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Your place in the Universe

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

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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: ____

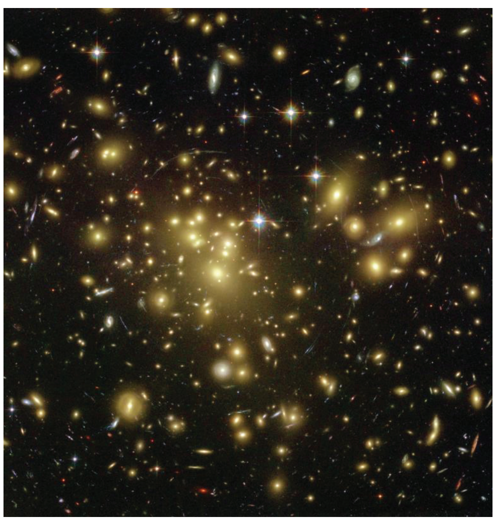
Your Solar System:____

Your Galaxy:____

Use this space to record your ideas, calculations and results.

< 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_earth-sun_ 200803XX_HI.jp

< 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

Use this space to record your ideas, calculations and results.

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?

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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

Use this space to record your ideas, calculations and results.

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

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.

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

Use this space to record your ideas, calculations and results.

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

Use this space to record your ideas, calculations and results.

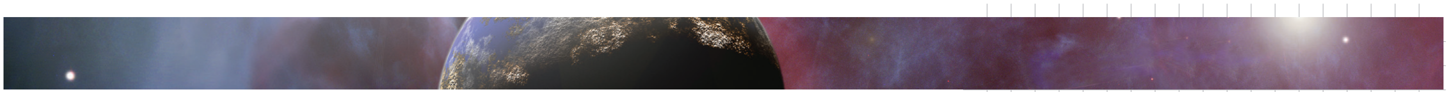
PART ONE

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.

Use this space to record your ideas, calculations and results.



ACTIVITY 1.1

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

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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 re-entered, 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	

Use this space to record your ideas, calculations and results.

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

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.

IMPORTANT: Be sure to download the version of your image that is in FITS format. The FITS image contains much more informa-

Remember

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

tion 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.

Use this space to record your ideas, calculations and results.

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

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

Use this space to record your ideas, calculations and results.

WHAT ARE YOUR THOUGHTS?

Use this space to record your ideas, calculations and results.

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.

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

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?

Use this space to record your ideas, calculations and results.

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?

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

Use this space to record your ideas, calculations and results.

ACTIVITY 1.2

Detecting an alien planet I: Modeling a Transit.

Use this space to record your ideas, calculations and results.

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.)

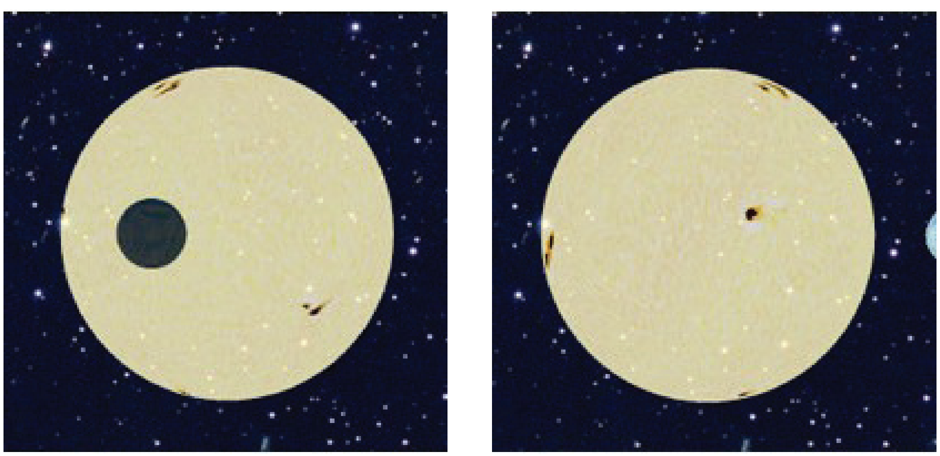


Figure 7: Left: As seen from Earth, a planet that passes in front of its star blocks some of the star's light. This is called a "transit." Right: After the transit, more of the star's light is visible (plus a little bit of light reflected from the planet.) [Note that "sunspots" on the star might be confused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

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.

Use this space to record your ideas, calculations and results.

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.

