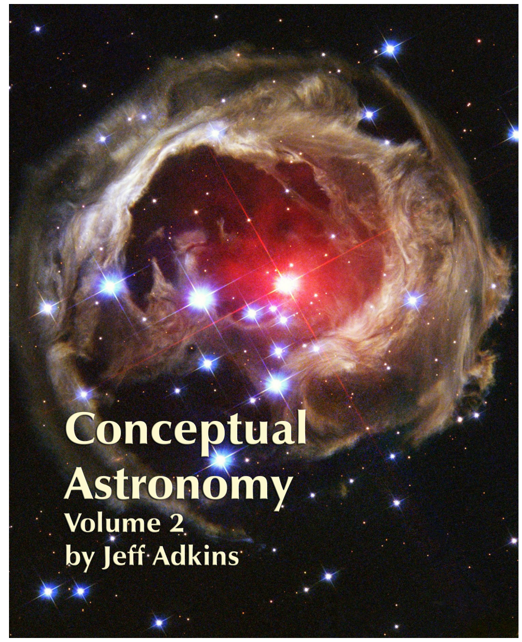
Conceptual Astronomy Part 2



Student Lab Manual and Activities

By Jeff Adkins

"I have loved the stars too fondly to be fearful of the night."

--Sarah Williams

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By Jeff Adkins

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Conceptual Astronomy 2
Student Edition of Lab Manual & Activity Book- Table of Contents

Introduction to Student Workbook 2

Welcome to *Conceptual Astronomy2*! Astronomy is a popular and interesting subject, but most people have to wait to go to college to learn about it. This book is targeted at high school students looking for a hands-on, conceptual approach to learning about the sky, followed by a solid grounding in the quantitative measurements that allow astronomers to do their work.

A *conceptual* course centers on the ideas behind the science before the mathematics is applied. Observations lead to patterns that must be explained with theories, which ultimately become mathematical so we can predict the behavior of objects in the sky in advance. There is math in this book, but it is arranged in such a way that most advanced math is optional.

There are so many good ideas for learning about astronomy we couldn't fit them all into one book. The book you are holding, called Part 2, is concerned with visual observational astronomy, primarily the behavior of the sun, moon, and planets that can be seen with the eyes. Part Two will deal with the stars and how we know what we know about them.

Hand drawn illustrations are used throughout much of the book so you can use to draw your own observations and diagrams instead of simply printing a picture you don't understand. The intention is that the drawings will look much like what your teacher will write on the board as they teach the course. The character's names are Cosmo and Astro.

New in this revision (October 2017) are several biographical sketches for famous astronomers on the ending even pages of some activities. You can use these as posters or use them as a launchpad for further investigations about how these people contributed to astronomy. There is no specific assignment for these documents.

I hope you enjoy using this book as much as I have writing it. I am indebted to a great many people including Jim Scala for his ongoing support and beautiful images, Mike Harms, Marni Berendsen, Dave Fredericksen for edits and mathematical language and Raymond Kuntz for his enthusiasm towards the project. I would also like to express appreciation for my student teacher Matthew Robison and former student Nick Pollard for feedback as well at the 2013 astronomy classes at Deer Valley High School for their patience and feedback on prototype activities. Any errors, of course, are entirely my own.

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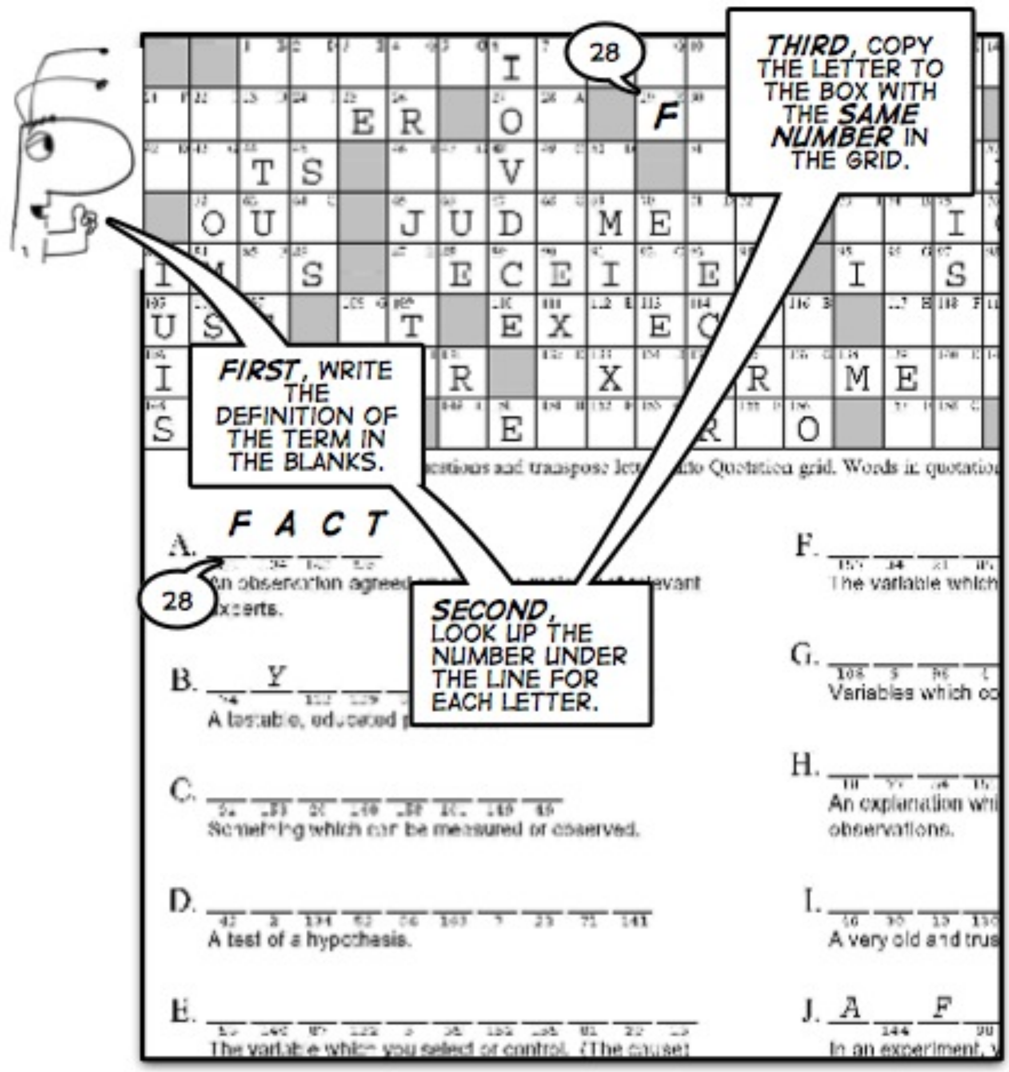
How to Solve the Puzzles



Note: In Volume 2 some terms of some puzzles have spaces in the clues, for example "black_dwarf." The space should be counted as a character in the puzzle solution.

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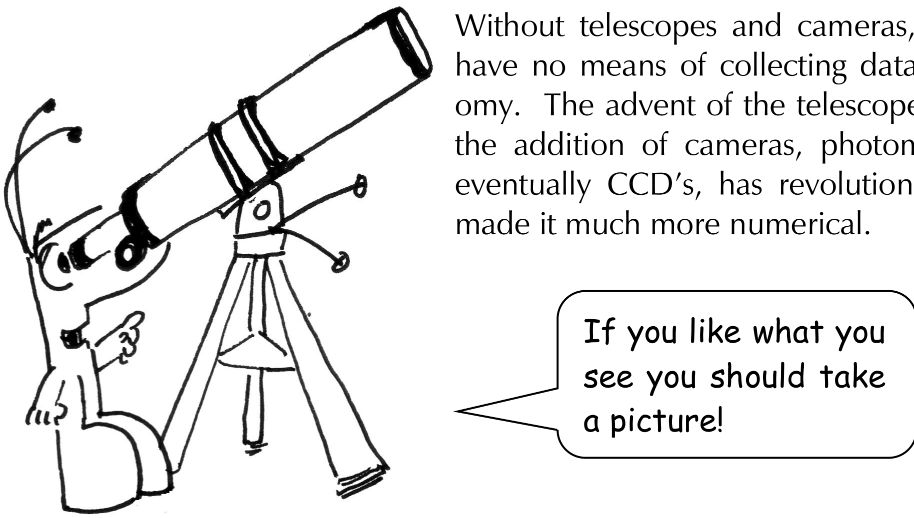
Conceptual Astronomy 2 Unit 1: Instrumentation



Without telescopes and cameras, astronomers would have no means of collecting data for modern astronomy. The advent of the telescope 400 years ago, and the addition of cameras, photomultiplier tubes, and eventually CCD's, has revolutionized astronomy and made it much more numerical.

Prior to these advances, much of extra-solar astronomy was **qualitative** (using comparisons and ratios). With the ability to measure brightness, color and position accurately and with consistency, the **quantitative** (based on measurement) story of stellar evolution and our place in the universe can begin to be understood. This unit is about the equipment astronomers use to collect light and measure it, known as **instrumentation.**

In this section we begin by studying reflection and refraction, and move on to telescopes and cameras. Reflection and Refraction are the basic principles of telescope functionality and are required to understand these important tools. Then basic telescope technology is shown, and the unit ends with an examination of what actually happens in a CCD camera.

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CA2 1.0: Instrumentation Objectives

By the end of this unit, students will be able to:

1. State the law of reflection and use it to predict the path of light rays that strike mirrors.
2. Use ray tracing techniques to find images in flat mirrors and concave mirrors.
3. State the law of refraction conceptually and use it to predict the path of light entering and leaving glass.
4. Understand how refraction is used to make convex lenses that can focus.
5. Find real images formed by convex lenses using ray tracing or the thin lens equation.
6. Describe images formed by concave mirrors and convex lenses in terms of their location, size, orientation, and nature.
7. Explain how to build a simple refracting telescope.
8. Discuss the most important characteristics of telescopes.
9. Compute the magnification of a telescope.
10. Compare and contrast several kinds of telescope designs.
11. Select telescopes based on the objective of the observer.
12. Understand what a CCD camera measures.
13. Define necessary vocabulary terms presented in this unit including:
    Aperture
    CCD
    Center of curvature
    Concave/Convex
    Eyepiece
    Focal length
    Focus
    Incident angle
    Law of Reflection
    Magnification
    Normal line
    Objective
    Pixel
    Real Image
    Reflected angle
    Refracted angle
    Resolution

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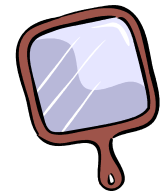
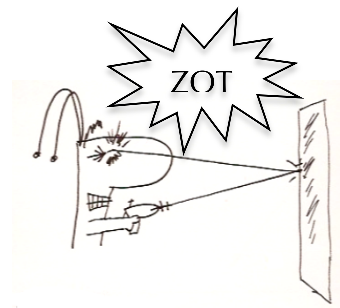
CA2 1.1: The Law of Reflection: Lab



Purpose: To observe the law of reflection in a plane mirror and in a curved mirror.

Materials needed: small low power laser, chalk erasers and chalk dust, flat mirror, concave mirror (such as a makeup mirror)



SAFETY PRECAUTION: Only use a small, low power, red laser pointer for these demonstrations. Do not point the laser at people's faces, or allow reflected laser light to hit faces. **Repeated or long-term exposure to laser pointer light is not good for your eyes.**

Procedure:

1. Set up the plane mirror flat on a tabletop, shiny side up. Using the chalk erasers, create a small amount of dust in the air. Shine the laser through the dust at the mirror. Observe the beam as it strikes the mirror and reflects. Sketch what you saw in the space to the right.

2. Is the angle the beam strikes the mirror equal to the angle it makes when it reflects?
____YES ____NO (check one)

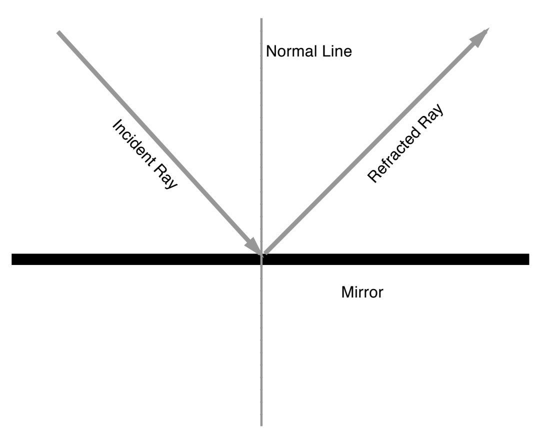
3. This is called **The Law of Reflection**. Write the law of reflection here.

____

____

____

4. The diagram at right shows a technical version of what this looks like. The horizontal line represents them mirror. Notice the vertical line. The definition of the **normal** line is a line that is perpendicular to the surface of the mirror. Label it. The **angle of incidence** is the angle between the incoming beam and the normal. In the diagram, label this θ_i. (θ is a Greek letter called theta and is commonly used to represent angles.) The angle between the reflected ray and the normal line is known as the **angle of reflection.** Label this θ_r.



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CA2 1.1: The Law of Reflection: Lab

5. Write the formal law of reflection using math symbols and words.

Flat mirrors cannot **focus** light, or cause it to gather together in a single place. To focus light, needed to make a telescope function, we need to use a curved mirror. The best shape for a curved mirror is parabolic, because it has the property that all light approaching the parabolic mirror parallel to the axis of the parabola will, when the law of reflection is applied, converge on a single point called the focus.

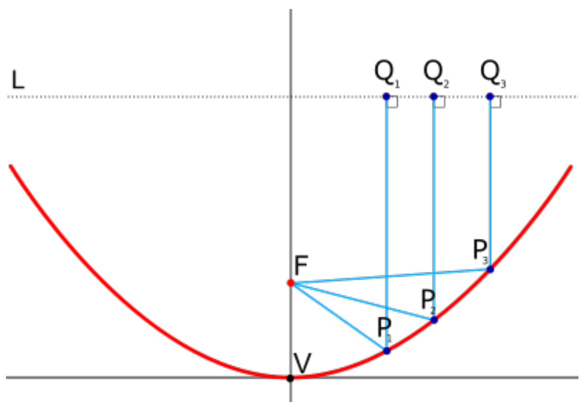

Figure 1. Image source: Wikipedia

In this diagram line segments QP represent light from a distant object, the parabola is shiny like a mirror, and F is the focus point where all the light meets. It turns out that each reflection point obeys the law of reflection for flat mirrors. In some telescope designs, the camera is located at point F.

6. Using the makeup mirror or concave mirror and some chalk dust, shine the laser at the mirror. Make sure the mirror is vertical on the desk. Aim the laser across the table at the mirror and move it back and forth to observe the light heading toward the focus. Sketch what you see here. Describe what you see. Are there any patterns?

7. What is the distance from this focal point to the surface of the mirror? This is called the **focal length** of the mirror.

Creating parabolic mirrors is difficult and expensive. It is somewhat easier to make a spherical mirror. If the radius of curvature is not too great, a spherical mirror behaves almost exactly like a parabolic mirror. In the next activity, we will investigate images formed by spherical mirrors.

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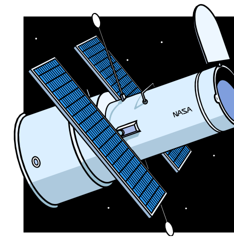
CA2 1.2: Ray Tracing and Image Formation in Concave Mirrors: Activity

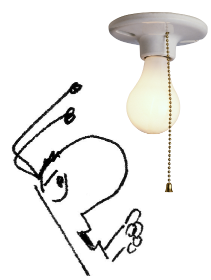


Purpose: To learn how concave mirrors can form images of extended objects.

Equipment needed: A ruler and pencil.

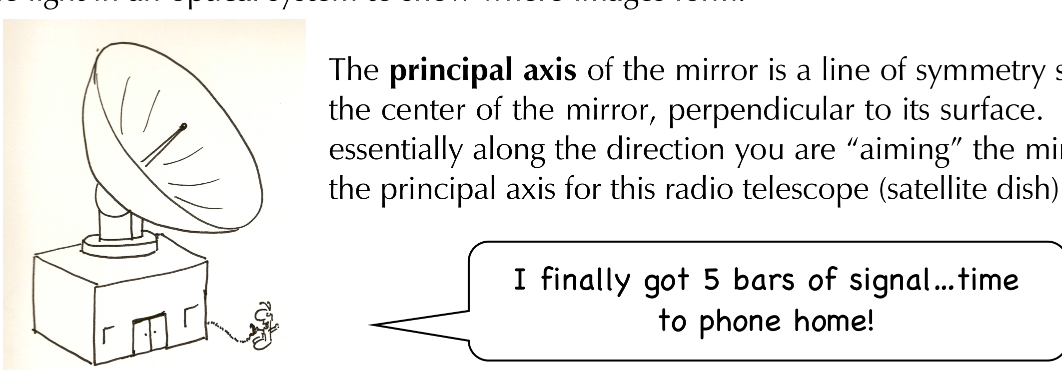
Background:
In this activity, we will use the rules we learned in the previous activity about the law of reflection and the rules for curved mirrors. The effects you observed in the previous activity can used to determine where images formed by the mirror will lie. These observations and exercises will show you how this works.

An object such the light as shown below emits light in every direction. Sketch rays coming off of this light bulb.



A mirror placed nearby can intercept *some* of the light. But which way will the light go after it hits the mirror? Predicting every path of every ray is difficult. However, there are two paths the light can take that are easy to predict.

To understand how a concave mirror can focus images of extended objects like planets or the moon, we will construct what is known as a **ray trace diagram.** A ray trace diagram follows the light in an optical system to show where images form.



The **principal axis** of the mirror is a line of symmetry starting from the center of the mirror, perpendicular to its surface. It is the line essentially along the direction you are "aiming" the mirror. Sketch the principal axis for this radio telescope (satellite dish) mirror.

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CA2 1.2: Ray Tracing and Image Formation in Concave Mirrors: Activity

In the previous activity we observed a curve mirror redirect a laser beam so it kept passing through a focus point. We're going to exploit that property and suggest the following rules:

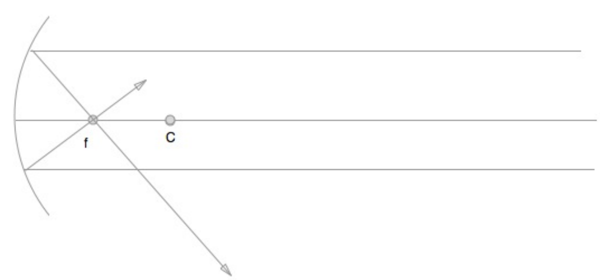
Rule 1: Rays approaching a parabolic mirror from a great distance, aligned with the axis of the mirror, will pass through the focus point.

Rule 2: Rays passing through the focus point of a curved mirror will reflect and follow a path parallel to the axis of the mirror.

We're going to use these rules to learn how to predict where the image of an object in front of the mirror will be.

1. A typical situation is shown at right. The **focal point**, or location where parallel rays converge after reflecting, is needed to solve these problems so that is shown. Point C refers to the **center of curvature** of the mirror that is exactly twice as far from the mirror as the focus point. Label the sketch to the right with these terms: mirror, principal axis, focus, center of curvature.

2. To see how the mirror works, we draw rays from a distant object approaching the mirror. The object is so far away; the incoming rays hardly diverge and appear parallel, heading in to the mirror and parallel to the principal axis. According to Rule 1, these rays will bounce off the mirror and pass through the focus point. Sketch this.



The intersection will show where the focus point is. Mark the focus point with an f.

The center of curvature of the lens is twice as far from the mirror as the focal point. Mark this spot with a C. Sometimes we call this point 2f.

3. This spot is where light from a distant source is concentrated. Such an arrangement might be used in a satellite dish or a solar water pre-heater assembly on a roof. If, on the other hand, we put a light bulb at the focus point, a beam is produced. What sort of technology is this arrangement used for?

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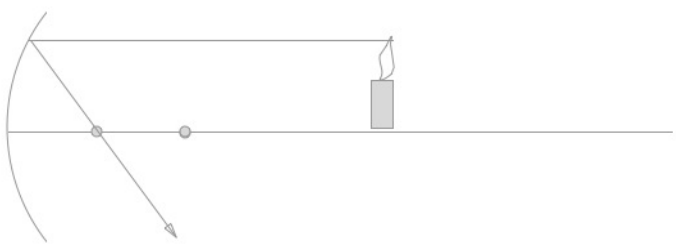
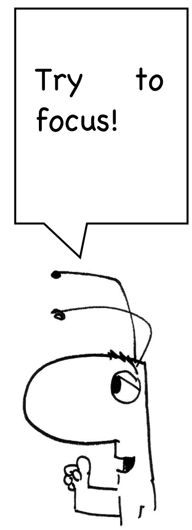
CA2 1.2: Ray Tracing and Image Formation

4. Now we turn to the situation where there is a relatively nearby object such as a candle. Light emanates from all directions from the candle, but some of it strikes the mirror. Some of it even approaches parallel, as before, and thus will pass through the focal point.

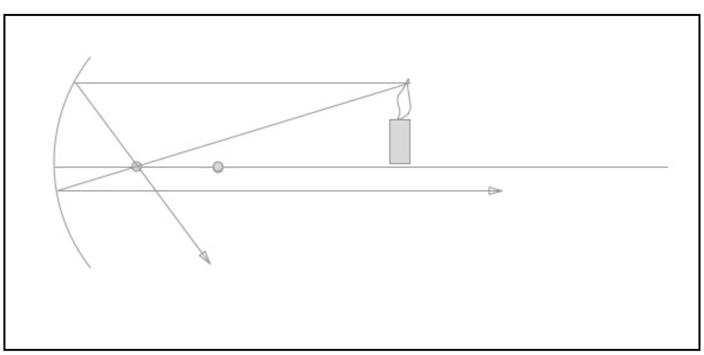
Sketch this. Place the candle (or object) to the right of the center of curvature.





