections they've documented as they've answered the "What are your thoughts?" questions. Based on their experiences during this project, have them write answers to the following questions; then, you may want to discuss them as a class: Field test teachers: please send us your students' answers to these questions!

Final Activity: What have you done? What have you learned?

What You Will Do: Pull together your mystery planet profile and develop a portrait of your mystery world.

Congratulations!

You used models to help decode light signals from a hypothetical alien world that we might detect…soon!

If you received these light signals and had to explain them to the world, what would you say? What kind of place is this mystery planet? Do you think it might have life? How do you know? This is your final challenge.

You've analyzed the graphs and documented your thinking about each signal. Now, you'll go back to your notes, pull together all of your evidence, and develop a hypothesis about what you think your mystery planet is like. Then, you'll prepare to present your conclusions to your classmates.

STEP 1: PULLING TOGETHER YOUR MYSTERY PLANET PROFILE.

How big is your planet compared to Earth? What are the surface conditions, and the composition of the atmosphere? What is your evidence? You'll need to be able to answer these questions to develop a portrait of your mystery planet, and to defend your ideas when you share them with your classmates. Using your notes in tables 2.1 through 2.5, pull together a profile of your mystery planet in the planetary profile in Table 2.6.

TABLE 2.6: MYSTERY PLANET PROFILE

	Description of your mystery planet	What evidence did you use to draw these conclusions?
How big is your planet compared to Earth?		
What are the surface conditions on your planet like? (oceans? continents? ice?)		
Do you see evidence of alien plant life?		
What can you say about the average temperature of your planet?		
What is the composition of the planet's atmo-sphere?		

YOUR CONCLUSIONS:

Based on the findings you recorded in Table 2.6, write your ideas about the following questions.

1. Do you think the conditions on your mystery planet are suitable for life? Why or why not?

2. If there might be life on this planet – possibly intelligent – what should the next steps be? Could we go there or communicate with them? What would we say to them…and how?

STEP 2: Creating a model of your mystery planet.

Now that you've answered some key questions about your mystery planet, it's time to draw a portrait of your alien world. Go to the Modeling Lab on the Other Worlds website. Select the Portrait Lab. Follow the instructions in the lab to create a model of what you think, based on the evidence in your light graphs, your planet is like.

Save the model that you create – it will be an important part of your presentation about your mystery world.

STEP 3: Prepare a presentation about your mystery world.

Now, prepare to share and defend your ideas with your classmates. Think of yourself as a scientist who is sharing their findings with other Earth-dwellers. That means, you should make your presentation interesting and understandable for the general public. Remember, though, that you may have some skeptics and it will be important to have evidence to support your claims! Your profile should include answers to, at a minimum, the questions in Table 2.6 and the conclusions you wrote in Step 1.

STEP 4: Share your ideas with your classmates.

Present your findings about your mystery world to your classmates, along with your supporting evidence. You should be ready to defend your interpretation, but keep an open mind – there may be a number of possible interpretations of your graphs.

Remember

The light signals are incomplete clues, and may not give you definite answers about your planet. There may be a number of possible worlds that would be consistent with your signals. Just do your best thinking and be prepared to defend your conclusions with the evidence that you have (and if you have doubts about certain aspects of your planet, it's okay to admit that and explain the different possibilities – it's important to keep an open mind!)

As you listen to your classmates' presentations, think about their conclusions and evidence. Do you have any questions that could push their thinking further? Ask them! This is how the frontiers of science keep moving forward with ever more ideas and discoveries.

FINAL THOUGHTS

As you've completed each step of your search for other worlds, you've taken time to document your thinking. Relive this journey by looking back through the ideas you've recorded. What have you learned? How has your thinking evolved? Please record your current thoughts about the following questions.

1. You've used two key scientific tools in this project – measurements and models. Based on your experiences…
   a. Describe some of the successes and frustrations you felt as you did your transit measurements.

   b. Think about one specific model you used during this project (it could be a physical model like a lamp and ball, or it could be one of the computer models). Describe two ways the model is similar to the real thing and two ways it is different.

c. Models are simplified versions of real phenomena. That means they don't show you exactly what happens. Why, then, do you think scientists use them? What are they good for?