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?

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?)

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?

Use this space to record your ideas, calculations and results.

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

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?

   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?

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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:

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 this space to record your ideas, calculations and results.

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?

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?

Use this space to record your ideas, calculations and results.

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?

Use this space to record your ideas, calculations and results.

Use this space to record your ideas, calculations and results.

ACTIVITY 1.3

Detecting an alien planet II: Making the observations

Use this space to record your ideas, calculations and results.

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.)

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.

Use this space to record your ideas, calculations and results.

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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7	7									7	7	7
7	7	7								7	7	7
7	7									7	7	7
7	7				1	1	1	1		7	7	7
7				8						7	7	7
					1						7	7
					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.

Use this space to record your ideas, calculations and results.

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

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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.

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.

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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 I.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	

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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'.

Use this space to record your ideas, calculations and results.

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?

Use this space to record your ideas, calculations and results.

How confident are you of the detection? Why?

Use this space to record your ideas, calculations and results.

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?

Use this space to record your ideas, calculations and results.

ACTIVITY 1.4

Create a first portrait of your planet

Use this space to record your ideas, calculations and results.

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?

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.)

____

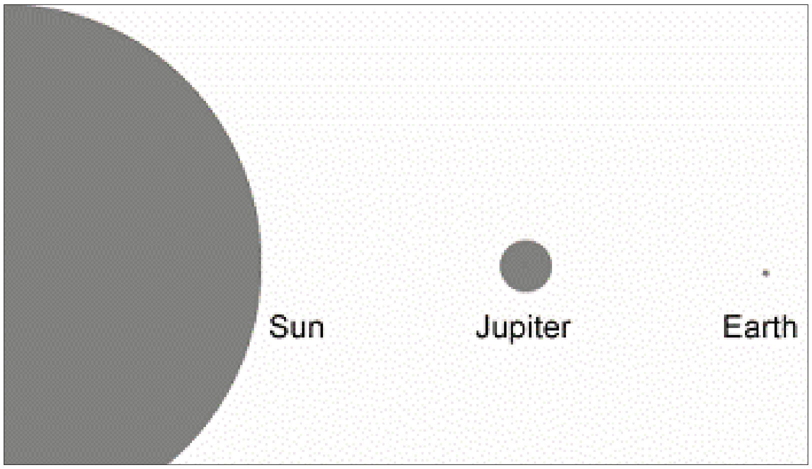


Figure 11: Earth's diameter is about 0.01 times the Sun's diameter. Jupiter is about 0.1 times the Sun's diameter.

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.)

Use this space to record your ideas, calculations and results.

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.

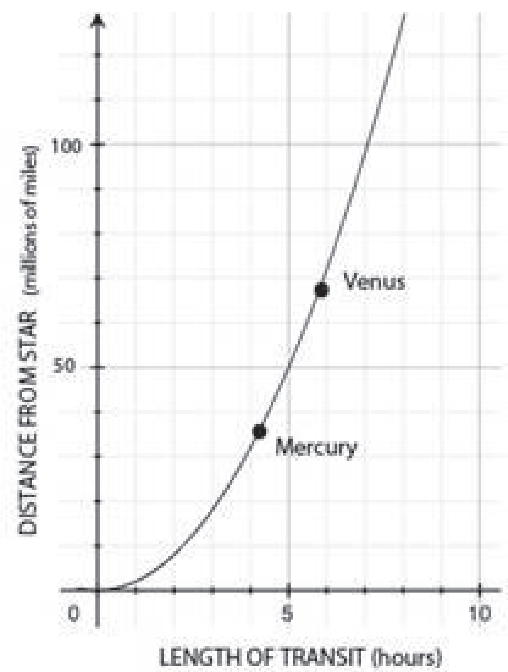


Figure 12: GRAPH OF TRANSIT DURATION vs DISTANCE FROM PLANET TO ITS STAR. Once you know how long your planet's transit takes, you can read off its distance from its star. This graph is only approximate, and applies to stars similar to our Sun.

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

Use this space to record your ideas, calculations and results.

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?

Use this space to record your ideas, calculations and results.

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.

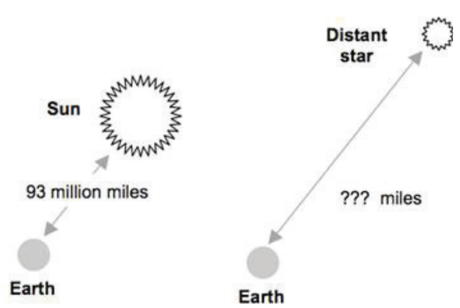
You'll use a simple concept: The farther away a light source, the dimmer the light it casts.