5. According to Rule 2, light leaving the top of the candle will sometimes pass through the focus *before* hitting the mirror, and will therefore bounce back parallel to the principal axis. Sketch this in the box above, and include Rule 1 as well.

6. Since the light came from the top of the candle, the intersection shows where the image will be. The candle's image appears between the intersection and the principal axis. Because the mirror bounces the light downward, the image will appear upside down— between the principal axis and the intersection. In the diagram below, add the image of the candle.



In this particular example, the image appears to be smaller than the original object. That is not always the case. Depending on where you put the object, several different outcomes are possible. These will be investigated in the next activity.

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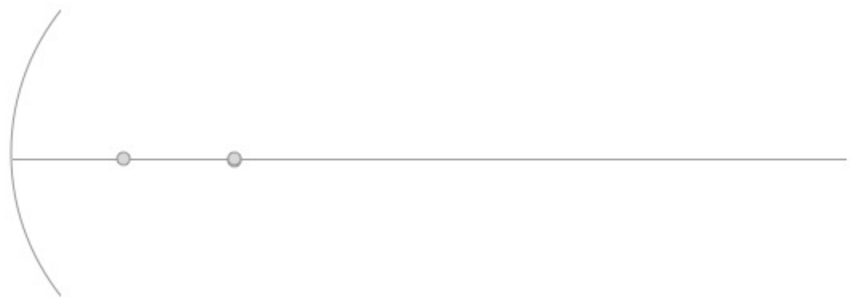
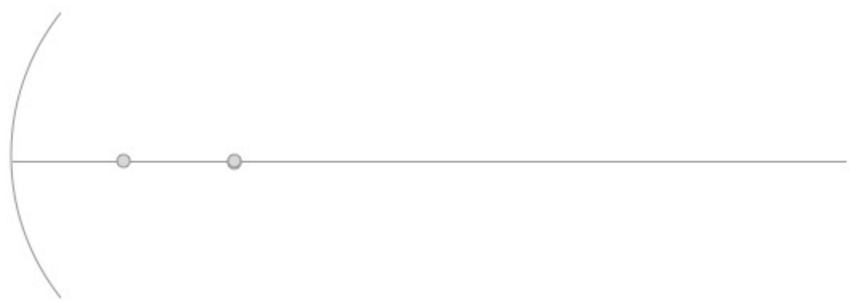
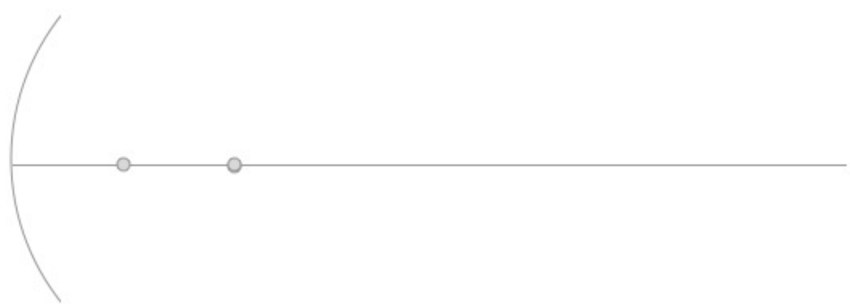
CA2 1.2: Ray Tracing and Image Formation in Concave Mirrors: Activity

Use this page to practice drawing ray trace diagrams.







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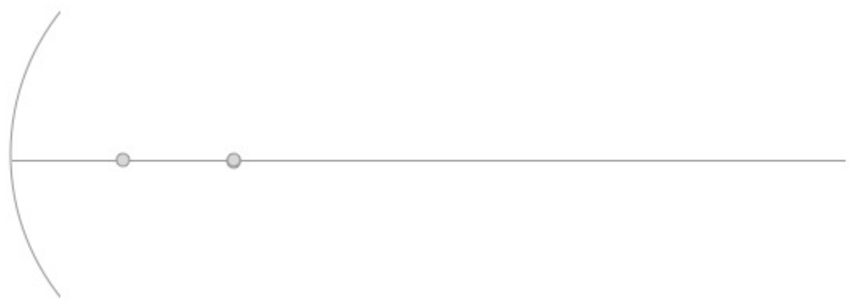
CA2 1.2.1: Curved Mirror Ray Tracing: Worksheet

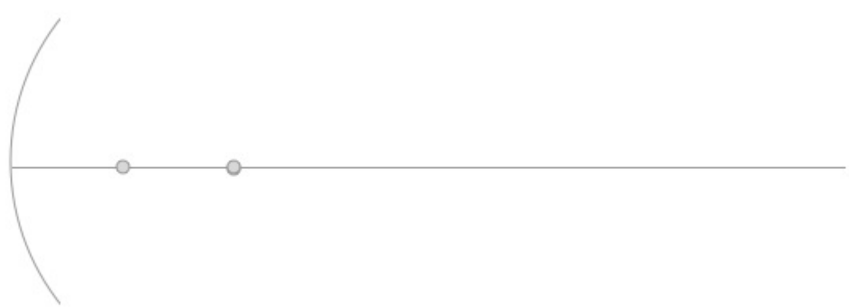
Using ray tracing, find the images for these three situations. Describe each image in terms of its **size** (larger or smaller than the original object), its **orientation** (upright or inverted) and its position (called the **image distance**, measured from the mirror.) For each of the following draw a candle sitting on the principal axis (at positions >C, = C, and >f but at the same time <C). Then use ray tracing to find the image, and describe it.

1. Object > C.



2. Object = C.

3. Object <C, >f.



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CA2 1.2.1: Curved Mirror Ray Tracing: Worksheet

Questions:

4. Will a mirror with a long focal length appear to be deeply curved or nearly flat?

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5. What other applications are there for curved mirrors besides telescopes?

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____

____

6. If the object is extremely far away, approximately where will the image form?

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7. Will a mirror that is larger in diameter make a brighter or dimmer image?

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8. Suppose a mirror with a focal length of 4 m is used to image the moon. Approximately where will it form an image?

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9. Astronomers sometimes refer to mirrored telescopes as "light buckets." What do they mean by this?

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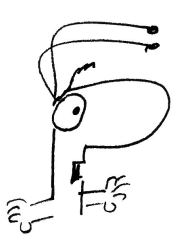
10. Why is it dangerous to carry a large concave mirror around outside?



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CA2 1.3: Refraction: Activity

Materials needed: People, pencil, cup of water. Prisms and rectangles of glass and a laser (optional)

Purpose: To see the effect of refraction in glass and water and understand how a lens works.

Procedure:

1. Have you ever seen light make a thing appear to be bent? Try this. Put a pencil inside a glass of water. As seen from some angles, the pencil will appear to be crooked. Sketch what you see here.

This effect is known as **refraction**, or the bending of light. In this activity we will do various demonstrations to explain why light bends as it enters a transparent material.

The main reason the effect of refraction occurs is because *light slows down in a transparent material***.** This occurs because transparent materials consist of atoms that intercept the rays of light and make them stop temporarily, held in place by the atoms until they are released. Between the atoms, light travels at the speed of light—but its overall average speed is reduced because of the interruptions. This is just like a car that travels at 65 mph between gas stations on the freeway, but stopping for gas lowers the average speed.

The average speed of a car is less because it stops for gas once in a while.

To demonstrate this effect, try this. Form a group of 4 students and stand together shoulder to shoulder in a row, linking arms together. Lay a stick on the floor a few feet in front of you, representing a wall of glass. The students represent a **wave front** and the direction they are walking represents the direction a **ray** of light would move. As the students approach the air glass **interface** or junction between two transparent materials, they move at the speed of light. After they cross the line, they slow down.

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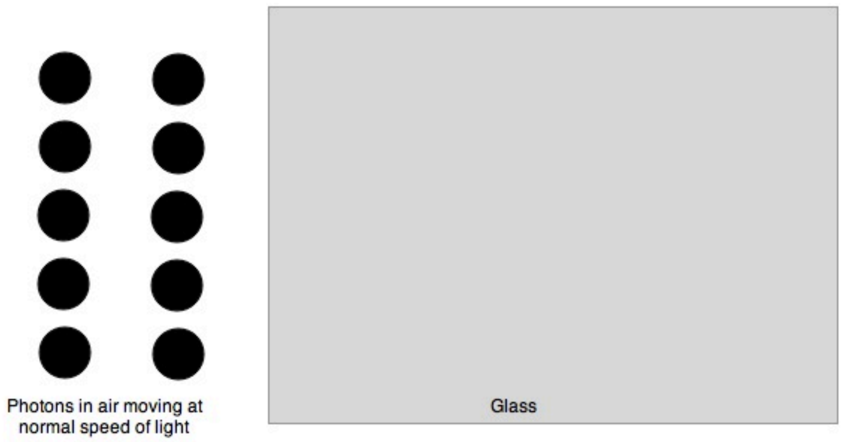
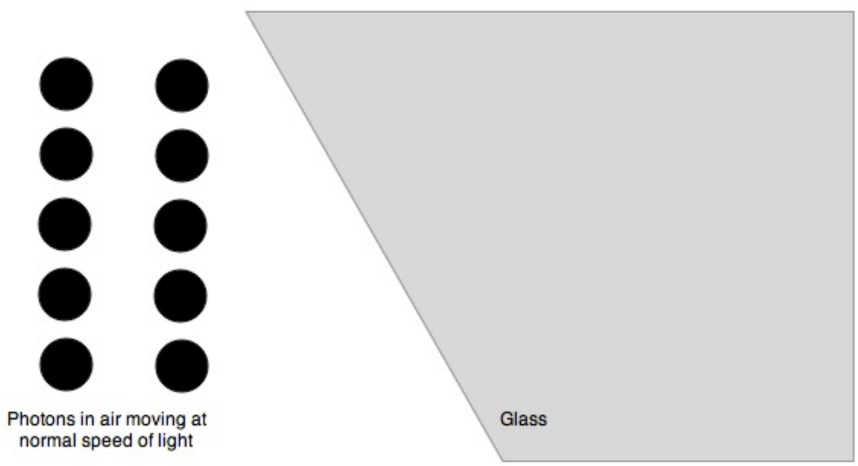
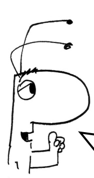
CA2 1.3: Refraction: Activity

2. In the illustration below, the circles represent people or photons of light. The second column represents the particles of light one nanosecond later as they approach the interface. Draw what happens to the photon-people after they cross the line into the "glass" and slow down.



3. Now try the demonstration again, this time with the interface at an angle as shown here.





If the students lined up in a row, representing photons, keep their arms linked, they will wind up changing direction. The same effect might occur if a marching band encounters a mud patch on one side. The band will slowly veer towards the mud because those marchers cannot maintain the same speed as the rest of the band.

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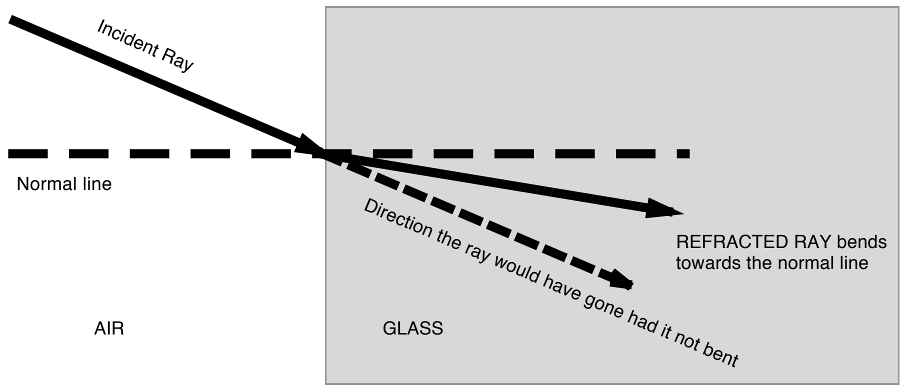
CA2 1.3: Refraction: Activity

As the light ray approaches the interface, it will bend in a predictable way. As shown in the illustration below, *a ray at an angle, approaching a material with a higher optical density (which means it is thinner, with fewer atoms per cubic centimeter) will bend towards the normal line.*



4. The opposite effect is also true. If a ray at an angle approaches a material with a smaller optical density, what will happen?

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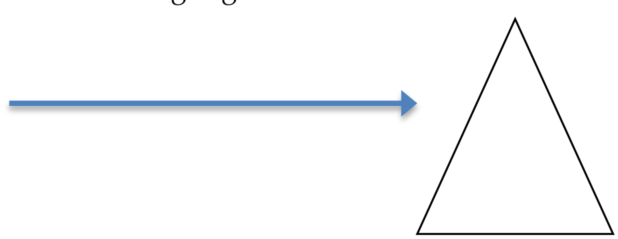
Of course, a ray that approaches an interface at a right angle will not bend, because neither side is slowed down preferentially.

5. Now let us consider a triangle of glass, as shown. Using the refraction rules above, predict where the laser beam might go.



6. What would happen if the triangle were upside down?

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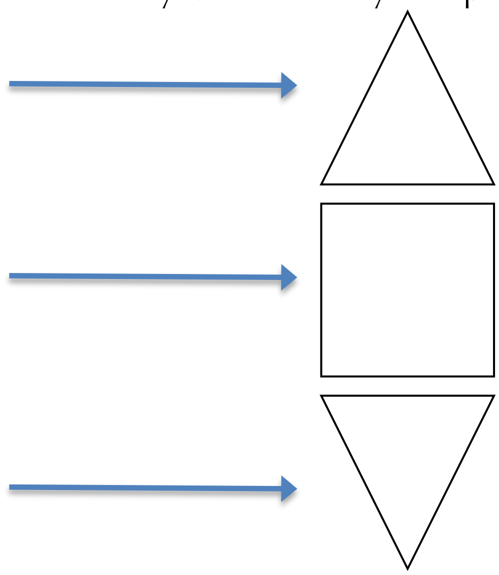
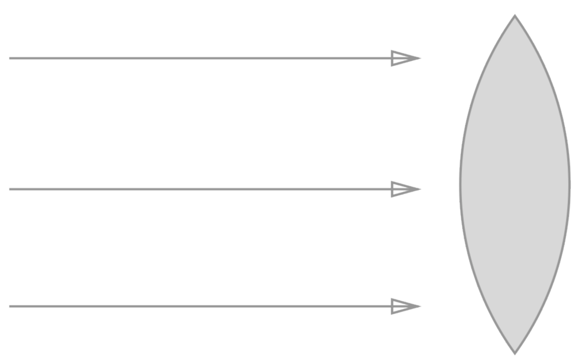
CA2 1.3: Refraction: Activity

7. Sketch where you think the rays will pass in the combined system below.



8. You may notice a resemblance to the shape of a magnifying glass, send from the side. This is known as a **double-convex or biconvex lens.** Such lenses can be used to construct telescopes and microscopes. If a continuously curving shape is used instead of triangles and rectangles, the focus will be more precise. In the sketch below, every ray approaching the lens parallel to its principal axis will wind up passing through the focus. Complete the sketch below to show this.



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CA2 1.4: Double-Convex Lens Ray Tracing: Activity

You may have noticed that the way light passes through a double-convex lens is exactly like the rules we discovered for concave mirrors. Because both devices converge light to a focus, they are equivalent optically. Everything a concave mirror can do, a double convex lens can do as well. The rules for mirrors are shown below. Rewrite them to apply to lenses. Note: light goes *through* a lens, and doesn't bounce back like it does for convex lenses.

Concave Mirror Rules

Rule 1: Rays approaching a parabolic mirror from a great distance, aligned with the principal axis of the mirror, will pass through the focus point.

Rule 2: Rays passing through the focus point of a curved mirror will reflect and follow a path parallel to the principal axis of the mirror.

1. Convex Lens Rules

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____

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____

____

2. What does it look like? Sketch rays following these rules below.

Questions:

3. Will a lens with a longer focal length than another be thicker or thinner in the center?

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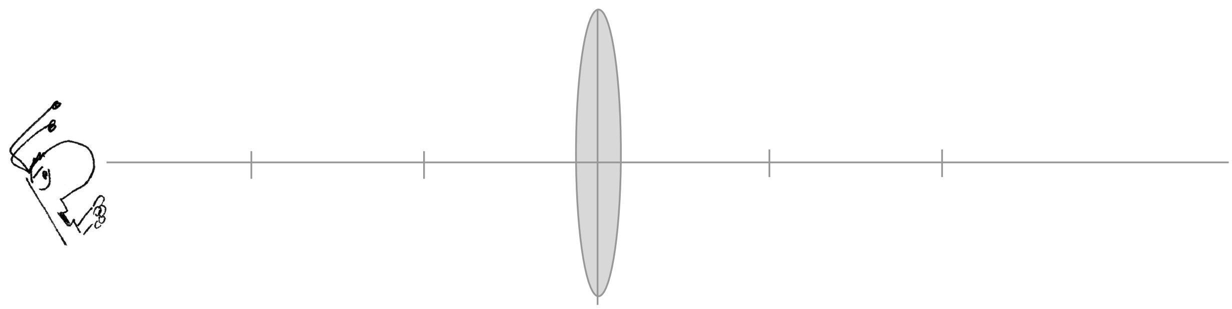
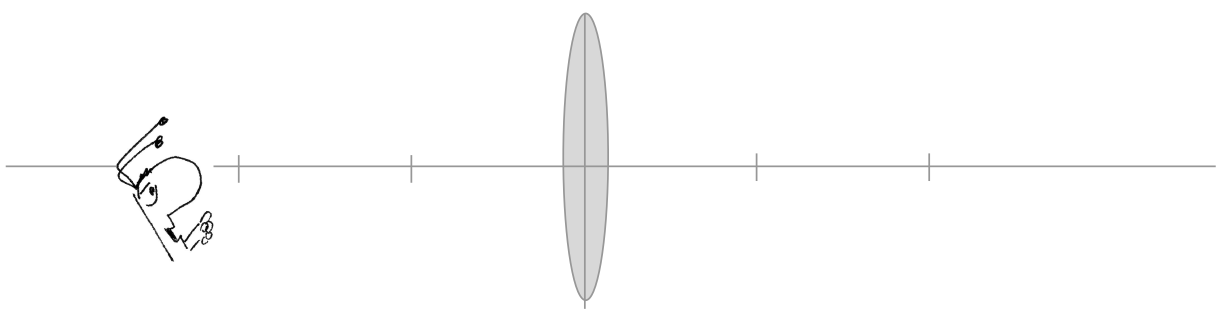
CA2 1.4: Double-Convex Lens Ray Tracing: Activity

4. What is the main difference in the rules for ray tracing for concave mirrors as opposed to convex lenses?

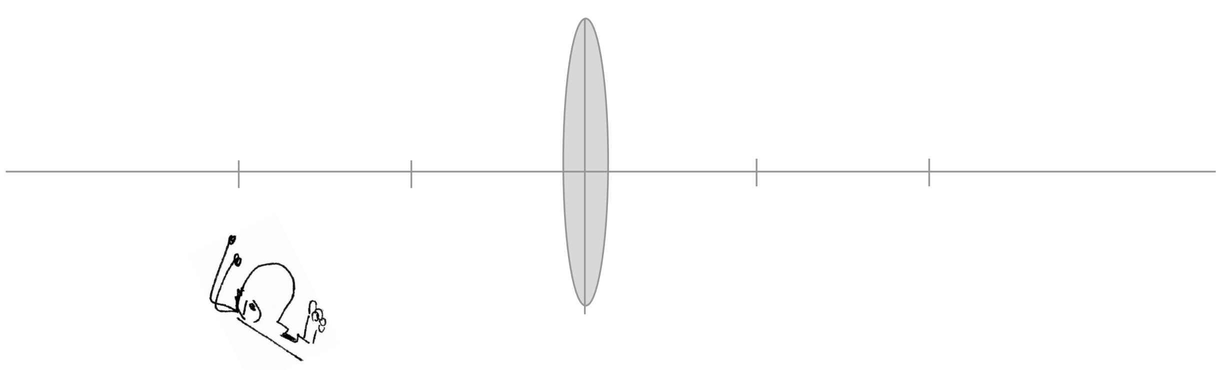
5. Recreate the three situations set up in the curved mirror worksheet. Draw the ray traces for each situation as shown below. For this one, place the object (candle) at >2f or >C. Cosmo is pointing to where you should draw your object (usually a candle.)



6. Place this object at C.



7. Place this object between f and 2f (C).



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CA2 1.5: Thin-Lens Optical Bench: Lab

Purpose: To show how double-convex lenses can make predictable images when the object is far away.

Equipment needed: Optical bench (meterstick, lens holder, small lamp or candle, candle holder, blank paper, double convex lens such as a magnifying glass)

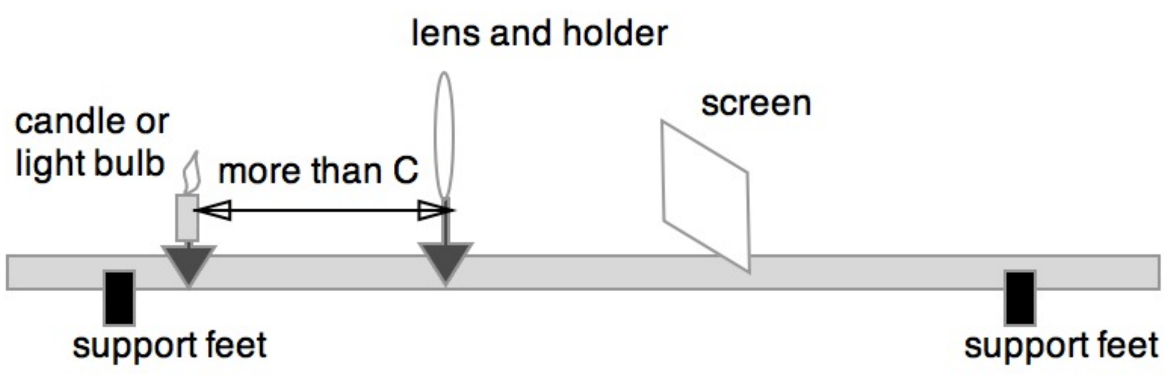
Precautions: If candles are used, students should remove baggy jackets, and tie back long hair. Open flames should be used with supervision and due caution.