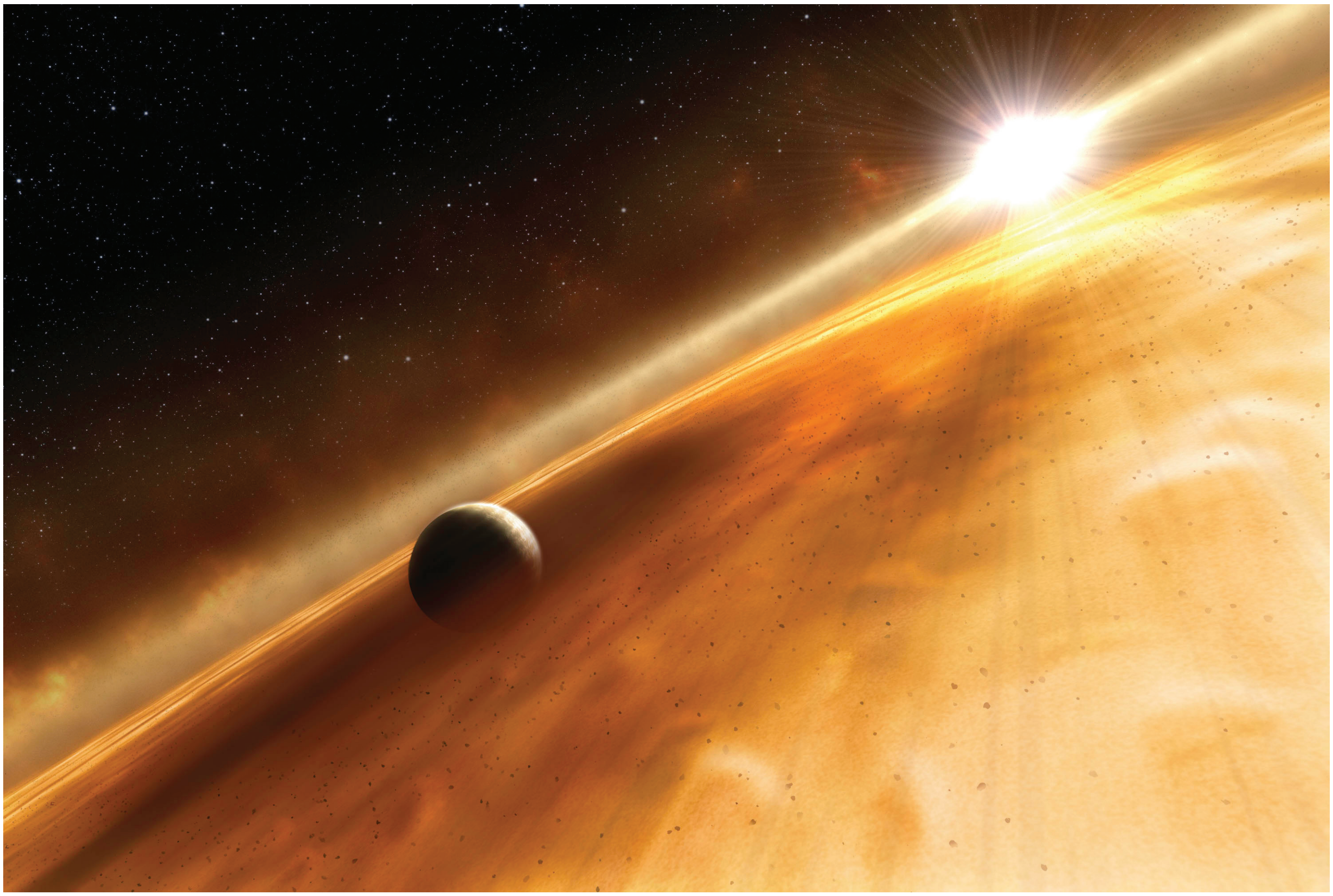
2. Describe something you learned in this project that you didn't know before.

3. What are your personal feelings: Do you think there might be another Earth out there? A planet with a diversity of life (including intelligent life) like our own? Explain your thinking.

Postscript:

The search for alien worlds is accelerating, as we get closer and closer to finding places elsewhere in the universe where there might be life.

Looking for alien worlds is not just about finding extra-terrestrial beings. It's about us… understanding who we are, where we came from…and how we came to be on this marvelous planet we call Earth… Tierra... Erde... Zemlya...



Credit: David Aguilar, Harvard Smithsonian Center for Astrophysics;