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.)



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

Use this space to record your ideas, calculations and results.

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

Use this space to record your ideas, calculations and results.

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.)

Use this space to record your ideas, calculations and results.

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.

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:

Use this space to record your ideas, calculations and results.

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.

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.

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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?

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?

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?

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

Use this space to record your ideas, calculations and results.

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?

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?

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?

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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!

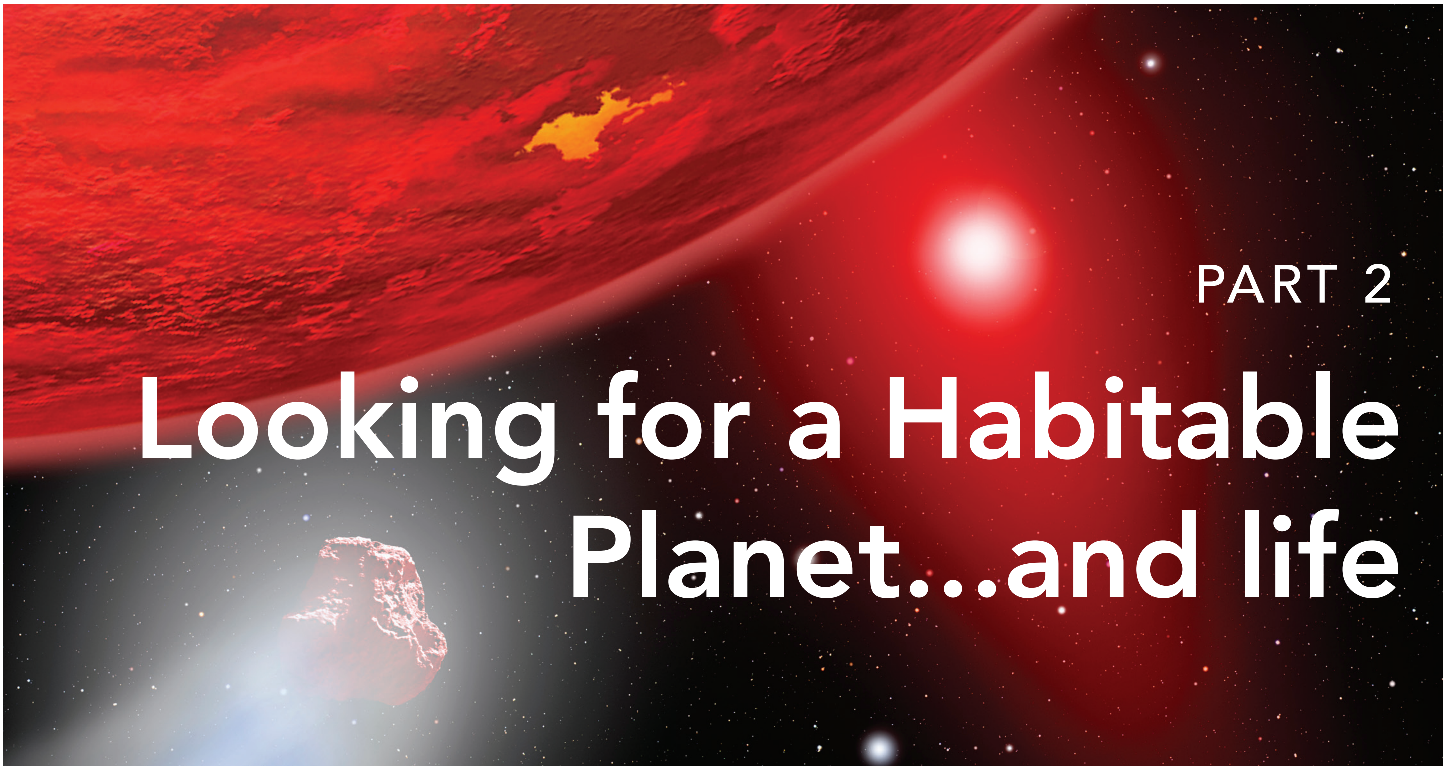
There are billions of planets out there, waiting to be discovered. As planet-hunters discover more and more planets — especially worlds that more closely resemble Earth — the big question is, "What are these worlds like?"