Procedure

1. Measure the focal length of the lens you are using by using it to project a focused image of a distant light source (such as a window from across the room) onto the blank paper. When the image is sharp, the distance between the lens and the paper is the focal length. Record the focal length of your lens here. Use centimeters for this lab.

F =

2. Set up the optical bench as shown. Arrange the light source so it is somewhat farther than two times the focal length of your lens. Focus the light onto some blank paper on the other side of the lens. Move the paper until the image is sharp.



Measure the **image distance** (between the focused image on paper and lens):

Measure the **object distance** (between the lens and light source):

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CA2 1.5: Thin-Lens Optical Bench: Lab

3. While you have the equipment set up, try this mini-experiment. What do you think will happen if you cover half of the light source with your hand? Try it and see.

____

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____

4. Use the **thin lens equation** to solve for f. Do not use the value of f from #1. We are attempting to see if we can get the answer two different ways, which is an important strategy in science. The thin lens equation is $\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}$, where d_o is the object distance and d_i is the image distance, and f is the focal length.

____

____

5. Now draw a ray trace diagram *to scale* using the measured focal length and object distance, and see if the image distance produced is the same as what you measured in #2.

6. Your teacher may ask you to repeat the lab with different object distances. Record these measurements on your own paper.

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CA2 1.5: Thin-Lens Optical Bench: Lab

Questions

7. Why is the image always inverted?

____

____

8. In what everyday technology are lenses used to make small images of distant objects besides telescopes?

____

____

9. The light through the lens is reversible. That is, you can place an object where the image was and it will create a larger image far away from the lens. What commonplace piece of technology uses this arrangement?

____

____

10. What effect do you think that diameter of a lens would have on the brightness of an image?

____

____

11. Suppose you put a light source at the focus point. What kind of image or pattern is formed?

____

____

____

12. One main purpose for convex lenses is for magnifying glasses. Use yours to look at something in the traditional way and answer this question: Where is the object in terms of the focal length? Describe the image you see compared to the object.

____

____

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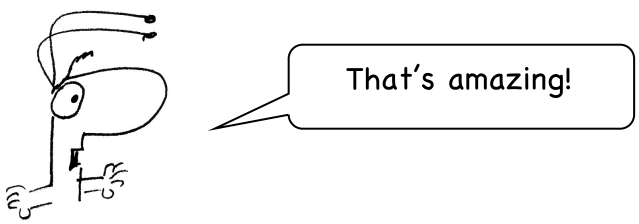
CA2 1.5: Thin-Lens Optical Bench: Lab

Going Further

13. Try designing a homemade camera or projector with a magnifying glass. If you draw a small picture on a piece of transparency, then light it from behind, the magnifying glass can be used to project the image onto a wall in a darkened room.

14. To make a primitive camera, put the lens at the end of a box and put a sheet of thin white paper at the other end. Adjust the distance from the lens to the paper until an image of a distant bright object is focused. Then you can trace the image on the thin paper. This was how portraits were sometimes painted before the invention of photographic film.



15. Try using the magnifying glass from a distance closer than f, as it was intended. You will not be able to focus the light on a screen. Additionally, when you look through the lens, the image will not be inverted. It will be larger and **virtual**. Try to learn to draw virtual image ray traces. (*Hint: you already did one, with the flat mirror activity.)

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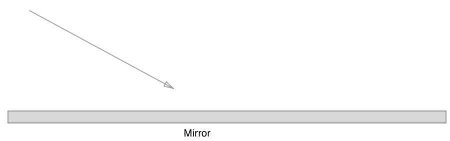
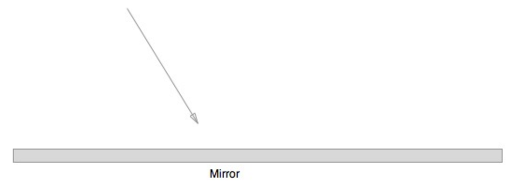
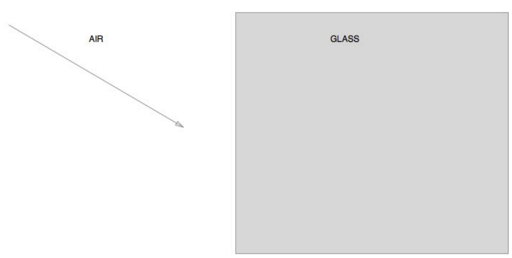
CA2 1.6: Reflection and Refraction: Activity

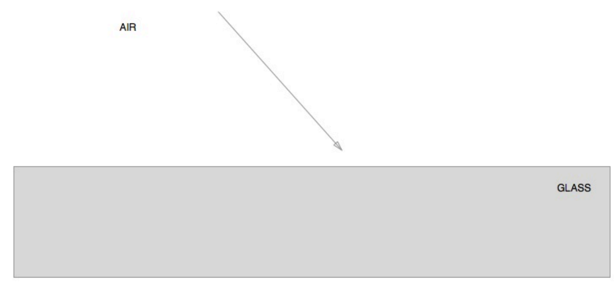
1. Predict (by sketching) which way you think these rays will go when they hit the mirror shown. Label the normal line, incident and reflected rays.





2. Predict (by sketching) which way you think these rays will go when they pass through the transparent interface. Show the normal line, the incident angle and refracted angle.





3. Ray tracing for curved mirrors.
Draw the ray trace diagram, finding the image, for the situations shown on the next page. Describe the image in words: Larger/smaller than the original object, upright/inverted, and image distance compared to object distance.

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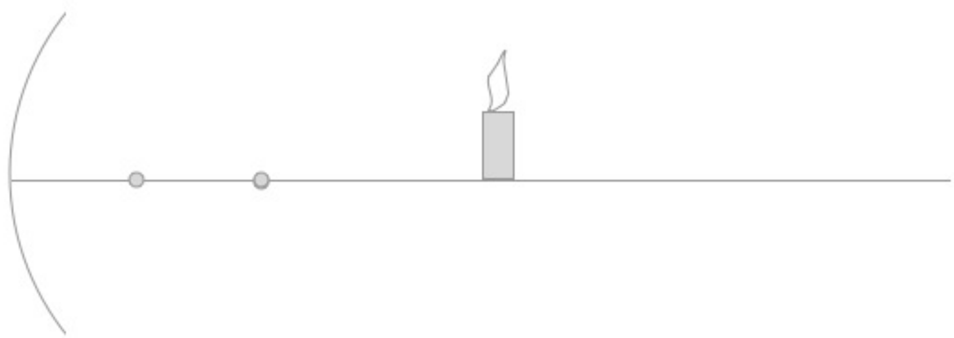
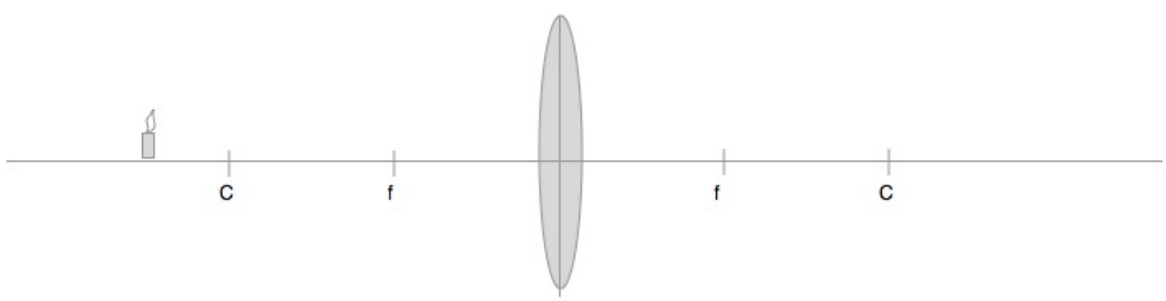
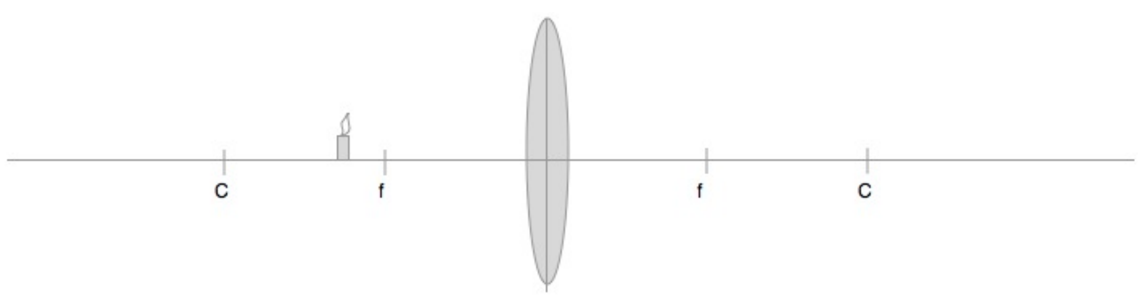
CA2 1.6: Reflection and Refraction: Activity



4. Ray tracing for convex lenses.
Draw the ray trace diagram, finding the image, for the situations shown. Describe the image in words: Larger/smaller than the original object, upright/inverted, and image distance compared to object distance.





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CA2 1.7: A Small Optical Bench Telescope: Lab

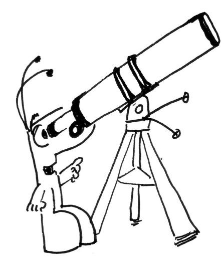
Purpose: To build a simple telescope with lenses and investigate its properties.

Materials needed: Two convex lenses of different focal length, resolution target, and magnification target.

Procedure:

1. Find the focal length of the two lenses and determine which one is longer. Record the method, and the values you obtained, in the space below.

2. Hold the lens with the longer focal length in one hand, extended away from your face. This one is closer to the object you are observing, so it is called the **objective.** Hold the lens with the shorter focal length near your face, as shown in the illustration. This one is closer to your eye so it is called the **eyepiece.** Look through both lenses at once, and adjust the distance between them until the view is clear and sharp. (Hint: the distance between the lenses will be approximately the sum of the focal lengths when the image is focused.)



This is a simple telescope. Describe the image below, as compared to what you see without the telescope.

3. The **magnification** of a telescope is how many times larger the image appears than what your eye can see. To *calculate* the magnification, use the formula

$$M = \frac{-f_o}{f_i}$$

Where f_o is the focal length of the objective and f_e is the focal length of the eyepiece.

Calculate the magnification of your primitive telescope and write it in the space above.

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CA2 1.7: A Small Optical Bench Telescope: Lab

4. To *observe* the magnification of your telescope, look at the magnification target printed in your workbook. The idea is to look at the grid with the telescope and compare it to the grid you see without the telescope. With practice, you can use double vision to do the comparison. Use one eye to look at the grid with the telescope, while *leaving the other eye open* to see the grid without the telescope. If you keep both eyes open, you can see both grids at once, and compare how many of the small boxes (seen with the unaided eye) fit in one of the large boxes (seen with the telescope-eye). The ratio should be approximately equal to the magnification you observed already.

Observe the magnification grid on the last page of this activity, and describe whether or not the magnification you see is similar to what the formula predicts.

5. Telescopes also make images brighter. Larger lenses can concentrate more light, and therefore yield brighter images. To show this effect, look at something bright inside a darkened room with your handheld telescope. (Recall in the optical bench lab, the projected image got dimmer when we covered half of the lens. It didn't cut the image in half.) While looking through your telescope have a partner cover half of the objective lens with their hand or a piece of paper. You should be able to see a complete picture, but dimmer than before. What this tells us is that brightness depends on surface area of the lens, and the surface area depends on the diameter, so the wider the telescope lens, the brighter the image.

Suppose a telescope has twice the diameter of its objective than another. How many times brighter will the image be?

6. Telescopes also enable us to see more detail than the eye can see alone. To see this effect, hang up the resolution target across the room and ask yourself: at what numbered level do the lines appear to merge together, showing no space between them?

Now observe the target with your homemade telescope and answer the question again. Telescopes allow you to see more detail than the human eye can perceive alone.

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CA2 1.7: A Small Optical Bench Telescope: Lab

7. If a commercially available telescope is available, or a pair of binoculars, use those and compare the results to what your homemade telescope saw. Describe the differences below.

8. f/ratio. The f/ratio of a telescope is determined as follows.

$$f/ratio = \frac{f_o}{aperture}$$

Equation for finding f/ratio

The *aperture* is the diameter of the objective lens. What is the aperture of your bench telescope?

9. What is the f/ratio of your bench telescope? (show your work below)

10. If a telescope or camera lens has a small f/ratio (e.g. 3, 4, 5, 6) it is called a *fast* lens. It creates small, bright images that require short exposures to complete images. Telescopes and cameras with a large f/ratio (e.g. 9, 10, 11) make larger images, but take more time to expose the images because they are dimmer. Thus they are sometimes called *slow* lenses. Is the optical bench telescope you constructed *fast* or *slow?*

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CA2 1.7: A Small Optical Bench Telescope: Lab

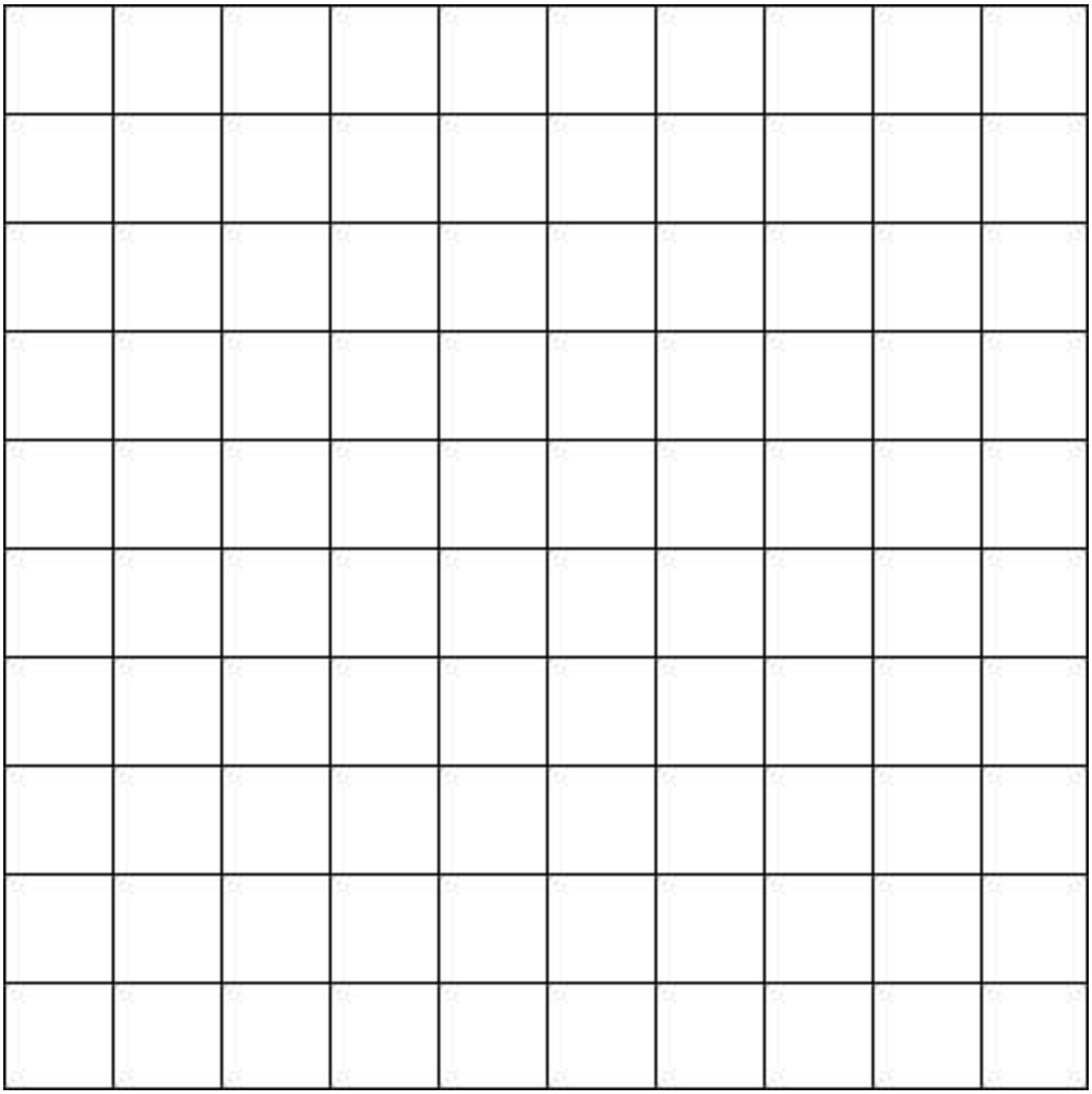

Figure 1. Magnification Grid.

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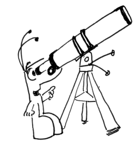
CA2 1.8: Telescope Types: Activity



Purpose: To investigate the different types of telescopes and learn which are best for a specific purpose.

Materials needed: Various types of telescopes, if available. Computer with internet access.

Background:
For each type of telescope mentioned, use the internet or the example telescopes provided to describe it and tell about its advantages and disadvantages.

1. **Refractors.** Galileo first built his refracting telescope in the early 1600's. Refracting telescopes use only lenses. The telescope you constructed for the optical bench telescope is a refractor. In a refractor, the tube is about as long as the focal length of the objective, which is typically much longer than the focal length of the eyepiece. Draw a picture of a refracting telescope that shows how the light passes through it.

What are the advantages and disadvantages of this design?

2. **Newtonian Reflectors.** Isaac Newton designed a reflecting telescope to overcome some of the problems with refracting telescopes. Instead of using lenses, Newton's design used a curved piece of metal (today, we use glass) to reflect the light to secondary mirror. The secondary mirror reflects the light sideways, out the side of the tube, near the large opening at the top. Thus the tube is approximately as long as the focal length of the mirror.

On the next page, sketch a picture of how the light goes through a Newtonian. Label the **primary mirror** and the **secondary mirror** as well as the location of the eyepiece.

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CA2 1.8: Telescope Types: Activity

What are the advantages and disadvantages of this design?

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3. **Cassegrain.** Cassegrain developed a telescope that took advantage of the fact that the secondary mirror in a Newtonian telescope blocks the light. Therefore the center part of the reflecting mirror is not used. To make the telescope easier to use, Cassegrain drilled a hole in the primary mirror and made the light bounce from the secondary through the hole, putting the observer (and cameras) at the bottom of the telescope rather than the top. This essentially folds the telescope in half, making the tube much shorter than the Newtonian design. Sketch a picture of how the light goes through a Cassegrain telescope below. Label the **primary mirror** and the **secondary mirror** as well as the location of the eyepiece. In some Cassegrain designs a corrector plate adjusts for some aberration caused by using a spherical mirror instead of a parabolic one. That particular design is called a **Schmidt-Cassegrain.**

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CA2 1.8: Telescope Types: Activity

What are the advantages and disadvantages of this design?

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4. **Prime Focus.** A **prime focus** telescope has no secondary mirror but places the observer (and/or the camera) at the focal point. Satellite dishes and radio telescopes often use this design. Extremely large telescopes may use this design, such as the 200-inch telescope at Mt. Palomar. The more reflecting surfaces a telescope has, the more light is focused by the mirrors. Having only one primary mirror reduces the amount of signal lost. Sketch how such a telescope focuses light or radio waves.

What are the advantages and disadvantages of this design?

____

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5. **Coude'.** A **Coude'** telescope focuses light off-axis so the secondary mirror does not block the light striking the primary. In other words, it is tilted with respect to the principal axis, and you do not point the mirror directly at the target like you would with an ordinary telescope. Otherwise, it is similar to a Cassegrain design. Some satellite dishes use this design for the same reason. On the next page sketch a pictures of a Coude' telescope's light path. Again, label the primary mirror.

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CA2 1.8: Telescope Types: Activity

What are the advantages and disadvantages of this design?

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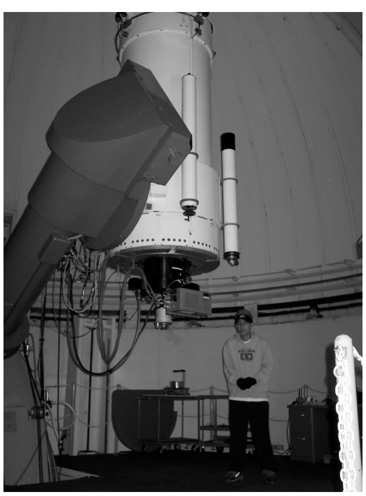
6. Which type of design do you think is illustrated in each picture below? How can you tell? (All photos by the author.)



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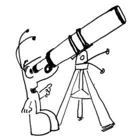
CA2 1.9: Comparing Telescopes: Activity



Purpose: To compare several telescopes and judge which is best for each purpose.

Materials needed: Several telescopes of differing design *or* several copies of advertising for telescopes in magazines such as *Astronomy* or *Sky and Telescope*. Online advertisements can be used from such sites as *telescope.com* (Orion Telescopes) or *telescopes.com* (a different vendor).

Procedure: Compare several telescopes either in person at a star party, in the classroom, or by reading advertising in an astronomy-related magazine or online. Telescope specifications can be found at Celestron.com, Meade.com, and other places. Complete the table below, using the instructions.

Type: Respond with **Galilean** (refractor), **Newtonian**, Dobsonian (essentially an inexpensive or homemade Newtonian), **Cassegrain** or **Schmidt-Cassegrain**, **Coude'**, or **Prime Focus**. (The last two would be unusual in backyard or school telescopes.) Other types exist, and if you cite them you should describe them.

A Newtonian Telescope with a German equatorial mount.

Aperture: This is the diameter of the primary lens or mirror. This will usually be the first thing an ad says about a telescope. It if is not printed on the ad or real telescope you are using, you can measure it with a ruler. Often astronomers refer to different telescopes only by their aperture as in "tonight I will be using the 100-inch telescope to photograph asteroids."