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

Use this space to record your ideas, calculations and results.



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?

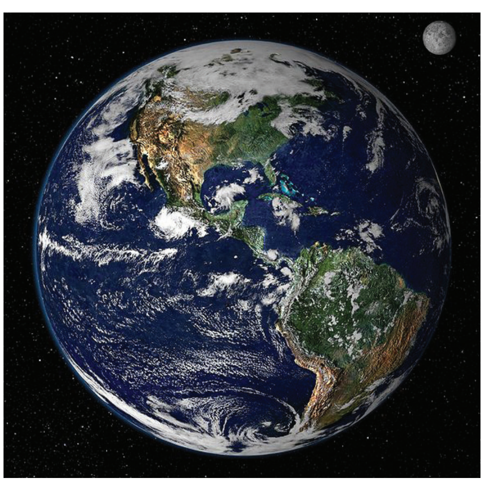


Figure 13: Earth from Space.
http://earthobservatory.nasa.gov/IOTD/view.php?id=885
Credit: NASA

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.

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.

Use this space to record your ideas, calculations and results.

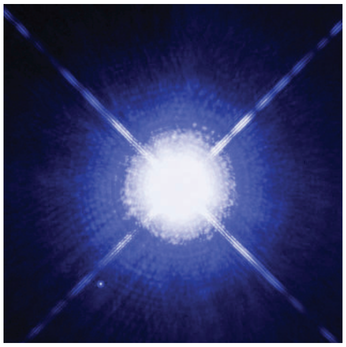


Figure 14: The light from a star is so bright it is very difficult to see the tiny bit of light from an orbiting planet.
Credit: NASA, H.E. Bond & E. Nelan(STScI); M. Barstow & M. Burleigh(Univ. of Leicester); & J.B. Holberg(UAz)

Use this space to record your ideas, calculations and results.

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:

ACTIVITY 2.1

Mystery Signal #1: Transit Graph

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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?	

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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.)

Use this space to record your ideas, calculations and results.

WHAT ARE YOUR THOUGHTS?

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

Use this space to record your ideas, calculations and results.

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?	

Use this space to record your ideas, calculations and results.

ACTIVITY 2.3

Detecting plant life using infrared light

Use this space to record your ideas, calculations and results.

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).

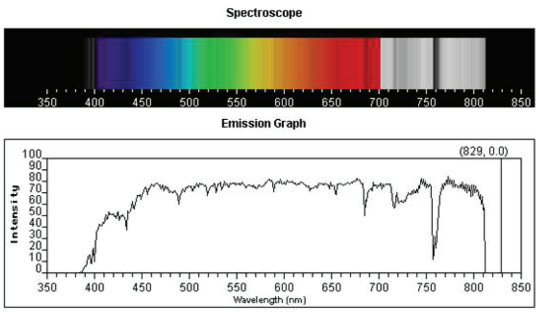


Figure 16: The spectrograph shows a rainbow of light — the wavelengths of light we can see with our eyes — and a bit further into the infrared.

Use this space to record your ideas, calculations and results.

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

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!

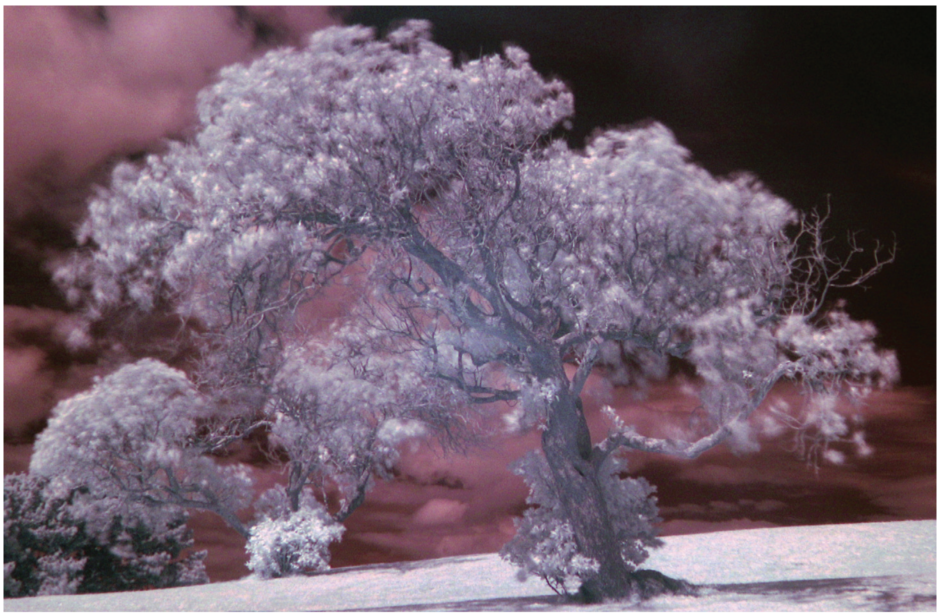


Figure 18: These two images show a tree photographed in the near-infrared range (top) and visible light (bottom).Plants reflect so much infrared light that they appear bright white— as though covered with snow. Credit: Daniel Schwen

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

WHAT ARE YOUR THOUGHTS?

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

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?	

Use this space to record your ideas, calculations and results.

Use this space to record your ideas, calculations and results.

ACTIVITY 2.4

Taking a planet's temperature using infrared light.

Use this space to record your ideas, calculations and results.

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:

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.

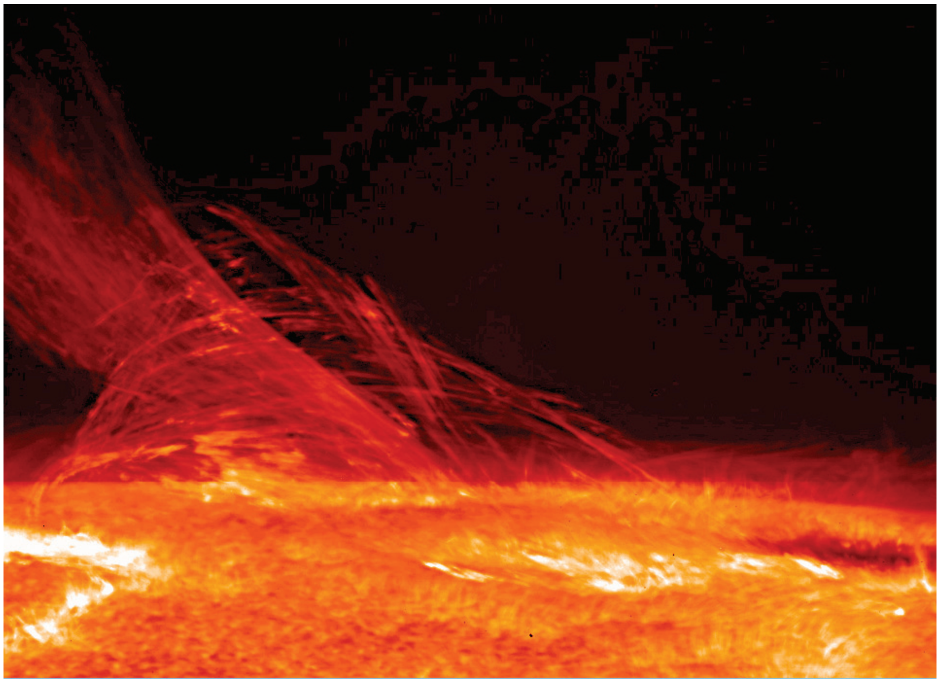


Figure 19: The surface of the Sun is so hot it glows with visible light. Credit: NASA

Use this space to record your ideas, calculations and results.

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.

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.

Use this space to record your ideas, calculations and results.

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.

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.