Focal length: In a refractor or Newtonian telescope, this is about as long as the tube. If it is not given in a telescope, you can compute it from the aperture and the f/ratio.

F/ratio: Usually given in an ad, but can be calculated from focal length and aperture.

Magnification with a 25 mm eyepiece: Since eyepieces can be changed easily, the best way to compare telescopes is to use the same eyepiece. Compute the magnification using the focal length of the objective and a 25 mm eyepiece.

Mount: The mount of a telescope is very important. A telescope which is not steady cannot be used no matter how good the optics.

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CA2 1.9: Comparing Telescopes: Activity

- Mounts can be motorized, computerized, or manual. A computerized mount can be directed with a telescope or control pad. In addition the structure of the mount can be one of the following:
- **Alt-az**: The telescope only can turn left and right, up and down, and without a computer, cannot easily follow the stars.
- **Equatorial**: This telescope is designed to follow the sky and has a tilted axis that can point to the North Star.
- **Fork**: Fork mounts hold the telescope on both sides. They are very stable and are often used in reflecting telescopes.
- **German Equatorial**: This design has an axis that points to the North Star and another that is perpendicular to that. These axes are mounted without a fork.

Special features: Special features include unusual finder scope technology such as lasers or reflex sights, computer control, cameras, moon filters, and so on.

Limiting resolution: **Resolution** can be theoretically computed using the equation R=144/D, where D is the aperture size in millimeters and R is the resolution or the smallest separation that can be seen as separate objects, measured in arcseconds. Earth-bound telescopes cannot usually exceed a resolution of 0.1 arcsecond due to the Earth's atmosphere. Any answer smaller than 0.1 should be rounded up to 0.1. Smaller values are sharper images.

Describe Telescope				
Type				
Aperture				
f/ratio				
Focal length				
M with 25 mm eyepice				
Mount				
Resolution				
Special features				

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CA2 1.9: Comparing Telescopes: Activity

1. In your opinion, which is the best telescope for viewing planets, and why?

____

2. Which telescope would be best for viewing large, dim galaxies?

____

3. Which telescope is easiest to carry around in your car for observing in a dark sky location?

____

4. Which telescope yields the brightest images?

____

5. Which telescope yields the sharpest images?

____

6. Which telescope will take images in the least amount of time?

____

7. Which telescope will yield the largest images with a 25 mm eyepiece?

____

8. Which telescopes are computerized, if any?

____

9. Suppose you had $2000 to buy any telescope you wanted (and nothing else more important that the $2000 would be spent on instead). What kind would you spend it on and why?

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CA2 1.9: Comparing Telescopes: Activity

10. On this page consider analyzing an advertisement for 3 different telescopes. List the features of each telescope, and decide which one is the best one for a particular purpose. (Pick one: observing planets and moon, deep sky visual observing, or astrophotography.) Advertisements can be found online or in issues of *Sky and Telescope* or *Astronomy* magazines as well as photography magazines in some cases.

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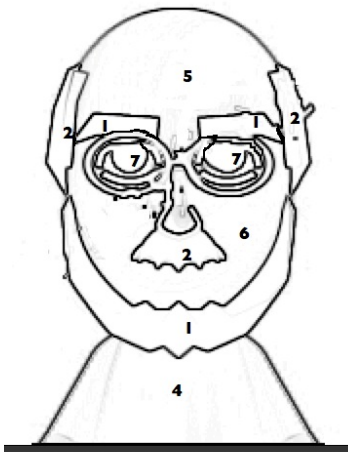
CA2 1.10: Digital Camera Images Color by Number: Activity

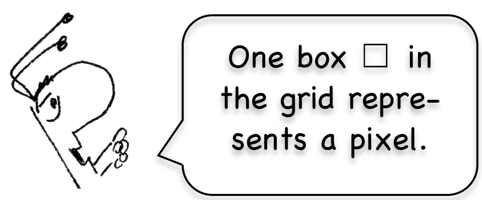


Purpose: To investigate how CCD cameras convert light into digital images.

Equipment needed: 5 colored pencils

Background and Procedure: Did you color-by-number when you were young? No? (Ask your parents.) Before computer-based art programs, children would sometimes paint pictures using a black-and-white drawing of an image labeled with numbers as shown here. Using colored pencils or crayons, children would fill each number with a corresponding paint color from a set of paints accompanying the drawing; 1 = black, 2 = grey, etc.

Today's digital cameras use **charge-coupled devices** (CCDs) which consist of millions of individual light sensors that essentially count the photons of light that hit them. Once collected, the computer converts these numbers into a picture. But how are the numbers converted? To find out, you will be doing something you haven't done in a long time. You will be coloring!



Look at the image on the next page. Each box contains a number that tells how many photons fell on that particular digital sensor. We call these individual brightness measurements **pixels** (picture elements). Your task is to color them in. But…there's a catch. (Isn't there always?) The catch is you will not have enough colored pencils to color all the numbers differently. So you will have to pick *ranges* that will be represented by different colors.

1. Look over the table carefully and find the largest number in the table. Write it here. ___

2. Look over the table carefully and find the smallest number in the table. Write it here. ___

3. In the table that follows, designate ranges of numbers to be represented by colors. For example, you could simply divide the range of numbers evenly by 5 and assign 1/5 of the range to each color. Or you could decide to make 1-500 one color, and divide the remaining colors unequally. It's up to you. Propose a coloring scheme in the table on the next page.

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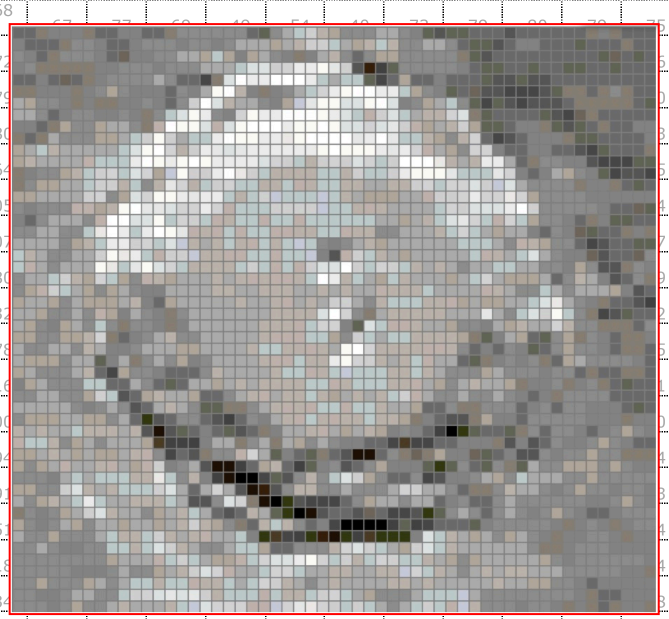
CA2 1.10: Digital Camera Images Color by Number: Activity

]Color					
Range					

\4. Now color your picture according to the scale.

5. What do you think the picture represents?
Choose one: Planetary nebula, crater, Saturn, space probe, edge-on spiral galaxy.

146	161	147	144	137	137	126	137	109	68	78	115	99	114	139	150	172	174	166	161	166
141	152	139	137	118	94	104	70	97	83	55	136	163	135	135	135	156	177	167	169	169
140	125	139	136	153	111	31	82	70	52	65	41	100	92	140	157	166	185	191	190	162
140	140	139	131	60	51	95	66	64	26	10	52	36	77	102	79	123	179	180	180	185
114	100	101	35	48	56	13	10	17	4	2	29	31	52	84	103	72	179	166	141	161
91	86	17	21	36	22	30	29	40	53	30	28	39	28	34	75	93	61	150	139	153
68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	91	61	30	42	65	59	86	145	116
72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	88	99	95	61	44	48	26	105	135
79	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	108	96	71	55	89	84	135	139
80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	99	101	100	85	85	98	80	137
64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	73	96	94	104	84	92	109	144
105	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99	80	81	90	98	88	110	84	30
107	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	90	80	86	94	118	94	98	75	14
80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	79	80	81	81	134	157	118	172	67
132	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75	86	81	110	153	119	137	138	75
78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	85	74	88	125	105	109	128	148	68
116	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	84	96	137	164	151	127	153	136	75
100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	127	170	178	198	170	154	162	164	67
94	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	157	139	156	159	152	164	161	139	69
91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	125	122	123	141	146	118	100	109	61
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	132	159	152	155	134	151	118	137	57
118	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	232	205	147	124	135	128	116	137	70
134	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	69	84	64	89	108	101	102	116	67
120	118	108	89	73	66	90	78	62	103	91	95	96	77	80	96	109	91	92	98	58



6. Compare your picture to your classmates. Can you see details in yours not in theirs, or vice versa? Describe them.

____

____

7. How could we improve the detail in the image without using more pixels?
\
____

____

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CA2 1.10: Digital Camera Images Color by Number: Activity

8. How many "pixels" are in this image?

____

____

____

9. How many pixels would be in an image 1000 pixels wide and 1000 pixels tall?

____

____

____

Going Further

Consider purchasing a paint-by-number kit and

- Using a different color palette than the one in the instructions
- Leaving parts of the painting unfinished to show others how it works
- Creating a paint by number for astronomical objects
- Using a photo of an object and converting it to a paint by number as in this activity to share

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CA2 1.11: Using Image J in Astronomy: Activity

Purpose: To learn how to use basic image processing software for later use in labs and activities

Equipment needed: Working copy of Image J software; astronomy plug-in; computer

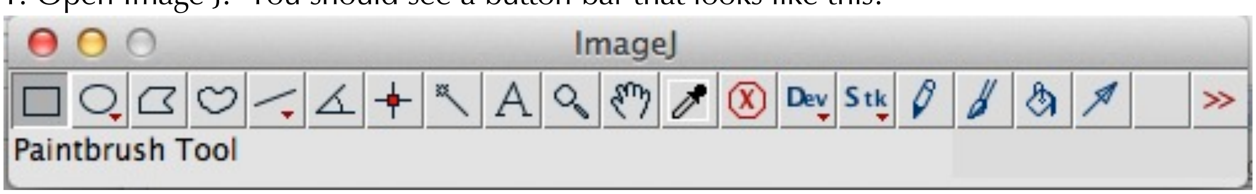
Background:
Image J is a free program available for multiple platforms and used for measuring and manipulating digital images. It was originally developed as a program for doing brain scans at the National Institutes of Health, but is now used for a variety of purposes including astronomy. It is available from http://rsb.info.nih.gov/ij/, and includes documentation and a variety of plugins including the Astronomy plugin package located here: http://www.astro.physik.uni-goettingen.de/~hessman/ImageJ/. The software installers and plugins should also be available on your teacher's resource disk that came with this book.

A complete tutorial on how to use Image J for astronomy is located at this web site:
http://www.astro.physik.uni-goettingen.de/~hessman/ImageJ/Book/index.html

The activity in this workbook is just an introduction to a few specific skills you will need for this course.

Purpose: To learn how to open and measure basic quantities in digital imaging software such as Image J.

Procedure:
1. Open Image J. You should see a button bar that looks like this:



2. Use the File menu to open the sample image sample.fits. Do not double click on the file in your operating system. What do you think the image is?

____

The most commonly used commands in this course are listed below. Try each one and tell the result after the item listed.

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CA2 1.11: Using Image J in Astronomy: Activity

3. Use the **straight line selections tool** to draw a line across the crater's diameter. The length will be displayed under the buttons as you go. Once you let go of the mouse, the measurement will disappear. What is the diameter of the crater in pixels?

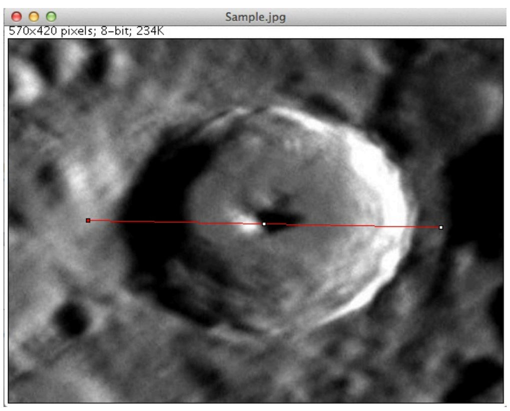

Figure 1. Picture courtesy of Jim Scala.

4. Perform a **plot profile** (Analyze>Plot Profile) across the crater, and sketch it here. Explain what you think the peaks and valleys represent?

5. Open the sample image sample2.fits. This image was used in an activity called Supplementary Activity 14 in the Hands-On Universe astronomy program (http://www.hou.lbl.gov) and is used with permission. What do you think this picture represents?

6. Use the astronomy plug-in "Aperture" under the Astronomy menu. (Information on how to install and access this plug-in is in Appendix CA2 A-7.) Click on one of the stars. A data table will appear where the total brightness enclosed by the innermost circle you see is displayed. Record the value you obtained here.

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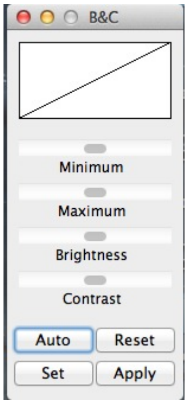
CA2 1.11: Using Image J in Astronomy: Activity



7. To make images easier to see, use the Image>Adjust>Brightness and Contrast command. Click "Auto" several times to see the effect on the image. You can also manipulate the settings manually. Describe the difference in the image.

8. You can zoom in and out to make the picture larger and smaller. Use the magnifying glass tool to zoom in. Click it, and then click on the area to zoom in. Press shift and click on an area to zoom back out.

If you zoom in too much, what happens to the image?

9. If you point to a particular pixel on the screen, a number appears on the button bar. This tells you the pixel value underlying that particular pixel. It also tells you the x, y coordinates within the image. Go to 100, 74 and find out the pixel value there. Record it here:

10. Image J can do many other things such as measuring angles and areas, combine images to form color pictures, animate stacks of images to create videos, and more. Try to use the online tutorials mentioned at the beginning to learn at least one or two more interesting skills.

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CA2 1.12: Instrumentation: Application

1. The world's largest telescopes have approximately a 10-meter diameter. Calculate the surface area of the mirror.

2. Compare this to the area of a typical 10-inch mirror used in a backyard telescope. Convert the inches into meters, find the area, and compare to #1 by dividing and finding the ratio.

3. Suppose the large 10 meter telescope is an f/6 telescope. Compute the focal length.

4. Such telescopes do not usually use eyepieces because they are meant for use with cameras. But just for fun, what if a 50 mm focal length eyepiece were used with such a giant telescope…what would the magnification be?

5. If the mirror were used to focus light from a nearby lighthouse, located 400 meters from the telescope, where would the image of the lighthouse form?

6. What kind of telescope is this?

7. Suppose you take a picture with the backyard telescope that exposes the camera for 100 minutes. How long would it take to expose the same picture to get just as much light for the larger telescope? (Assume the same f/ratio.)

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CA2 1.12: Instrumentation: Worksheet

8. How big a building would be required to hold such a telescope? How many stories tall would it be? Assume a story is 3 meters tall, and the telescope design is Newtonian. Is this a good choice for the telescope design?

9. When observing the moon, astronomers using the telescope note the image is too bright; they cannot take pictures of it with the camera they have. So they cover the aperture with a **mask**, that covers most of the telescope's diameter except for a small circular hole. Describe what this does to the telescope's

a) focal length
b) f/ratio
c) image brightness
d) magnification

10. An astronomer often uses the technique of "mosaic" imaging, where several CCD chips are used to create a much larger imaging area. How many pixels are in an image from 4 CCD chips each with an area of 1000 x 1000 pixels?

11. Explain why all digital images are essentially color by number.

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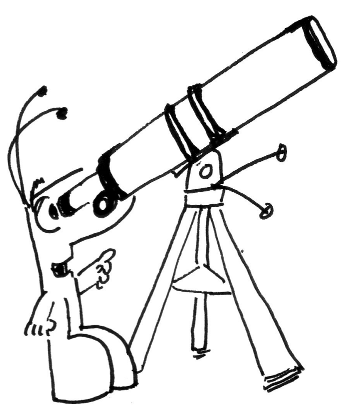
CA2 1.13: Instrumentation: Puzzle

Fill in the terms at the bottom of the puzzle. Then write the same letter in the box with the corresponding number. A quotation or phrase will be spelled out in the grid at top.

1	2	3		4	5	6	7	8	W		9	10	11	12		13	14	15	
16	17	18		19	20	21	22	23		24	H	25	26	D		H	27	28	
29		30	31	32	33	34	35	36	37	38		39	40	41		42	43	44	'
45		M	A	K	46		A	47	Y	48	49	D	Y		B	50	51	52	53
54	55		H	56		H	A	57		58	N	59	-	W	60	61	L		62
M	63	T	H																

1. _ (1) _ (3) _ (6) _ (5) _ (16) _ (13) _ (8) _ (37) _ (17) MEANS "FAR-SEEING"; TUBE WITH 2 LENSES
2. _ (36) _ (39) J _ (18) _ (35) _ (9) _ (52) _ (54) _ (20) CLOSEST TO THE OBJECT
3. _ (25) _ (19) _ (31) P _ (60) _ (33) _ (42) _ (38) CLOSEST TO THE EYE
4. _ (4) _ (49) C _ (11) _ (7) _ (32) _ (46) _ (15) G _ (12) _ (2) DISTANCE BETWEEN FOCUS POINT AND LENS
5. _ (14) P _ (50) _ (22) _ (30) _ (40) R _ (53) DIAMETER OF OBJECTIVE
6. R _ (55) _ (23) _ (58) _ (51) U _ (41) _ (63) O _ (44) SHARPNESS OF IMAGE
7. C _ (21) _ (28) _ (34) _ (56) G R _ (24) I _ (47) HAS A HOLE IN CENTER OF OBJECTIVE MIRROR
8. P _ (26) R _ (27) _ (48) O _ (61) I C SHAPE OF TELESCOPE MIRROR FOR BEST FOCUS
9. C _ (10) _ (29) R G _ (59) COUPLED DEVICE; USED IN CAMERAS
10. _ (57) P E C _ (45) R _ (43) _ (62) C O P E USED TO SEE COLORS



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CA2 1.13: Instrumentation: Puzzle

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Conceptual Astronomy 2 Unit 2: Starlight

In any image of stars, you might notice that the stars are merely small dots. Some are bigger, some are smaller. They may have different colors as well. The information we get from analyzing stars is extremely limited. Only in rare cases can we see an image large enough to show detail, and even then there isn't much to see. How do astronomers know so much about stars when only dots and specks are visible?

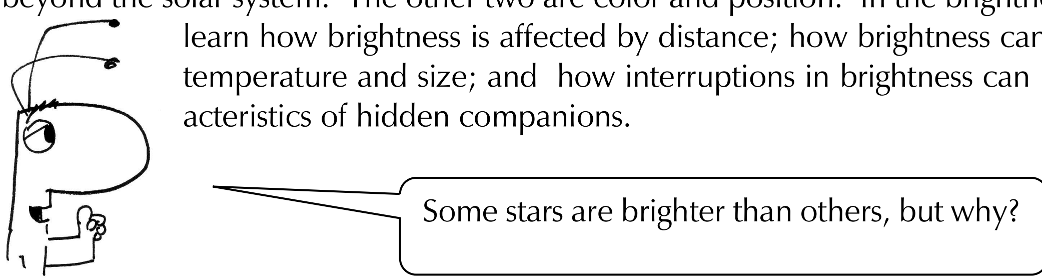
Astronomers only have 4 bits of information to rely upon when analyzing starlight. These are

Brightness,
Color,
Position,
and Time of Observation.

Each of the first three items on this list is investigated within the next several sections, showing you how astronomers collect and interpret the data that reveals to us the nature of stars.

Conceptual Astronomy 2 Unit 2A: Brightness

This unit contains labs and activities related to the brightness of a star or other object. Brightness is the first of three primary characteristics we will investigate as we learn about astronomy beyond the solar system. The other two are color and position. In the brightness unit, we will learn how brightness is affected by distance; how brightness can be affected by temperature and size; and how interruptions in brightness can reveal the characteristics of hidden companions.



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CA2 2.0: Starlight Objectives

Upon completing this unit, students will know and be able to…

1. State and use the inverse square law of light to solve problems involving brightness and distance.
2. Given brightness ratios, find distance ratios and vice versa.
3. State the basic definition of visual magnitudes.
4. Compare magnitudes to linear brightness scales as measured by cameras.
5. Convert brightness counts to magnitudes and vice versa.
6. Explain the need for standard stars in magnitude calculations.
7. Compare the brightnesses of two different stars given their magnitudes.
8. Sketch the light curves of several common variable stars including eclipsing, pulsating, standard, and exploding stars.
9. Use magnitudes to estimate distance to stars using spectroscopic parallax.
10. Use light curves to determine the orbital period of a star with a planet that eclipses the star's light.
11. State the major domains of the electromagnetic spectrum in wavelength order.
12. State the different kinds of spectra and explain how they are formed.
13. Use an emission or absorption spectra to identify the chemical composition of an object.
14. Locate the peak wavelength of a star's spectrum to determine its temperature using Wien's Law.
15. Define blackbody radiation and list its characteristics.
16. Qualitatively explain the Doppler effect and tell what it can reveal about a star.
17. Explain the uses of color in analyzing starlight.
18. Use parallax to determine the distance to objects in space or on the ground given appropriate baselines and angles.
19. Convert arc seconds to degrees and radians, and vice versa.
20. Explain the limitations of geometric parallax in stellar astronomy.
21. Define and use the following terms:

Absolute magnitude
Absorption
Apparent magnitude
Arc minutes
Arc seconds
Baseline (Base)
Brightness
Continuous
Degrees
Doppler effect
Eclipsing
Emission
Intrinsic
Light curve
Light year
Magnitude
Nova
Parallax
Parsec
Peak Wavelength
Radians
Spectra
Spectrascope
Spectroscope
Spectrum
Variable
Wavelength
Wien's Law

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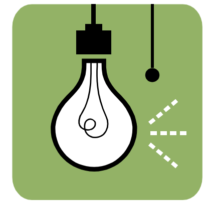
CA2 2A.1: Brightness vs. Distance: Lab

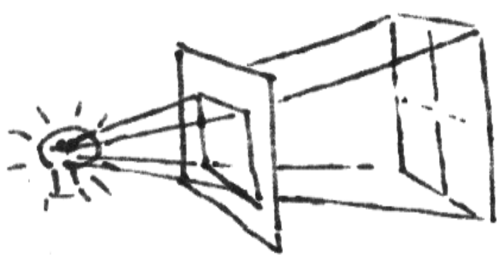


Purpose: To experimentally verify the relationship between brightness and distance.