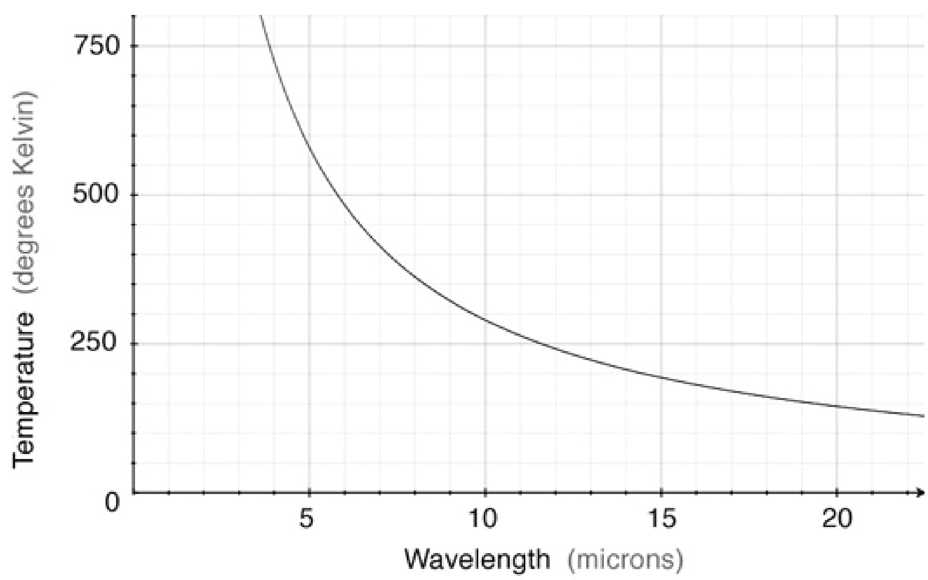


Figure 21: The cooler an object, the longer the peak wavelength of light it emits.

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.

Use this space to record your ideas, calculations and results.

WHAT ARE YOUR THOUGHTS?

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

Use this space to record your ideas, calculations and results.

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?	

Use this space to record your ideas, calculations and results.

ACTIVITY 2.5

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

Use this space to record your ideas, calculations and results.

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.

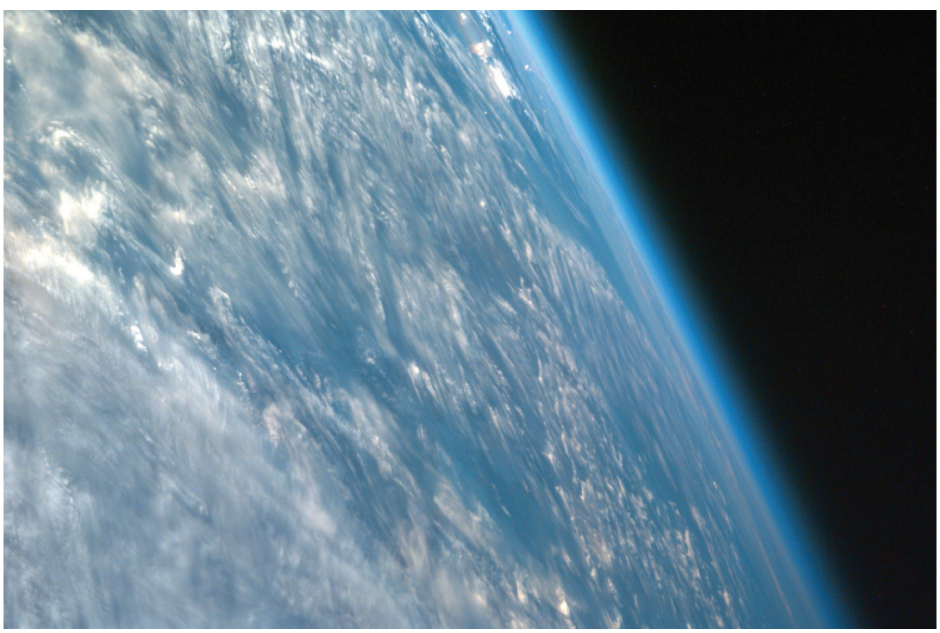


Figure 22: Earth's atmosphere absorbs light at a variety of wavelengths beyond the visible range we can see. Credit: NASA

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.

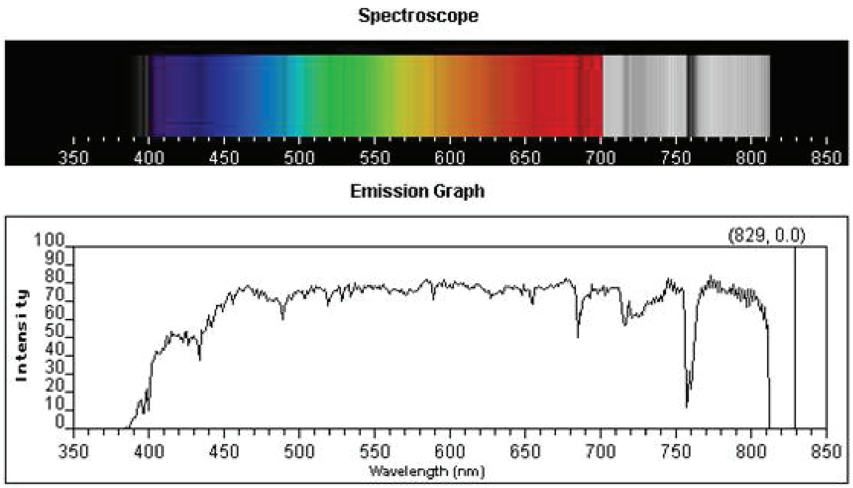


Figure 23: The spectrum of sunlight.