Equipment needed: Small lamp (not a flashlight—see below); ruler, light-sensing device such as a photocell and voltmeter or Vernier light probe; black construction paper; room which can be darkened.

Background:
Light expands outward in waves similar to ripples in a pond. Because of this, the brightness of a light source decreases as distance increases. This is called an *inverse* relationship. (Other inverse relationships exist, although they aren't well understood by people who avoid math. For example, if you drive with *more speed* to get somewhere, it will take *less* time.)

The relationship between the brightness of light and distance is a little more complex, however. Because light spreads out over an area, the light gets dimmer even faster than the inverse of the distance. In fact, since a source of light twice as far from an image spreads light out over four times the area, the light will be four times dimmer. Here is an illustration to help you understand this concept.



1. Light from a source twice as far away is four times dimmer. This can be easily observed using a light bulb shining through a square window in a piece of cardboard. As you move the light bulb and cardboard away from a screen, the square of light projected gets larger—and dimmer.

If a light source is 3 times farther away, it will be dimmer still. In the space below, sketch how much area the light from a source will spread out if the light's brightness is observed 3 times farther away.

1. Light from a source 3 times farther away will be _______ times dimmer. This can also be said to be _________________ as bright.

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CA2 2A.1: Brightness vs. Distance: Lab

If you understand this relationship, you can see that a simple inverse relationship is not sufficient to explain the changes in the brightness of light. Not only is the light inversely related to the distance, the fact that the light is spreading out over an area causes the light to be inversely proportional to the *square* of the distance.

2. Complete the following table and predict how the brightness of light will be affected by changes in distance. In the table, everything is compared to the first observation; that is, where the brightness is initially observed, we call the distance 1 unit and the brightness 1 unit.

Number of times farther	Brightness (times as bright)
1	1
2	
3	1/9
4	
	1/25
6	
8.6	
13.2	
x	

3. The pattern you have discovered is called an *inverse square* relationship. Describe in complete sentences how to figure out the brightness change given any distance shift as shown in the table.

____

____

Graphing:
Now plot a graph containing all the data points in your table. You will need to invent a scale that allows all the individual points to be plotted.

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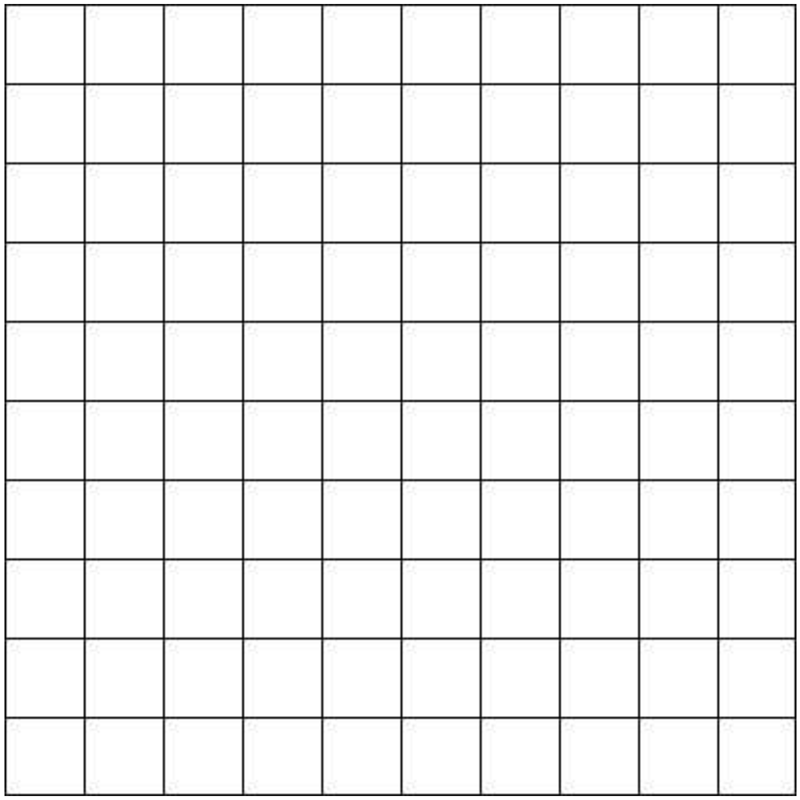
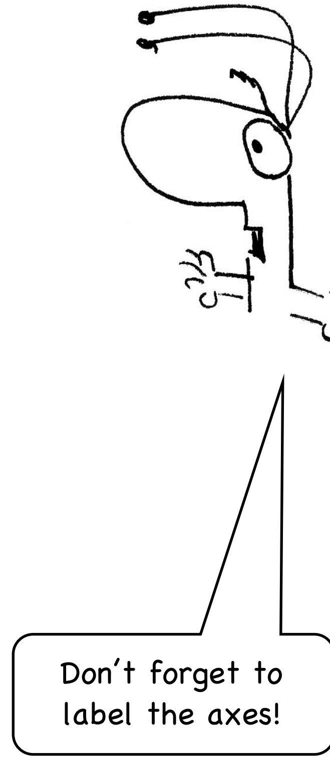
CA2 2A.1: Brightness vs. Distance: Lab





This shape is characteristic of inverse square relationships.

Applications to Astronomy:
Astronomers use the inverse-square law frequently in their work. For example, suppose you have two stars, A and B, which are known to be identical. However, when observed through a telescope or in a photograph, A appears to be one sixteenth as bright as B. To avoid confusion for the remainder of these activities, we will no longer be using the terminology "times dimmer" in these problems; instead, we will always refer to "times as bright" which involves the multiplication of a fraction as shown on the table you just completed.

4. Which star is farther away? __________________

5. How many times farther is it? __________________

6. If B is located 10 light-years away, how far is A? ___________________

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CA2 2A.1: Brightness vs. Distance: Lab

Doing the Brightness vs. Distance Lab

Next you will do a lab to experimentally verify the relationship you have analyzed on the previous pages. The analysis you just did merely gives you reason to believe the relationship between brightness and distance is inverse square. In science, observations of the real world are required to make a theoretical prediction convincing.

7. Your task is to experimentally verify the inverse-square relationship between brightness and distance. Write your hypothesis below.

8. In this experiment, what is the independent variable?

9. What is the dependent variable?

10. Now consider what you would do if you actually did this experiment using a light bulb and some sort of brightness detector. What are the interfering variables for this experiment? In practice, how will you control them so they won't interfere?

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CA2 2A.1: Brightness vs. Distance: Lab

11. Next, set up and conduct your experiment. To take measurements you will need a photocell and a voltmeter, or a light sensor such as the ones sold by Vernier (www.Vernier.com) or Pasco (www.pasco.com). If your school has a physics class, the teacher may have the necessary equipment. Explain below the method you intend to use to collect data.

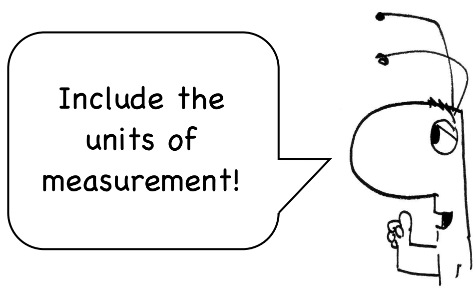
12. You may find you did not anticipate all the interfering variables or you have some technical problem with the experiment. Make a note here of any adjustments to your original plan.

13. Record your data on the table provided, and plot a graph.

You should collect a minimum of 5 different data points, and more if you can.

Also, avoid putting the sensor directly on the light bulb for a distance of zero; you may get false data by overloading the sensor. If the sensor reading is large and doesn't change, you are too close. If the sensor reading is far and doesn't change, you are getting room light only and the bulb you are using makes no difference. Only record data when the two conditions mentioned above are not happening, in other words, when the data is changing from position to position, use it.

Distance	Brightness



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CA2 2A.1: Brightness vs. Distance: Lab

14. Now write a conclusion based on your observations and graph. Did you see an inverse square relationship or not, and how can you tell?

When astronomers measure the brightness of stars, they use a digital camera containing a CCD (charge-coupled device). This is essentially a collection or grid of digital light sensors that records a number proportional to the number of photons (light particles) that strike it. Suppose a CCD is used to measure some stars in a picture. Star Q reveals a brightness count of 10,000. Star Z has a brightness count of only 100.

15. How many times brighter is star Q?

16. Assuming the stars are identical, how many times farther away is Z?

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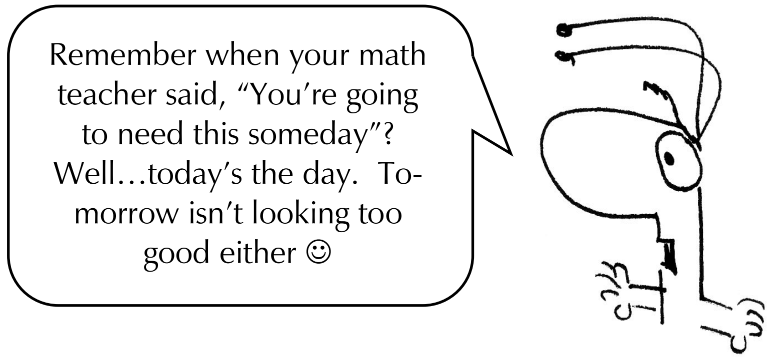
CA2 2A.2: Brightness vs. Distance: Worksheet

In the previous lab we learned that the relationship between brightness and distance is: $B \propto \frac{1}{d^2}$. But what is it good for in astronomy? Here is a short guide to using this relationship to compare stars. Since the proportionality symbol implies there are unknown constants (related to the intrinsic brightness of stars and the sensitivity of our equipment) we will often specify "identical" stars so these considerations will not matter. Thus, to compare two stars, the following idea is used to eliminate unknown values and get to the main point as quickly as possible.



When a problem says *compare* two values, it almost always means you should *divide* them.

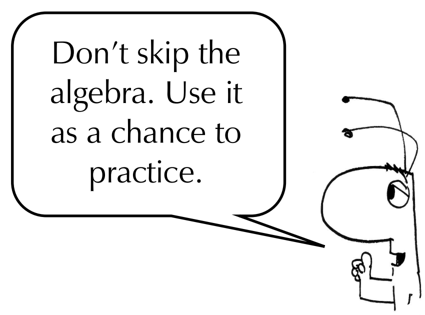
For example, if we wish to compare brightness of star A and star B, asking how many times brighter A is than B, we would write:

$$\frac{B_A}{B_B}.$$

But this is just equal to

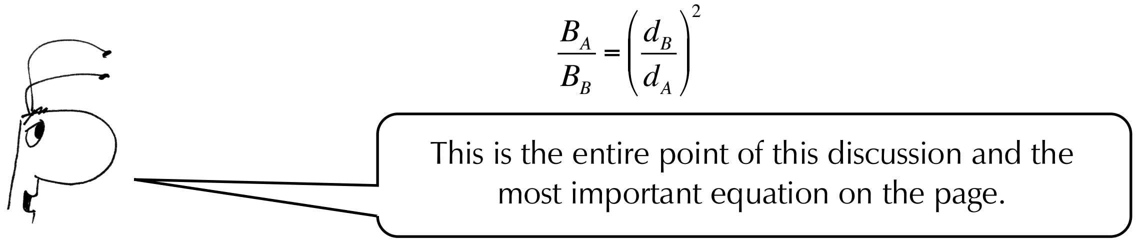
$$\frac{1}{d_A^2} \text{ divided by } \frac{1}{d_B^2},$$

$$\text{or } \frac{\frac{1}{d_A^2}}{\frac{1}{d_B^2}} = \frac{d_B^2}{d_A^2} = \left(\frac{d_B}{d_A}\right)^2.$$



Thus, if you were asked to compare the brightness of A and B given their distances, you would write

$$\frac{B_A}{B_B} = \left(\frac{d_B}{d_A}\right)^2$$



and substitute the given distances.

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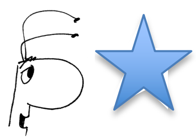
CA2 2A.2: Brightness vs. Distance: Worksheet

Example: Two identical stars, A and B have different brightness. A is 5 light-years (ly) away and B is 20 ly. Which star is brighter, and how many times brighter is it? (Recall a light-year is the distance light travels in a year. It's just like a mile or kilometer—just lots longer.)



Star A (5 ly away) Star B (20 ly away)

Answer: A is closer, so it is brighter. But how many times brighter?

In this example, d_A is 5, the distance to star A. Similarly d_B = 20 light years. Substituting these values in the formula we see

It is $\frac{B_A}{B_B} = \left(\frac{20}{5}\right)^2 = 4^2 = 16$ times brighter.

Notice how this result agrees with what we observed in the table we constructed conceptually. The A and B subscripts are not both on the same side as the dividing line. For brightness, A is in the numerator. For distance, A is in the denominator.

If a problem says "how many times closer" or "how many times farther" you would solve the equation for the ratio of distances like this:

How many times farther is B than A? This implies B is a larger number, so it goes in the numerator.

Begin by writing the equation with no values in it:

$$\frac{B_A}{B_B} = \left(\frac{d_B}{d_A}\right)^2$$

Now solve for the ratio that means "How many times farther is B than A? Like this:

$$\left(\frac{d_B}{d_A}\right) = \sqrt{\frac{B_A}{B_B}}$$

Example: How many times farther is star B than A, if star A is identical to B in appearance but is intrinsically 25 times brighter?

$$\left(\frac{d_B}{d_A}\right) = \sqrt{\frac{B_A}{B_B}} = \sqrt{\frac{25}{1}} = 5$$

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CA2 2A.2: Brightness vs. Distance: Worksheet

Intrinsically means due to its own internal characteristics, having nothing to do with distance. Stars that are identical intrinsically would appear to be the same brightness if they were the same distance. So Star B is 5 times farther than A, or Star A is 5 times closer than B, which means essentially the same thing. If the question says *times brighter or farther* solve with the variable on top of the fraction. If it says *times dimmer* or *closer* solve with the variable in the denominator. In this book we will generally use *times brighter* and *times farther* to avoid confusion.

Brightness vs. Distance Problems

Complete the following problems, showing your work, and turn in. It is strongly recommended you begin each problem with the "empty" equation as shown in the example.

1. Two identical point sources (stars), A and B, are observed to be different brightness. A is forty-nine times brighter than B. How many times farther is B to the observer than A?

2. Two identical stars, A and B, are observed to be different brightnesses. Star A is 100 times brighter than star B. Which star is farther, and how many times farther is it?

3. Star A is 50 ly away, while star B is 500 ly away. If they are known to be identical, which star is brighter? How many times brighter?

4. Two stars are intrinsically identical. Star A is 2,345 times brighter than B. How many times farther is B than A? If A is 20 light-years away, where is B?

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CA2 2A.2: Brightness vs. Distance: Worksheet

5. Star Alpha is identical intrinsically and forty times farther away than star Beta. How many times brighter does Beta appear than Alpha?

6. Suppose Star Alpha is 1,000,000 times brighter than star Beta, which is located 500 light-years away. Where is star Alpha?

7. On a CCD, star A is measured to have 4580 brightness counts while star B, known to be identical, is measured to be 1150 brightness counts. Which star is closer? If Star B is 49 ly away, where is star A? (In this problem the brightness ratio is not given, but the individual brightnesses B_A and B_B.

8. Star Alpheratz is 97 light years away. An identical star, called Bellatrix, is 150 ly away. If Bellatrix registers 5400 counts on a CCD camera, how many would we observe for Alpheratz with the same equipment in the same time?

9. Suppose a certain star is 14 billion ly away from us, as compared to Alpha Centauri, which is 4 ly away. How many times brighter would this Alpha Cen be if its distant twin were located 14 billion ly away?

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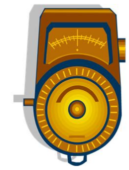
CA2 2A.3: The Magnitude Scale: Worksheet



The magnitude scale was introduced in Volume 1 of this work, but a brief review of some basic concepts may help you understand magnitudes better. To see magnitudes with your own eyes refer to the activity Observing Magnitudes in volume 1.

Figure 2. Hipparchus developed the original magnitude scale. This is a stamp from Greece honoring him.

Ancient observers of the heavens tried to organize their observations, as all scientists do. Stars in the night sky only have three observable characteristics as seen with the unaided human eye: brightness, color, and position. Comparing one star to another, the ancients could see (as we can) that the stars vary greatly in all three. In particular, the brightness of stars varied from barely visible under the best of conditions to stars so bright they were occasionally visible in the not-quite darkness of sunset and twilight. The Greek astronomer Hipparchus (190-120 BC) developed a system whereby the stars were arranged according to their relative importance. Bright stars were obviously the most important, so they were given the rank of 1. Stars barely visible in a very dark sky were given the rank of 6. Every other star fit between these standards, sorted into a total of 6 categories, which eventually came to be known as **magnitudes**.

Eventually, mechanical methods of measuring brightness revealed that a difference in magnitudes from 6 to 1 (5 magnitudes) was almost exactly 100 times brighter as measured by photography or electronics, so this became **the *definition* of 5 magnitudes: Two stars which are 5 magnitudes different in brightness are now *defined* to be exactly 100 times different in magnitude.**

In other words, if you subtract two magnitudes and the difference is 5, the brightness ratio is 100. This can be translated into mathematics as:

$$\text{If } (m_2 - m_1) = 5, \text{then } \frac{B_2}{B_1} = 100$$

If asked what the ratio of brightness is given the magnitude difference, first subtract the magnitudes. If the difference is 5, the ratio is 100. If the difference is 10, then the ratio is 100*100 = 10000 (one hundred for each magnitude jump of 5.)

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CA2 2A.3: The Magnitude Scale: Worksheet

The invention of the telescope allowed Galileo and others to see that there are stars dimmer than the human eye can see. Galileo proposed extending the scale to 7 or 8; now we know there are stars of magnitude 25 to 30 which are many millions of times dimmer than the human eye can see. Such stars are so dim they can only be seen in long-exposure images.

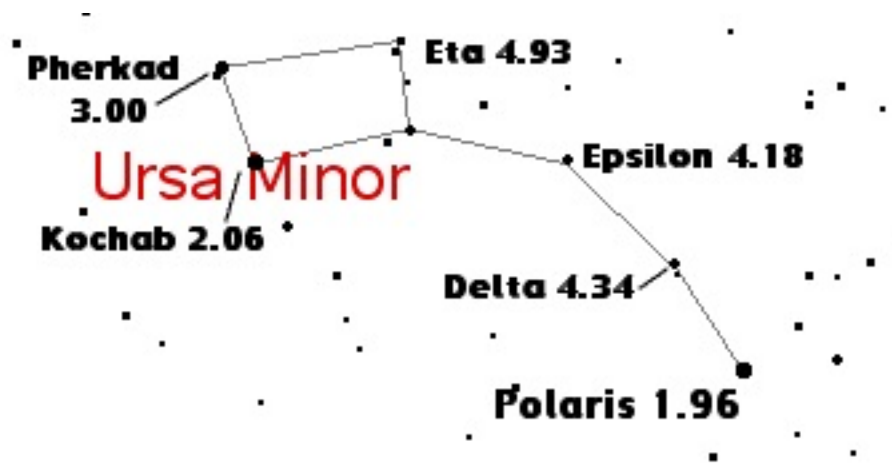

Figure 3. From CA1 4.7, Estimating Visual Magnitudes. Polaris is the brightest star in Ursa Major. Eta is the dimmest among those labeled here.

Similarly, the redefinition of the magnitude scale left a few stars off the scale, brighter than a 1st magnitude star; such stars are called magnitude 0 or even -1. On this scale, the full moon appears to be a -13, and the sun is -27.

This doesn't mean the sun is about twice as bright as the moon because of the exponential nature of the brightness ratios, as already explained. A difference of -27 to -12 is a million times brighter. (27-12 = 15, which has *three* sets of 5 magnitudes, each of which is 100 x brighter; 100x 100x 100 = 1,000,000). So the sun is not quite a million times as bright as the moon. It's about one magnitude short, which is (for reasons to be explained later) about 2.512 times less, leaving the sun only 400,000 x brighter than the moon.

You might wonder why astronomers still use the magnitude scale when more measurement-based systems, such as brightness-measuring CCDs, are available. One important part of astronomy is the comparison of present-day observations to those in the past. Some astronomical events take longer to unfold than all of human history. Thus, astronomers are very interested in comparing ancient observations to those in use today. This gives them a powerful motivation to continue using this ancient system of measurement.

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CA2 2A.3: The Magnitude Scale: Worksheet

For the following problems, please show your work.

1. How many times brighter is a magnitude 1 star than a magnitude 6 star?

2. How many times brighter is a magnitude 2 star than a magnitude 7 star?

3. How many times brighter is a magnitude -2 star than a magnitude 3 star?

4. How many times brighter is a magnitude 1 star than a magnitude 11 star? (Careful.)

5. How many times brighter is a magnitude 10 star than a magnitude 25 star?

6. How many times brighter is a magnitude 0 star than a magnitude 25 star?

7. Approximately how many times brighter is the sun (at roughly magnitude -25) than the dimmest stars that can be seen in a giant telescope (approximately magnitude 25)?

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Famous Astronomers

Maria Mitchell (1818-1889)

First Female Professional Astronomer in the United States

Maria Mitchell was noted for discovering a comet (named "Miss Mitchell's Comet"), and for reporting details about serious observations of a total eclipse in 1878 that greatly increased the reputation of American scientists in Europe and around the world. She was a professor at Vassar College and insisted she be paid as much as more junior male professors. Today her telescope is on display at the Smithsonian Institution. This portrait is a painting by Dasell in 1851.