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.

Use this space to record your ideas, calculations and results.

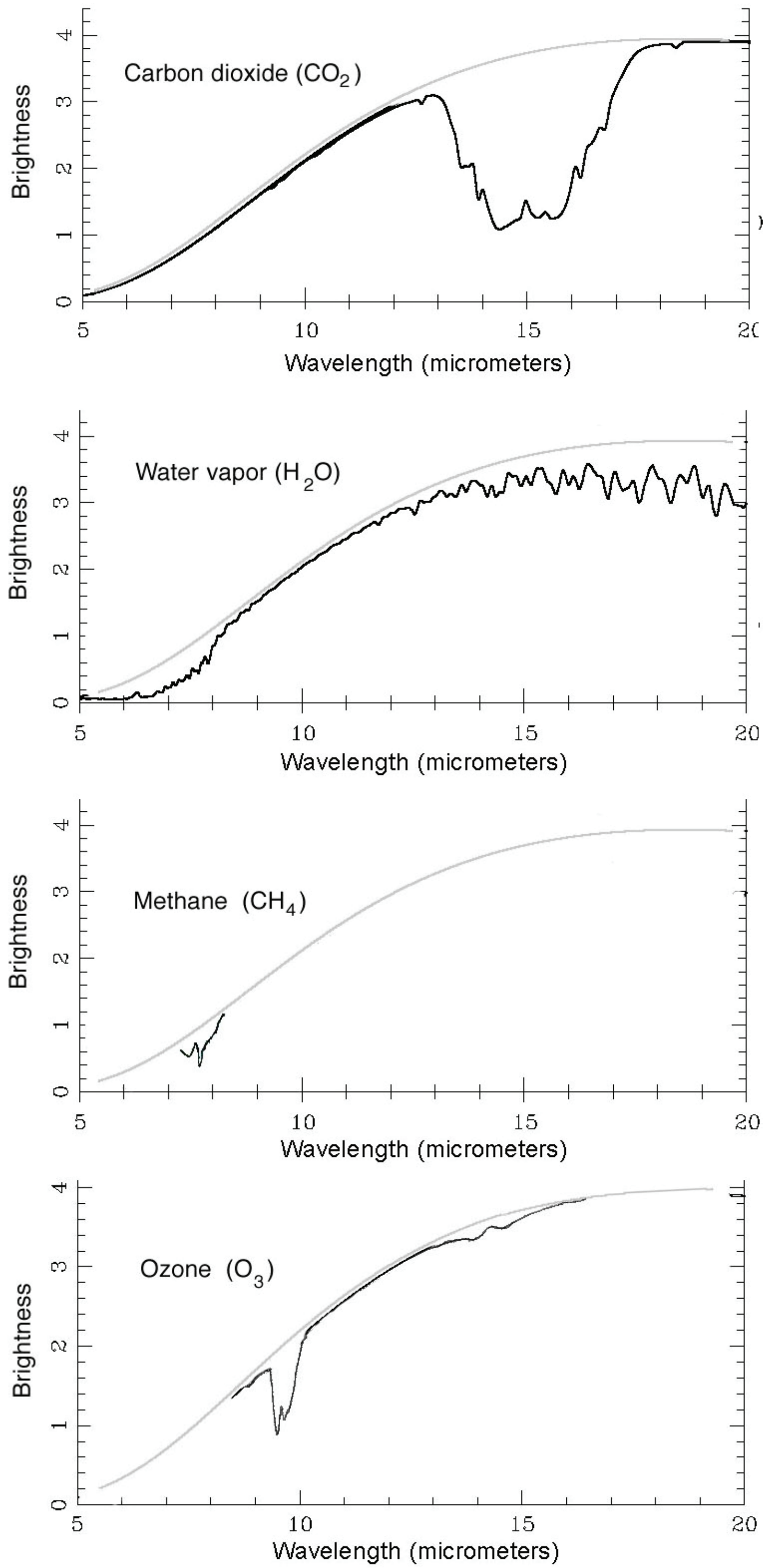


Figure 24: The wavelengths of light absorbed by molecules that are present in Earth's atmosphere.