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CA2 2A.4: Converting Brightness to Magnitudes: Activity

Purpose: To learn to convert arbitrary magnitude pairs into brightness and vice versa.

You may be wondering how it was your astronomy course turned into a math class. The fact is that the world is a mathematical place; if you want to understand it at all, you need to command some of the math that describes it. The purpose of all of this math is to enable us to measure the light curves of stars, and learn more about them in the process, in the same way that professional astronomers do it.

Instead of fretting about how you will use this in the future, consider this: How does Angry Birds prepare you for the future? Or watching a TV show about duck hunting? Perhaps you can contrive a scenario where these activities will enable you to earn a living or live a happy life. If so, more power to you. The math we do here, and in your math class, may or may not be directly applicable to your life as a real estate agent (or whatever you become as an adult.)

Studying it anyway does two things for you. It gives you the ability to *choose* to study advanced topics later. As the lottery people say, you can't win if you don't play. It also *trains you to be persistent* to solve puzzles using systematic logic. That's a skill that goes beyond the limits of any one individual mathematical lesson. Don't despair, and don't give up.``

With that little pep talk out of the way, let's begin. By definition, a star 5 magnitudes less than another is 100x brighter. This leads us to the definition of a single magnitude.

Thus, when

$$m_{\dim} - m_{bright} = 5$$

then

$$\frac{BrightnessCounts_{bright}}{BrightnessCounts_{\dim}} = 100$$

This means the following: If you have a bright star and a dim star which are 5 magnitudes apart, then the ratio of their brightness measured by machine will be 100. So, what does

CA2 2A.4: Converting Brightness to Magnitudes: Activity

one magnitude represent? Many students think the answer is 20, because 5 magnitudes added together are 100 times brighter:

$$m + m + m + m + m = 100$$
$$5m = 100$$
$$m = 20$$

However, this is the wrong interpretation. The magnitudes do not represent how many MORE brightness counts are detected, but how many TIMES more. The correct interpretation is

$$m \bullet m \bullet m \bullet m \bullet m = 100$$
$$m^5 = 100$$

This is not an ordinary Algebra 1 equation. The simplest approach to solving it is to use the fifth root function on both sides of the equation. The fifth root cancels the exponent to the fifth power just like a square root cancels a square ($\sqrt{3^2} = 3$ for example).

$$\sqrt[5]{m^5} = \sqrt[5]{100}$$
$$m = \sqrt[5]{100}$$
$$m = 2.51$$

2.51 is the fifth root of 100 because when you multiply 2.51 by itself 5 times, you get 100. Thus, one magnitude smaller is not 20 x brighter; it's 2.51 x brighter.

To sum up:
Smaller magnitudes are 2.51 times brighter than the next larger magnitude.

There are some practice questions on the next page to test your understanding of this material.

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CA2 2A.4: Converting Brightness to Magnitudes: Activity

Guided questions:

1. Since every magnitude smaller is 2.51 x brighter, how many times brighter is a difference of *two* magnitudes? Say, for example how many times brighter is a 3rd magnitude star than a 5th magnitude star?

___

___

___

You can compare the brightnesses of stars even if they are not simple integer magnitudes apart. Here are the steps you can follow:

1. Subtract the two magnitudes.
2. Raise 2.51 to the number you got for #1.
3. This is the number of times brighter the bright star is than the dim star.

2. How many times brighter is a 5th magnitude star than a 7th magnitude star?

___

___

3. How many times brighter is a 1st magnitude star than a 10th magnitude star?

___

___

4. How many times brighter is a 9th magnitude star than a 15th magnitude star?

___

___

5. How many times brighter is a 3.4 magnitude star than a 7.5 magnitude star?

___

___

Don't stop working…there's more on the next page.

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CA2 2A.4: Converting Brightness to Magnitudes: Activity

Finding an unknown magnitude:

Suppose you are comparing two stars, one with a known magnitude, and the other unknown. You can use the relationship we just figured out to find the unknown star's magnitude. If you know the stars' brightness counts from a CCD image, you could write the following:

$$\frac{BrightnessCounts_{bright}}{BrightnessCounts_{\dim}} = 2.51^{(m_{\dim} - m_{bright})}$$

The equation for finding brightness ratio of different magnitudes

This is just a summary of the steps you have just been doing. Because of the parentheses, you'd subtract the magnitudes first; and exponents come before division in the hierarchy of operations, so you'd raise 2.51 to that power as a second step, and thus find the ratio of brightnesses. This is just a more compact way of writing it.

Solving this equation for an unknown magnitude is a bit harder than the first solution we tried, however. To solve this equation, you will need to learn about logarithims.

About logarithims

Have you ever noticed that on a calculator there are functions that cancel each other out? For example, 3 +6 -6 = 3. So in that sense + and – cancel each other out. Similarly, $\sqrt{x}$ and x^2 cancel out, leaving x. You could write

$\sqrt{x^2} = x$ to illustrate this. So what is a logarithm? Logarithm (or log) is that function that cancels out 10^x. So since 10^3=1000, log (1000) must equal 3. Formally,

$\log(10^x)=x$. It is worth noting that log(10) = 1.

Logs have many properties, but one property they have that is of immediate use to us is this one:

$\text{Log}(y^x)= x \log y$. This important property shows the usefulness of logs in algebra:

Logs eliminate exponents by making them multiplication factors.
Let's use this property to find out something new about magnitudes.

In this sequence of algebra steps, we apply a log to both sides of the equation to make the exponent "come down" so we can solve for it.

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CA2 2A.4: Converting Brightness to Magnitudes: Activity

$$\log\left(2.51^{(m_{\dim}-m_{bright})}\right) = \log\left(\frac{BrightnessCounts_{bright}}{BrightnessCounts_{\dim}}\right)$$

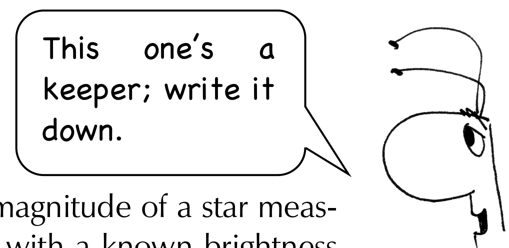
$$(m_{\dim} - m_{bright})\log(2.51) = \log\left(\frac{BrightnessCounts_{bright}}{BrightnessCounts_{\dim}}\right)$$

$$(m_{\dim} - m_{bright})0.4 = \log\left(\frac{BrightnessCounts_{bright}}{BrightnessCounts_{\dim}}\right)$$

$$(m_{\dim}) = 2.5\log\left(\frac{BrightnessCounts_{bright}}{BrightnessCounts_{\dim}}\right) + m_{bright}$$

Now, if we merely substitute *known* for *bright* and *unknown* for *dim*, we have an equation which can be used to determine unknown magnitudes:

$$(m_{unknown}) = 2.5\log\left(\frac{BrightnessCounts_{known}}{BrightnessCounts_{unknown}}\right) + m_{known}$$



This equation can be used to determine an unknown magnitude of a star measured with a CCD, if there is another star in the image with a known brightness count and a previously determined magnitude.

Here's an example:

Suppose in an image a star of magnitude 6 was measures to be 4000 counts in a CCD. An unknown star is measured to be 250 counts. This star is dimmer, so the problem will yield a larger magnitude.

$$(m_{unknown}) = 2.5\log\left(\frac{4000}{250}\right) + 6$$

$$(m_{unknown}) = 2.5\log(16) + 6$$

$$(m_{unknown}) = 2.5(1.2401) + 6$$

$$(m_{unknown}) = 9.01$$

Which is larger than 6, as predicted.

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Famous Astronomers

Annie Jump Cannon (1863-1941)

Pioneer in Stellar Spectral Classification

Annie Jump Cannon helped create the current system of stellar spectral classification (OBAF-GKM) She classified tens of thousands of stars and became the world's leading expert of stellar spectrum classifications. The system she developed is still in use today. She was valedictorian at Wellesley College and began her career with a degree in Physics, like many astronomers. Stricken with scarlet fever, she was nearly deaf after she was an adult, restricting her social life and allowing her to dedicate her time more for astronomy.

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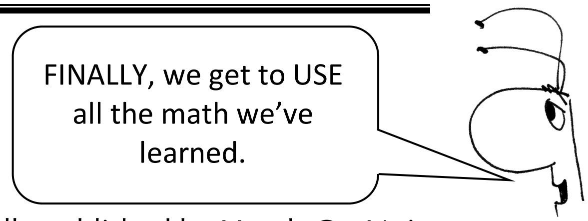
CA2 2A.5: Measuring Brightness and Converting to Magnitudes: Lab

Purpose: To measure the brightness of several stars and compute their magnitudes using the magnitude formula.



This activity is based on the SA-14 activity originally published by Hands On Universe. The SA-14 image *mgclust.fits* is used with permission, but we call it the *sample star field.fits* here.

Equipment needed: computer, Image J, Astronomy Plugin, Image *sample star field.fits*. For information on how to get Image J and how to install the Astronomy Plugin, see Appendix 7.

Procedure:

1. Load the sample star field image using Image J. Adjust the size, and brightness and contrast until you can see as many stars as possible. In the example below, I used "Process>Math>Log, followed by Adjust>Brightness and Contrast: Auto button (twice).

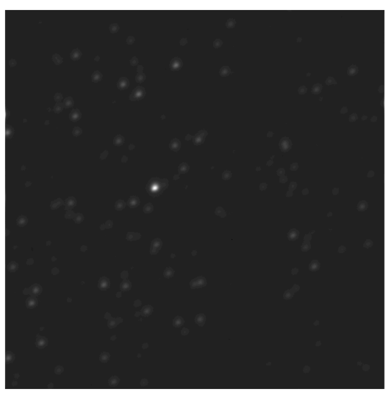


Figure 1. Without processing.

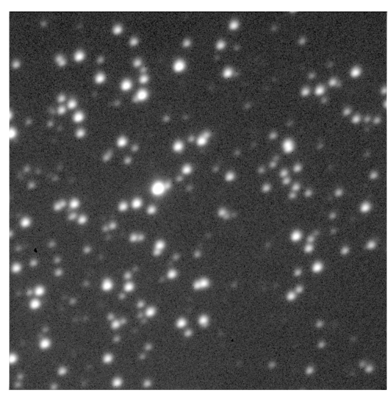


Figure 2. With Processing.

2. Click on one of the stars. From the Plugin menu select Astronomy>Aperture.

3. In the image, a bullseye consisting of 3 concentric circles will appear around the star. See the section entitled *About the Aperture Settings* at the end of this activity to learn about what these circles mean. At the same time, a data table window should pop up which shows the following headings:

Image	Slice	X	Y	Source-sky	Sky/pixel	JD-2400000	x-width	y-width

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CA2 2A.5: Measuring Brightness and Converting to Magnitudes: Lab

For this activity, all you need to record is x,y, and source-sky. Source-sky will be referred to as the *Brightness Count* of the star elsewhere in these instructions. Record these numbers in the data table.

4. Your teacher will assign how many or which stars to measure. Continue measuring until all the stars required are measured. Copy the data into the data table provided on the last page of this activity, or on separate paper.

5. Let's suppose that the brightest star in the image is a magnitude 6.0 star. Locate the brightest star and record its magnitude and brightness measurement at the top of the data table.

We are now going to use the magnitude conversion formula to convert the brightnesses of the *other* stars into magnitudes.

Here is how you do a sample calculation. The formula we will use, previously derived, is:

$$(m_{unknown}) = 2.5\log\left(\frac{BrightnessCounts_{known}}{BrightnessCounts_{unknown}}\right) + m_{known}$$

In this formula m_{known} is 6.0, the $BrightnessCounts_{known}$ is the value you got for the brightness of the brightest star in the picture. Throughout this activity, this value will not change. $BrightnessCounts_{uknown}$ is the brightness of the other stars, done one at a time.

Suppose you determined that the brightness of the brightest star was 4000, and the brightness of some other unknown star was 250. The calculation would then look like this:

$$(m_{unknown}) = 2.5\log\left(\frac{BrightnessCounts_{known}}{BrightnessCounts_{unknown}}\right) + m_{known}$$

$$(m_{unknown}) = 2.5\log\left(\frac{4000}{250}\right) + 6$$

$$(m_{unknown}) = 2.5\log(16) + 6$$

$$(m_{unknown}) = 2.5(1.2401) + 6$$

$$(m_{unknown}) = 9.01$$

If we measured another star with a brightness count of 345, then the only number that would change is the brightness count of the unknown, like this:

$$(m_{unknown}) = 2.5\log\left(\frac{4000}{345}\right) + 6$$

$$(m_{unknown}) = 8.66$$

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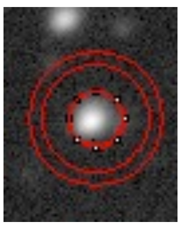
CA2 2A.5: Measuring Brightness and Converting to Magnitudes: Lab

6. Click on the brightest star and perform an aperture measurement on it. Record that at the top of the data table.

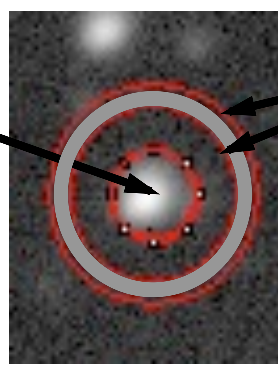
7. Now proceed to do this calculation for all the *other* stars in the image assigned by your teacher. This might be as many as a couple of hundred stars. For your calculations, show your work as above *once*, then repeat as necessary to measure all the stars assigned by your teacher. The x,y values are used to make sure you do not do any star twice.

About the Aperture Settings



It is probably not necessary to change the aperture settings for this activity, but if you analyze any other image, you may need to adjust the settings. When you click on a star, three red circles appear around the star. The innermost circle defines the area that will be measured. Every pixel in the inner circle is measured, added together, and this grand total is called the *source*.

The area between the outermost circles is used to measure the *sky*. The idea is that the sky may not be totally black; moonlight, light pollution and other factors may cause the pixels in the supposedly empty part of the sky to accumulate light. This happens even in the inner circle where the star is located. The computer counts all the brightness of the pixels between the outermost and center circle, then averages the readings and generates an average *sky*



brightness per pixel. Then this value is used to estimate the amount of sky brightness within the measurement circle not due to the target star, and this is subtracted from the measurement. This is called *source-sky*, and represents the light coming from the star without the sky brightness included. We refer to this as the “Brightness count” of the star as measured with the software. Professional astronomers refer to this more properly as “Counts” or “Flux,” but “brightness count” will work for our purposes.

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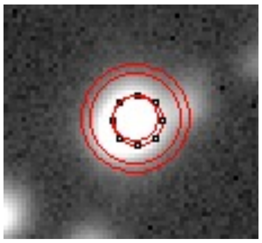
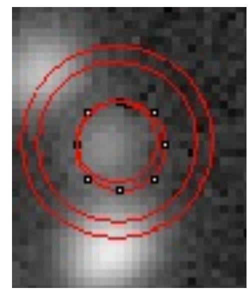
CA2 2A.5: Measuring Brightness and Converting to Magnitudes: Lab

All of this is done automatically for you, but there are three situations where you should be concerned that inaccurate values may be collected

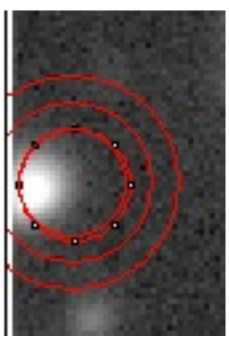
.



a. If the measurement circle is too small to contain all the starlight, you will get a measurement that is too small. To fix this, choose Plugins>Astronomy>Set Aperture (click through the first screen without selecting anything) and increase the size of the measurement radius in the second window that appears. The sky radii must both be larger than this, and it is typically a few pixels larger than the inner circle. A typical setting for this lab is inner radius 10, outer radii 12 and 15.



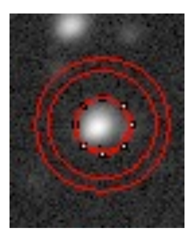
b. If there is a star right beside the one you are trying to measure, then the sky measurement will include it, and the sky measurement will become too large. If this occurs in a formal lab, you should either skip that star, or enlarge or shrink the sky radii in that specific case so the interfering star is not included. This will often manifest itself as a negative value in the *source-sky* column, indicating that the sky was brighter than the source you are trying to measure.



c. If the star to be measured is right next to the edge of the image, the sky circle may extend off the edge of the image and cause an error. This software and technique cannot be used to measure such situations.

For the purposes of this exercise, neither adjustment should be necessary. You may skip any star that is either very close to another and places a star in the sky circle, or a star that is too close to the edge of the image.

The best measurements will be obtained when the aperture circles look like this:



8. So, if you haven't already, start clicking and measuring, and compute the unknown magnitudes in the last column of the data table.

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CA2 2A.5: Measuring Brightness and Converting to Magnitudes: Lab

DATA TABLE

Coordinates of brightest star: _________
Brightness Count of brightest star: __________

Data Table

X	Y	Brightness Count	magnitude

X	Y	Brightness Count	magni-tude

Questions:
1. All the values in the table should be larger than 6. Why?

2. Is there perhaps a more efficient way to complete this task? If you had it to do over, how would you approach it? (Use more paper if needed.)

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Famous Astronomers

Cecila Payne-Gaposchkin (1900-1979)

Discoverer of the Abundance of Hydrogen in the Universe

Cecilia Payne-Gaposchkin was the first person to separate the amounts and temperatures of elements in a star's spectrum, and thus doing isolate the true abundances of elements within the sun. She realized the tremendous amount of hydrogen in the sun implied that most of the universe was hydrogen and helium. Other astronomers gradually came around to this view. She was the first woman to head a department at Harvard, and worked in astronomy her entire life.

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CA2 2A.6: Light Curves: Activity

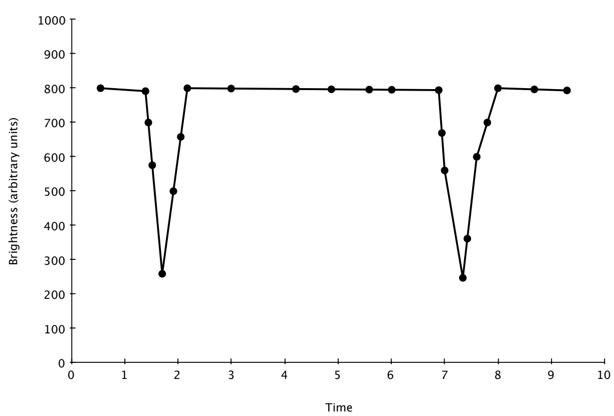
Purpose: To classify light curves of stars into one of several categories.

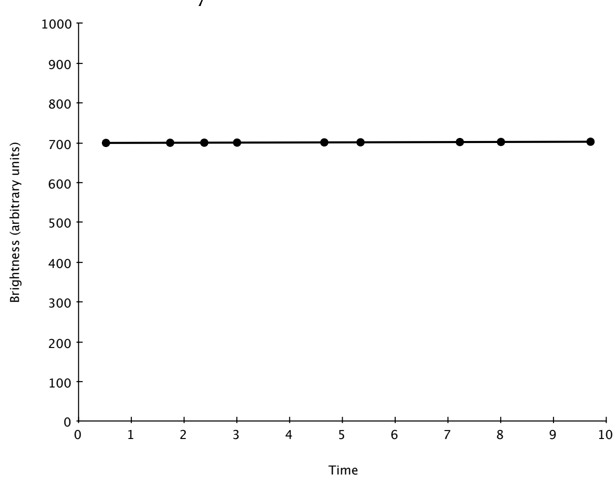
Materials needed: Light curves chart (below)

Procedure:
A **light curve** is a special type of graph in astronomy that reveals how a star's brightness changes over time. All light curves have brightness, or something equivalent to it (such as flux, magnitudes, etc.) on the y-axis, and time on the x-axis. In general, there are only a few different types of light curves, with many subtle variations. The basic types are defined below. As you read, match each description to a light curve shown in the drawings below. Write the name of the light curve on each image.

Light Curve Descriptions.
A **standard star** is a star that does not change in brightness over time. It may have small variations due to the earth's atmosphere, instrumentation changes, and so on, causing small random variance in the measurements, but the star itself is remarkably steady and often used as a comparison for other stars in the image.
An **intrinsic variable** star changes periodically over time for various reasons, but does so systematically and gradually. The variation repeats over and over. Such stars pulsate and change size as well as brightness.
An **eclipsing variable** star changes brightness because something (like a planet, or another star) gets in front of it from our perspective and basically dims the star slightly.
A **nova** or **supernova** is an exploding star.

1-4. Identify the light curves shown below. (Note, the data is simulated to avoid confusion caused by noise in actual data.) Assume the time units are days.





Keep going to the next page; you're not done yet!

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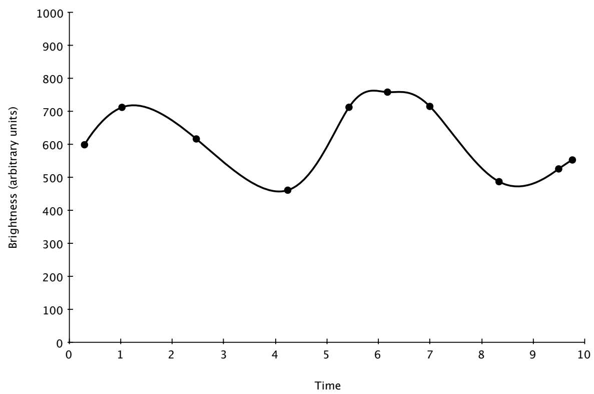
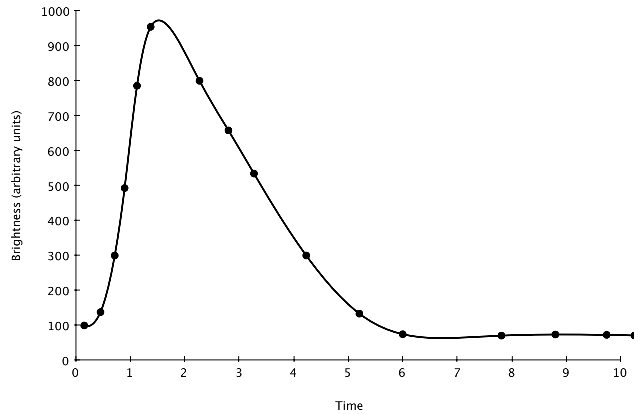
CA2 2A.6: Light Curves: Activity





Questions:

5. Why do we need to measure standard stars, when they don't change?

6. For the light curve from the intrinsically variable star, how long does it take to pulse once? What is the maximum brightness reading?