Use this space to record your ideas, calculations and results.

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.

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!)

Use this space to record your ideas, calculations and results.

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.

Use this space to record your ideas, calculations and results.

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

Use this space to record your ideas, calculations and results.

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?	

Use this space to record your ideas, calculations and results.

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?

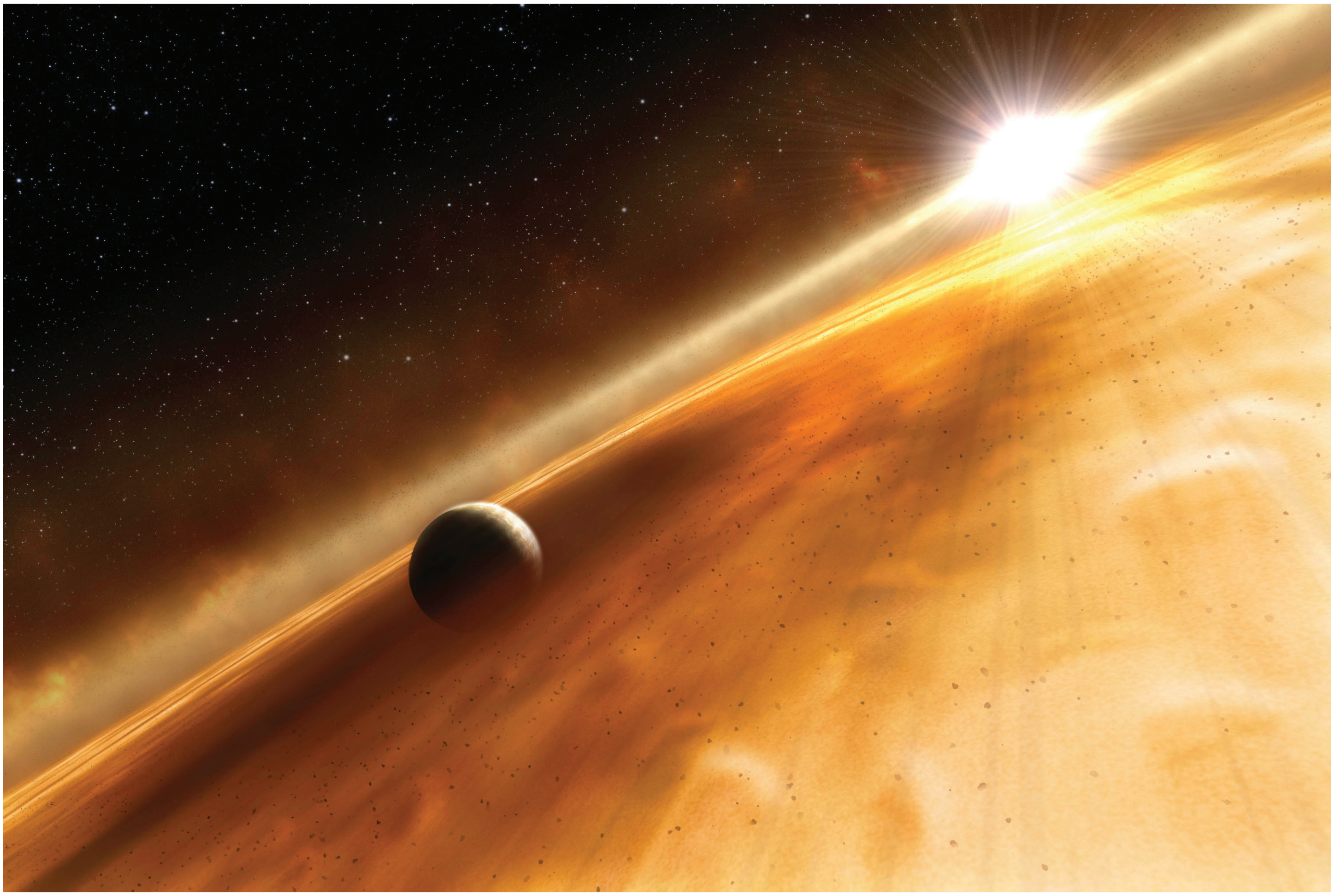
2. Describe something you learned in this project that you didn't know before.

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;