7. For the light curve from the eclipsing variable star, what is the orbital period of the companion?

8. For the light curve of the nova, how much time does it spend getting brighter compared to the time it spends getting dimmer?

9. Why wouldn't an astronomer just want to take one picture of a star on one night?

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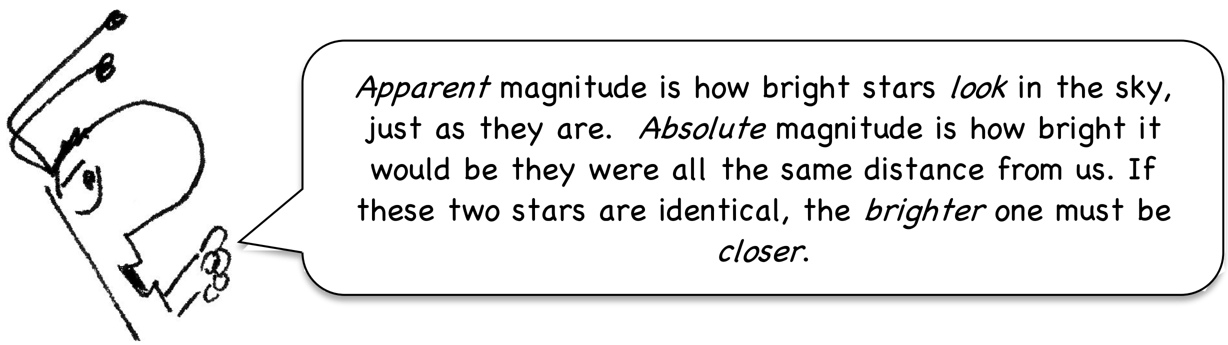
CA2 2A.7: Magnitudes and Distance: Activity

Purpose: To use magnitudes to estimate the distance to a star, using conceptual methods.

Background: A star's **apparent magnitude** is the magnitude it shows when observed from the earth, in comparison to the system devised by Hipparchus where a 6th magnitude star is as dim as the human eye can see and a 1st magnitude star is 100 times brighter than that. A star's **absolute magnitude** is defined to be the apparent magnitude it would have if it were located 10 **parsecs** from the earth. A parsec is a unit of distance used in astronomy. It is 3.26 light years. Why it is called a parsec is related to some geometry terms and methods we will use later.



Based on these definitions, and remembering that *smaller* magnitudes represent *dimmer* stars, answer the following questions.

1. Suppose a star has an apparent magnitude of 7. Can you see it with your eyes?

____

____

2. Now suppose a different star is an identical twin physically to the first, but it has an apparent magnitude of 4. Which star is brighter?

____

____

____

3. If the stars are truly identical, which one is closer?

____

____

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CA2 2A.7: Magnitudes and Distance: Activity

4. Now let's consider a different star. This star has apparent magnitude of 5. If we could magically move it to 10 pc away, it then has an apparent magnitude of 7. Because it is 10 pc away, we would say its *absolute magnitude* is 10. In which position (the original or 10 pc) would the star be brighter?

5. If the star got *dimmer* when we moved it to 10 parsecs away, it must have started…where?

6. For the table below, tell whether the star is closer or farther than 10 pc to begin with. (respond with *closer* or *farther* or *equal*).

Apparent magnitude	Absolute magnitude	Original position compared to 10 parsecs
10	3	
4	9	
9	9	
3	18	
5	-1	
-3	3	

7. Can you state a general rule about how to interpret distance using absolute and apparent magnitudes? (Well, if you *can*, go ahead and state it then.)

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CA2 2A.8: Magnitudes and Distance (Quantitative): Activity

Purpose: To practice using formulas about magnitudes and see how they can be used to generate precise distance estimates.

Equipment needed: Scientific calculator.

Background: The formula we used to define magnitudes can be solved in various different forms to help compute things like brightness ratios, distances to stars, and so on. Below, we present four useful formulas used by astronomers to compute information about stars based on their brightness and magnitudes.

How To Compare Brightness When Magnitudes are Known:
Given: Two magnitudes to compare
Formula:

$$\frac{BrightnessCounts_{bright}}{BrightnessCounts_{\mathrm{dim}}} = 2.51^{(m_{\mathrm{dim}} - m_{bright})}$$

1. How many times brighter does Beta Centauri (apparent magnitude = +0.63) appear to be than Fomalhaut (apparent magnitude +1.19)?

2. How many times brighter does the moon (apparent magnitude - 13) appear to be than the brightest star in the sky Sirius (apparent magnitude -1.46)?

3. How many times brighter is Aldebaran (apparent magnitude 0.86) than Luyten 789.6 (apparent magnitude (+12.18)?

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CA2 2A.8: Magnitudes and Distance (Quantitative): Activity

How to Find a Star's Apparent Magnitude
Given: Brightness counts of the star and of a known, standard star
Formula:

$$(m_{unknown}) = 2.5\log\left(\frac{BrightnessCounts_{known}}{BrightnessCounts_{unknown}}\right) + m_{known}$$

4. A star of unknown magnitude has a brightness count of 22,000. In the same image, a standard star of magnitude 4 has a brightness count of 50,000. Compute the magnitude of the unknown star.

5. A star of known magnitude 15 is in a picture with a star of unknown magnitude. The known star's brightness count is 356. The unknown star's brightness count is 2,400. What is the unknown star's magnitude?

6. A star of known magnitude -1 has a brightness count of 1230. The unknown star has a magnitude of 450. Calculate the unknown star's magnitude.

How to Find a Star's Absolute Magnitude:
Given: Star's apparent magnitude (m) and distance from Earth in parsecs (d).
Formula:

$$M = m - 5\log(d) + 5$$

Absolute magnitude (M) is the visual magnitude a star would have if it were located 10 parsecs, or 32.6 light years, from Earth.

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CA2 2A.8: Magnitudes and Distance (Quantitative): Activity

7. What is the absolute magnitude of Procyon? Procyon is 3.51 pc away and has an apparent magnitude m = 0.37.

8. What is the absolute magnitude of the sun? The sun is 0.0000048 pc away, and has an apparent magnitude m = -27. Could you see it?

9. What is the absolute magnitude of epsilon Eridani? Epsilon Eridani is 3.44 pc away and has an apparent magnitude of +3.73.

How to Find the Distance to a Star Given Apparent and Absolute Magnitudes
Given: Apparent(m) and absolute(M) magnitudes of a star.
This particular problem is known as **spectroscopic parallax**. Usually a spectrascope is used to determine the spectral class of a star, which tells us its absolute magnitude without needing to know the distance.
Formula:

$$d = 10^{\frac{m-M+5}{-5}}$$

Hint: Compute the exponent completely before raising 10 to that power.

10. What is the distance to the star Deneb? (m = 1.26, M = -6.9)

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Challenge. Using the appendix of near stars in the back of this book, pick a star for which the absolute and apparent magnitudes are listed, and calculate the distance to the star using the equation above. Compare to the value in the table.

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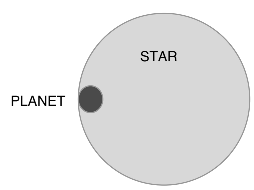
CA2 2A.9: Detecting Exoplanets: Lab

Purpose: To characterize a planetary system based on the light curve of a star with a planet that eclipses it.

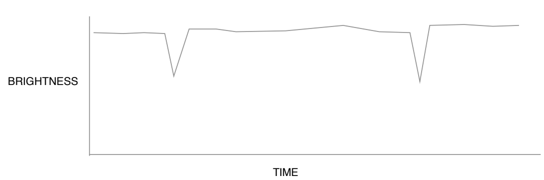
Equipment needed: Light curve of a star data, graph paper, calculator

Background: The data you are about to investigate is based on data obtained by NASA's Kepler mission. The Kepler mission looks at a fixed location in space and takes many repetitive pictures. The light curves of thousands of stars are measured. Then when an interesting star is found, such as a star with an **exoplanet** orbiting it, the data is analyzed further to determine the characteristics of the planet.

When a planet is lined up with the earth and its star, it will eclipse the light of the star and make the star slightly dimmer, as shown in the drawing.



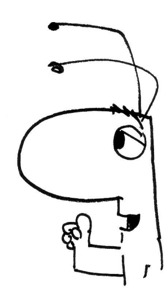
As a result, brightness measurements, calibrated against standard stars, will show a small dip in the brightness of a star as shown in the light curve below.



The data in this activity is from the publicly available data published by the Kepler mission. You will plot the data and determine whether or not there is a companion that eclipses the star, and then answer some questions about it.

The Data

The data table is *very* long. Robotic telescopes can collect vast amounts of data. Part of the task astronomers face is how to manage so much data.
In the table, the elapsed time has been adjusted to start on the first day of the observation (day 0). The brightness data was **normalized** (reduced in proportion to have a maximum of 1.0), but for this exercise it has been multiplied by 100 to avoid having so many data points be decimal values.



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CA2 2A.9: Detecting Exoplanets: Lab

Table 1. Light curve data

Time (days)	Brightness (normalized)
0.634368	100.8
1.002187	100.9
17.273821	100.2
22.586712	73.7
37.462719	100.1
45.288914	100.0
45.697592	100.1
46.576248	100.0
48.497029	100.0
48.721801	100.0
59.633422	100.1
63.536247	99.9
80.557337	99.9
80.639071	100.0
80.966004	100.1
81.211205	74.6
88.546756	100.0
92.817296	100.0

The star is identified as a spectral class K dwarf star, Kepler ID kplr007620844. For more information about the star in a technical sense, go to this website http://archive.stsci.edu/kepler/data_search/search.php and enter the number 007620844 in the Kepler ID field.

Procedure

1. Use the graph grid provided to plot the data. *Plot time on the x axis and brightness on the y axis*. Label these on the axes.

2. Identify on the graph and in the data table where the curve falls significantly below 100. Circle these points on the graph. On what days of the experiment did the graph fall in brightness significantly?

3. How many days elapsed between the two dimming events? ________

4. Is it possible that there were other eclipsing events between or beyond the two you can see, on other days? How do you know?

5. How many planets are indicated by this limited data set, and how do you know?

Print Name ____________________________Period _________ Date _________________

CA2 2A.9: Detecting Exoplanets: Lab

Using the Data to Investigate the Planet

This next section is designed to use your knowledge about planets gained in Volume 1 of this workbook, to reach conclusions about this particular exoplanet.

6. Convert the orbital period of the planet in days to seconds. Show your work.

____

____

7. Look at the Stellar Spectral Types table in the appendix and find out what the mass of a typical K-dwarf star is. It will be expressed as a range of solar masses.

____

____

8. Use the maximum value of the mass for the next step. Convert the maximum mass into kilographs by using this conversion factor: 1 solar mass = 2 x 10^{30} kg.

____

____

____

9. Now, using Newton's version of Kepler's third law, derived in volume 1 and shown here, calculate the orbital radius of this unknown exoplanet.

$$r^3 = \frac{Gm_1P^2}{4\pi^2}$$

____

____

____

____

10. Compare this value to 1 AU, the distance of earth to the sun. 1 AU = 150 x10^9 meters.

____

____

11. Propose a name for this new planet.

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Famous Astronomers

Jocelyn Bell Burnell (1943-)

Discoverer of the First Neutron Star

Jocelyn Bell Burnell is notable for being the discoverer (as a research student) of the first known pulsar. A pulsar is a spinning neutron star that emits radio waves. She examined huge amounts of data to isolate the signal and was a co-author on the original paper. However, she did not get named as a recipient of the Nobel Prize for this work; her supervisor did. She was the first female President of the Royal Society of Edinburgh, among many other distinguished positions she has held (and still holds today.)

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CA2 2A.10: Brightness Puzzle

Fill in the terms at the bottom of the puzzle. Then write the same letter in the box with the corresponding number. A quotation or phrase will be spelled out in the grid at top.

W	1	2	3		W	4		5	6	7	8		9	10		11	12	13	H
14		W	15		16	17	18		19	20	21	22	23	24		25	O		26
H	27		F	28	29	30	31	32	33	34	35	36	37		38	C	T	39	40
41	T	Y		42	43		W	H	44	C	H		45	X	I	46	T	47	N
C	E		H	48	49		I	T	50		51	52	O	53	N	54	.	.	.
55	I	G	H	T		I	56		T	H	E		57	O	T	E	N	T	I
58	59		O	F		E	60	E	61	Y	T	H	I	N	G		E	L	62
E	-	63	E	N	E	E		W	E	64	E	65							

1. _ Q _ _ _ _ (46, 28, 16, 17, 2) LIGHT FOLLOWS THE INVERSE _____ LAW
2. _ _ _ _ _ _ _ _ _ (7, 31, 13, 3, 12, 9, 53, 30, 4) VISUAL BRIGHTNESS CLASSIFICATION SYSTEM
3. _ _ _ _ _ _ _ (54, 22, 21, 32, 8, 49, 14) MAGNTIUDE 6 IS THE ____ YOU CAN SEE WITH EYES
4. _ _ _ _ _ U _ _ (36, 64, 50, 6, 11, 25, 15) MAGNITUDE A STAR HAS AT 10 PARSECS
5. _ _ P _ _ _ _ _ (38, 57, 48, 52, 18, 23, 26) MAGNITUDE AS OBSERVED IN NATURE
6. _ _ _ _ _ _ (56, 27, 29, 62, 10, 61) DETECTOR
7. _ _ _ _ _ _ U _ _ _ (37, 39, 24, 1, 35, 5, 63, 40, 33) GRAPH OF BRIGHTNESS VS. TIME
8. _ _ _ _ A B _ _ (60, 58, 65, 41, 55, 45) STAR THAT CHANGES BRIGHTNESS
9. _ _ _ _ P S _ _ _ (47, 19, 59, 42, 44, 34, 51) KIND OF VARIABLE CAUSED BY BLOCKING LIGHT
10. _ _ V A (43, 20) EXPLODING STAR

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CA2 2A.10: Brightness and Puzzle

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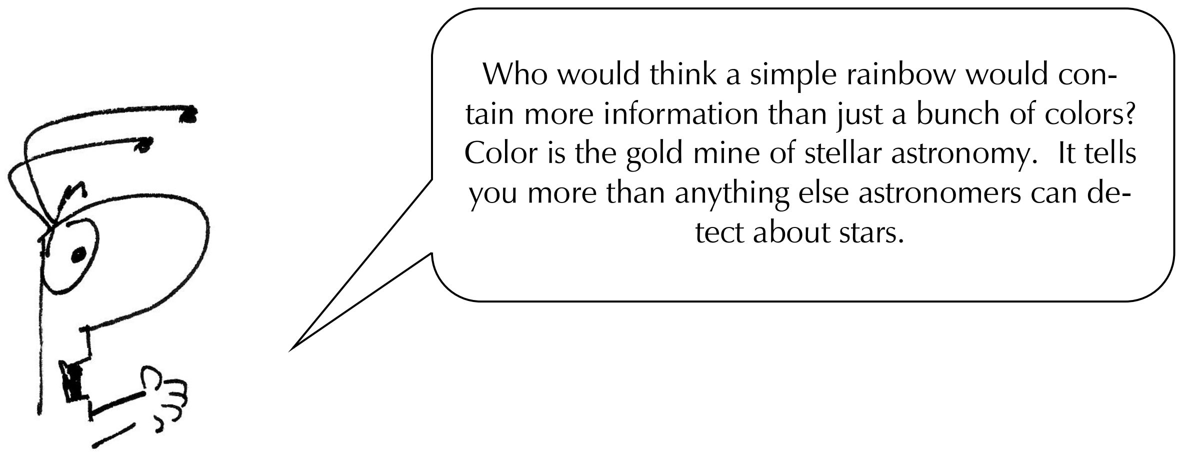
Conceptual Astronomy 2 Unit 2B: Color

This unit contains labs and activities related to the color of a star. By analyzing a star's color in detail, astronomers can gain an amazing amount of information: the star's radial velocity, its composition, its temperature, and sometimes whether or not it has a planet can be derived from its color. Some stars have a distinct color when seen by the naked eye, and others do not. The main tool of astronomical color is the **spectrascope**, which breaks light up into its component colors and provides a way of measuring the wavelengths of those colors.



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Famous Astronomers

Vera Rubin (1928-2016)

Discoverer of Dark Matter

Vera Rubin's pioneering work on the odd rotation curves of galaxies showed that galaxies spin far too fast in comparison to the amount of matter visible inside them. The only explanation (even today) is that there must be substantial amounts of "dark matter," matter which has gravitational attraction but does not interact with ordinary matter and energy. The theory of dark matter is now commonly accepted in astronomy but the search for exactly what dark matter is continues. Despite the fact that women were not allowed to observe at Palomar observatory, she created her own women's restroom and became the first female astronomer to observe there.

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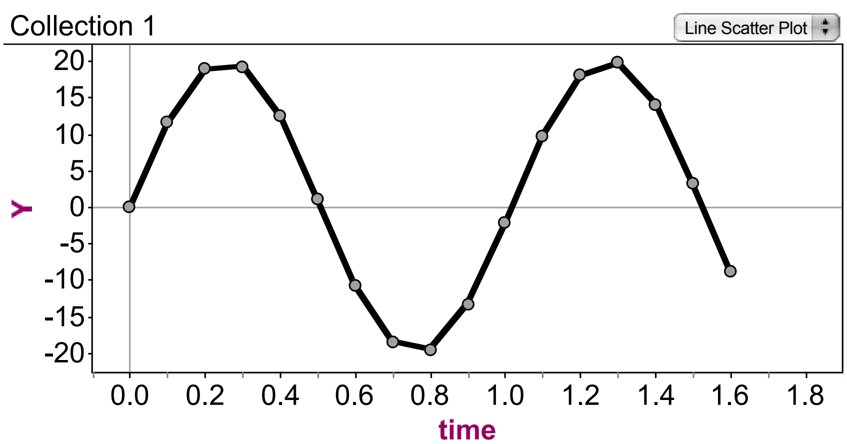
CA2 2B.1 The Electromagnetic Spectrum: Activity

Purpose: To understand properties of light in terms of its wave nature, and become familiar with wave terminology

Equipment needed: A slinky.

Light is a **wave**. Many things exhibit wave properties, such as water, sound, light, and earthquakes. Waves are characterized by oscillations that deliver energy from one spot to another. Sometimes this energy can do useful work, such as when a surfer rides a wave. Sometimes the waves simply carry information, such as when you speak. But all waves, regardless of their type, have certain characteristics in common.

Here is an illustration of a typical wave.



The wave shown above has certain features, which are defined below. You should label the wave above with these features.

1. **Wavelength** is the spacing between repeating waves. In equations, it is often given the variable λ, (lambda).
2. The **crest** of a wave is its highest point.
3. The **trough** of a wave is its lowest point.
4. The **amplitude** of a wave is one half of the vertical distance between a crest and a trough.

Some features are hard to illustrate in a drawing, but your friendly neighborhood astronomy teacher will try. Imagine you are sitting on a dock by the bay, wasting time one day, counting the waves as they roll in. Suppose 10 waves pass your position in a minute. Then we would refer to the number of waves per minute as 10, known as the **frequency.**

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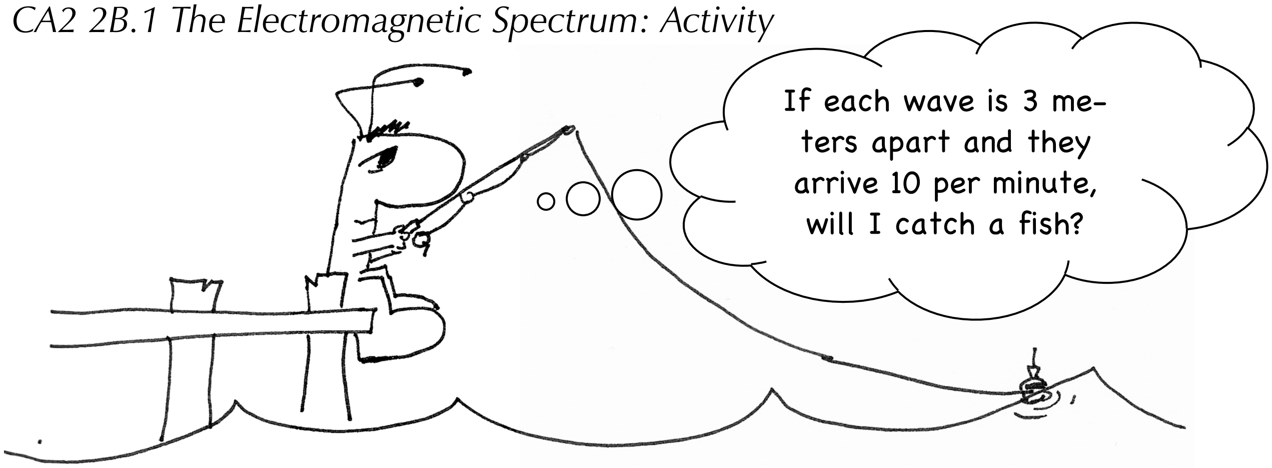
CA2 2B.1 The Electromagnetic Spectrum: Activity



Each wave moves along with a certain speed. Since each wave has a length, and the frequency tells you how many waves pass you by each second, it stands to reason that the combination of these pieces of information will tell you how fast the wave is moving. If ten waves passed by in a minute, and each wavelength was 3 meters apart, the wave speed would be 30 meters per minute. More generally,

Speed = frequency (waves per minute) x wavelength (length per wave)

Or in math-symbols:

$$v = f\lambda$$

5. What is the speed of a wave that has a wavelength of 2 meters and a frequency of 6 waves per second?

____

____

6. What is the frequency of a wave that has a wavelength of 80 nanometers (1 nm= 10^{-9} m) and travels at the speed of light v = $3x10^{8}$ m/s?

____

____

7. A sound wave has a frequency of 170 Hertz (a *Hertz* is a wave per second) and a wavelength of 2 meters. What is the speed of sound?

____

____

(Keep going on to the next page.)

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CA2 2B.1 The Electromagnetic Spectrum: Activity

Properties of Waves You can Observe

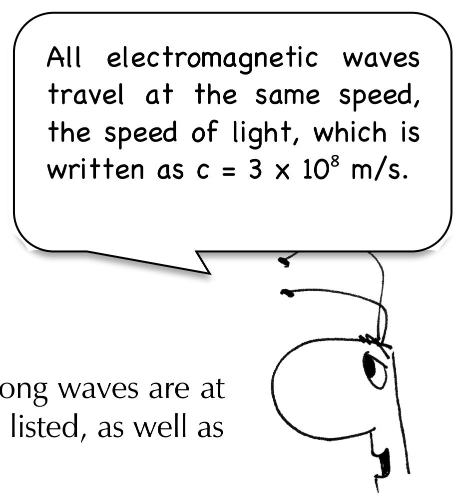
Each type of wave exhibits its properties in different ways. For sound waves, for example, the wavelength (or the frequency) determines the **pitch** of the sound, or how high or low it sounds.

7. Complete the table below that describes each kind of wave in a different way. What properties of light do you think go in the boxes below?

Wave type	**Wavelength (or frequency)**	**Speed**	**Amplitude**
Water	cm to meters; distance between adjacent crests	Varies; a few m/s	Height of the wave above sea level
Sound	cm to meters; distance between adjacent high pressure areas; pitch	340 m/s depending on the weather	Loudness
Light			

Wavelengths and the Electromagnetic Spectrum

It was discovered a long time ago that light is only one example of **electromagnetic radiation**, a form of wave consisting of crossed electric and magnetic fields.



Many phenomena in nature, vastly different in behavior (such as x-rays and radio) are all essentially the same thing: an electromagnetic wave with different wavelengths.
The chart at on the next page is organized by wavelength. Long waves are at the left, and short ones are on the right. Frequencies are also listed, as well as some technological applications such as FM radio.

Based on this chart, answer the following questions.

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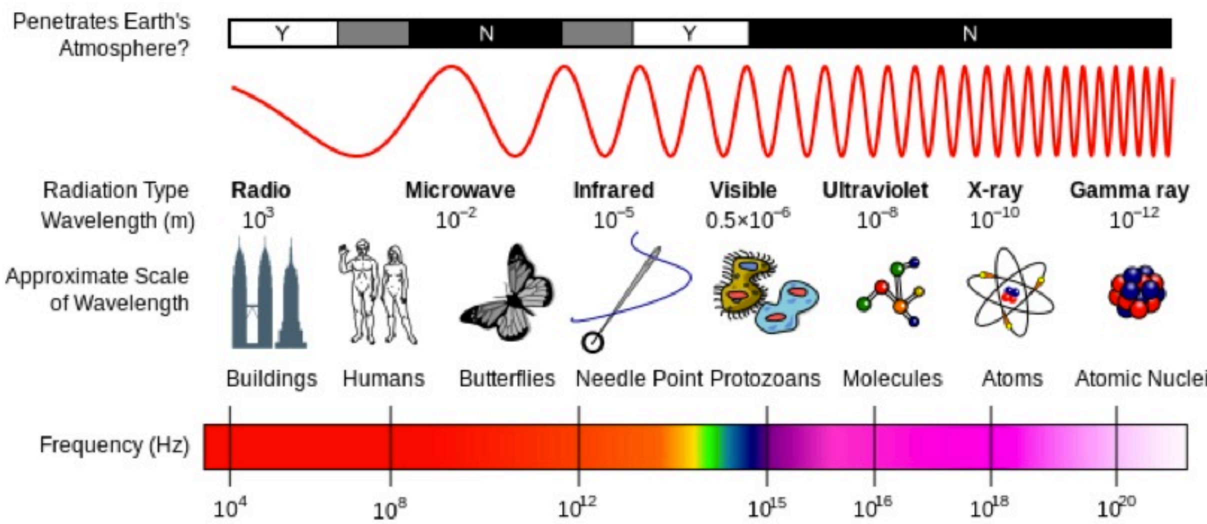
CA2 2B.1 The Electromagnetic Spectrum: Activity



The Electromagnetic Spectrum. Source: Wikipedia.

8. Use the diagram above to complete the missing information in the chart below.

Radiation type	wavelength (approx.)	frequency (approx.)	Scale	Penetrates Earth's atmosphere
Radio	10^3 m	10^4 Hz		
	10^{-5} m	10^{12} Hz	Needle points	Partially
Visible	0.5 x 10^{-6} m		Protozoans	Yes
UV			Molecules	No
Gamma Ray	10^{-12} m		Atomic Nuclei	

9. Name the colors of the rainbow in increasing order of frequency.

____

10. If higher frequencies are more energetic, they are also more dangerous. Which kind of radiation is the most dangerous?

____

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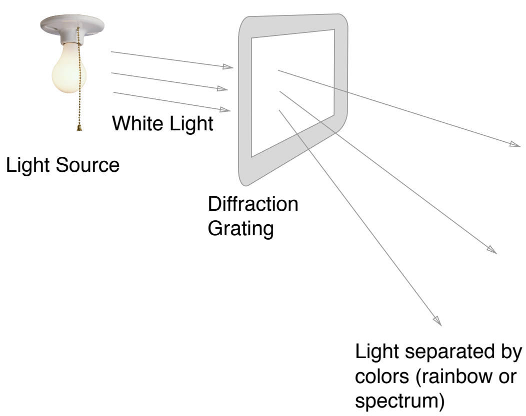
CA2 2B.2: Observing Spectra: Lab

Purpose: To build a small spectrascope and observe various spectra and record images of them.

Equipment needed: diffraction grating, small cardboard tube, opaque sticker (such as a silver colored sticker), digital camera (optional), various light sources, especially discharge tubes (mercury, hydrogen, helium), fluorescent light, incandescent light

Background:

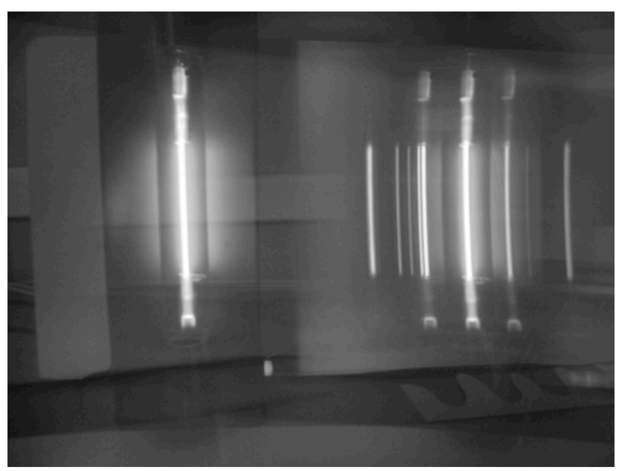


A **diffraction grating** is a device that uses tiny openings to separate the colors of light and sort them out by wavelength. If you pass a beam of sunlight through a diffraction grating, you would see a rainbow on the other side.

White light is a mixture of all the other colors of light. (This isn't the same as when you mix all colors of paint, which yields black or dark brown.) Passing the light through the grating causes each color to bend a different amount.

Astronomers use diffraction gratings to analyze the precise colors emitted by stars and other objects.

Procedure:



Set up various light sources around a darkened room. Having a dark background, such as black construction paper or poster board, behind each light source may help see the spectra you are about to observe.

Hold up a diffraction grating in front of your eyes, and look through it to see the light source. On either side of the light source, you should see something like the picture at right (only in color, of course.)

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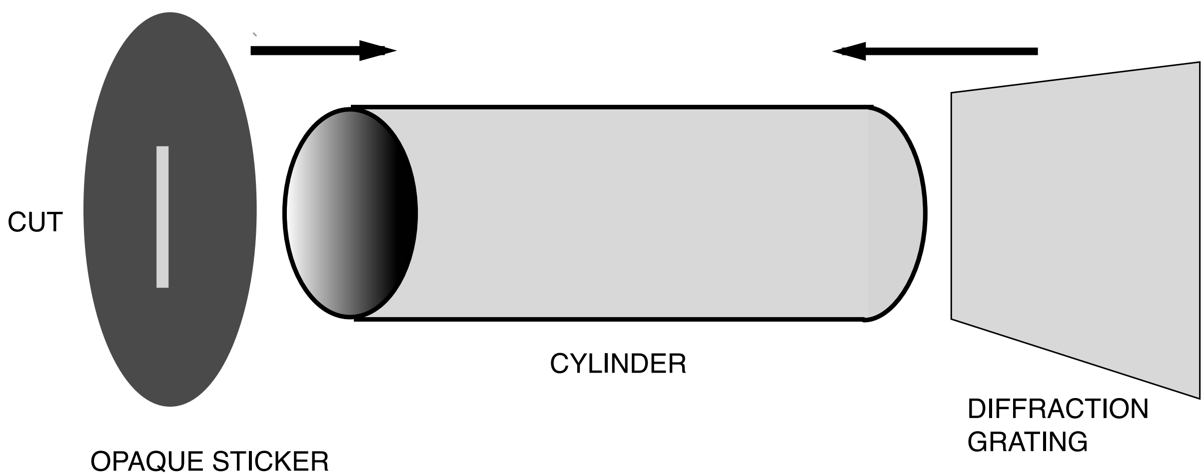
CA2 2B.2: Observing Spectra: Lab

In a spectrum drawing or photograph, it is important to record not only the colors you see, but the spacing between the colors as well. You can probably photograph the spectrum with a digital camera, if the light is bright enough. Try placing the grating over your camera lens to try it.

Making a Small Spectroscope

Your task is to record as many spectra as you can with your diffraction grating. It may help to place the grating at the end of a long tube as shown.

If the light source you have is not long and thin (such as a fluorescent light bulb) you may not be able to see the spectrum clearly. To fix this, put a silver sticker on the end of your tube and use a knife to cut a thin, straight hole in the sticker, aligned with the colors you see when you hold the grating. It is important to pre-test the diffraction grating to make sure the images of the spectrum tube are aligned with the opening you cut.



Now you have a primitive spectroscope. When using it, you may need to move it back and forth slightly to make the light pass through the tube correctly. You may not be able to see the lamp through the cut at the same time you see the spectrum.

1. Use your camera, eyes, or spectroscope to observe several spectra and record what you see below. Pay careful attention to brightness, color, and position of the lines you see.

You might consider using colored pencils to draw the colors correctly. Record, as carefully as you can, which color is brightest, the positions of the colors, and label the colors if you do not have colored pencils.

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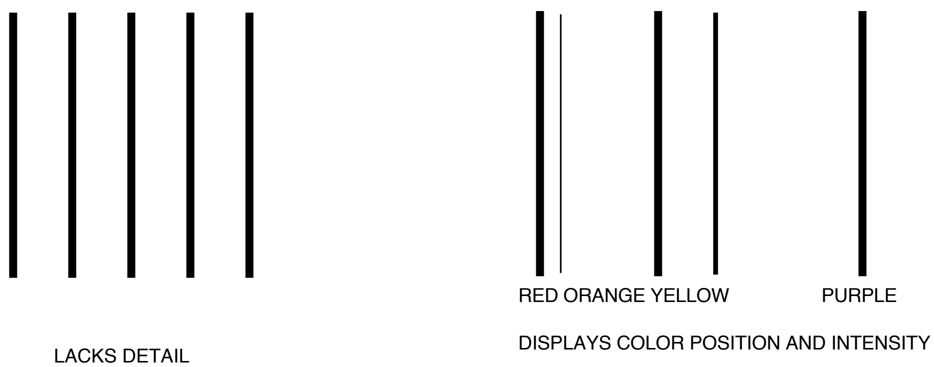
CA2 2B.2: Observing Spectra: Lab



The illustration shows sample spectra drawn carelessly and with some detail as an example. (It is not a real spectrum. Don't copy it.)

There are 3 types of spectra, described below. Classify each spectra you observed using these definitions. The example above would be an *emission* spectrum.

Appearance of various spectra

Continuous – every color is present. Resembles a rainbow.
Emission – only certain colors are present. Looks like individual colored lines.
Absorption – most colors are present, but certain ones are missing and appear as black lines in the spectrum picture. It is unlikely you will observe any of these in a normal setting.

Source	Type	Spectrum sketch

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Famous Astronomers

Andrea Ghez (1965-)

Discoverer of the Black Hole at the Center of the Milky Way

Photo credit: Credit: John D. & Catherine T. MacArthur Foundation

Andrea Ghez led a research team that discovered the motions of giant stars in the center of the Milky Way could only be due to the presence of a giant multi-million solar mass black hole in the center of the galaxy. To gather the information at such great distances, she had to combine speckle interferometry with adaptive optics using some of the world's largest telescopes. She is currently a professor of physics and astronomy at UCLA.

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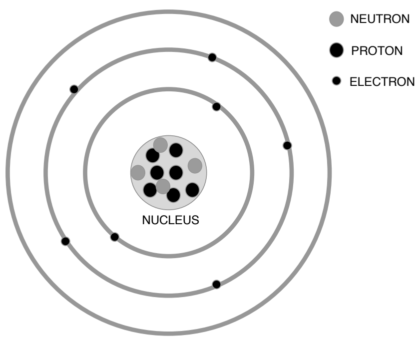
CA2 2B.3: Atomic Theory and Spectra: Activity

Purpose: To understand how spectra are formed by atoms.

Background:
Most students are familiar with a typical sketch of an atom with the proton as the nucleus, and an electron orbiting it, shown here:

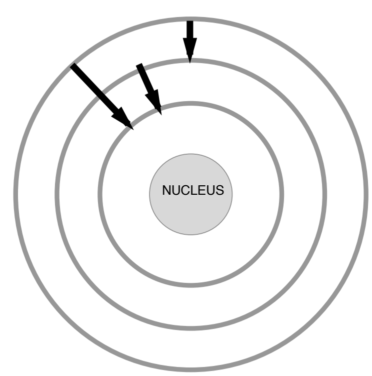


Everything is made of atoms. The number of protons refers to the **atomic number** of the atom, and determines what element the atom is. For example, element 1 in the periodic table is hydrogen. Element 2 is helium. Element 82 is lead (Pb). If it were somehow possible to knock loose 3 protons from a nucleus of lead, you could transform it into gold (atomic number 89). Unfortunately this is impossible to accomplish with chemistry, which only interacts with the shroud of electrons on the outsides of atoms. That is why the ancient quest to turn lead into goal through alchemy never succeeded.

When two atoms collide, or free electrons strike an atom, sometimes energy is added to the atom's electrons. Each electron has a specific slot, or **orbital** where it fits. The lowest energy level of a hydrogen atom, for example, can hold two electrons.

When you lift a rock on the earth, you are adding energy to it. In the case of a rock, this is called **gravitational potential energy**. When you release the rock, you can get the energy back in the form of energy of movement, called **kinetic energy**, which we discussed in Volume 1 referring to the impact energy of asteroids and meteors.

When you lift an electron (which is negative) from its normal energy level and raise it higher, the attractive force of the proton in the nucleus causes energy to be stored in the electron in the same way a rock stores gravitational potential energy. In the electron, however, this is called **electrical potential energy**. The exact amount of energy stored is a function of the number of energy levels higher you lift the electron. The higher you lift it, the more energy you store.



Unlike a rock, the electron gives back the energy you stored in it not as kinetic energy, but rather it converts it into electromagnetic energy. As the lifted electron falls, it emits a **photon (**particle) of light. This is shown by the black arrows in the illustration.

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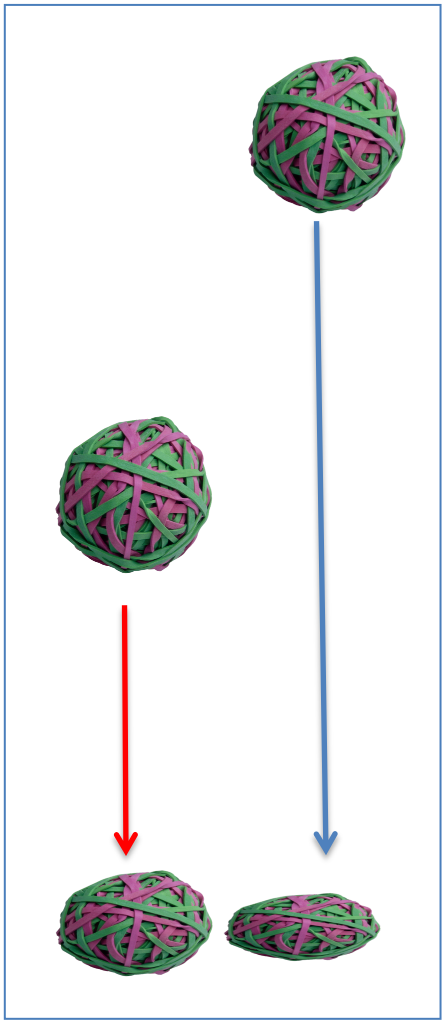
CA2 2B.3: Atomic Theory and Spectra: Activity



The farther the electron falls, the more energy it releases. Just as a ball of rubber bands will deform more if you drop it from a higher position.

The more energy the photon has, the shorter the wavelength it has. **Long jumps tend to be more towards the blue end of the spectrum.**

Therefore, ***every different energy level transition in an atom generates one (and only one) specific color.*** Since the number of energy levels in an individual atom is limited, the number of transitions is also limited, and so the energized atom emits only a few colors.

Atoms of the same element are always identical in structure. But the structure of one element is always different than all the other elements. Since every energy level structure in different atoms is different, the pattern of colors generated by different elements is also different. **Each element has a unique characteristic pattern** caused by its structure.

This explains why emission spectra can be used to identify elements at a distance without having a sample to examine. Two scientists, **Gustav Kirchoff and Robert Bunsen** (yes, the guy who invented the Bunsen burner), showed that individual elements had unique emission spectra, and more importantly to astronomy, discovered that sunlight passing through a sodium flame was *missing* some colors—the same colors that sodium emits when it is glowing on its own. This is called an **absorption** spectrum. (A detailed explanation for the continuous spectrum will be presented in a later activity.)

This explains why there are three kinds of spectra. We observed two of them in the previous activity, but now we can explain them.

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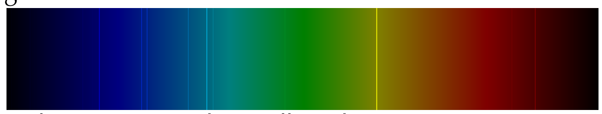
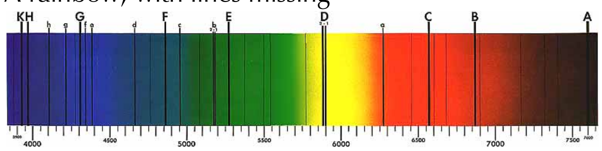
CA2 2B.3: Atomic Theory and Spectra: Activity

Type	Generated by	Looks like	Explanation
Emission	Hot, transparent gases	Individual, separate bright lines against a dark background.  Helium spectrum by Neill Tucker	Each element has a unique arrangement of atomic energy levels. Electrons falling back into place emit a single color per transition.
Absorption	Cool gas between the observer and a source of continuous spectrum	A rainbow, with lines missing 	Elements that are not energized will absorb the same colors they emit when hot.
Continuous	Hot, opaque objects	A rainbow 	Since all sorts of energy levels can be stored in and between the atoms of a solid, many different transitions are possible, and not just ones from electron transitions. So every color is generated.

The sun's spectra, which generates a rainbow when interacting with water droplets, is actually an absorption spectrum. However, a rainbow *looks* like the continuous spectrum given off by other opaque objects such as incandescent light bulbs.

Spectra questions

1. Which element has the simplest spectrum? (Hint: it's the simplest element)

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2. Explain how a spectrum picture could be used to identify an unknown substance.

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3. In the drawing below, draw all the energy transitions possible. If the colors emitted are red, green, and blue, identify which transition is which color and how you figured that out.

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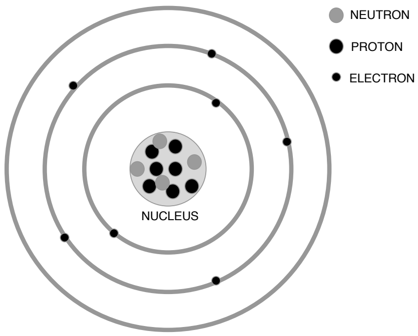
CA2 2B.3: Atomic Theory and Spectra: Activity



4. In the late 1800's Pierre Janssen, a French astronomer, discovered previously unseen lines in the sun's spectrum. No known element or compound could account for the presence of these lines. Eventually scientists determined that a new element had been discovered on the sun before it was known on the earth. It was named after the Greek word for sun, *helios*. What do you think we call this element today?

5. The sun has an absorption spectrum. The dark absorption lines in the sun's spectrum allow us to identify what elements are in the sun. Through this analysis we were able to tell over 100 years ago that the sun is made primarily of hydrogen and helium. This is called **spectroscopic analysis**, which identifies elements in the sun and has been used to discover new elements such as cesium. What other simple element, besides helium, has been detected in the sun's spectrum?

6. Conceptually, the emission spectrum and the absorption spectrum are the same patterns, but they are opposites in what way?

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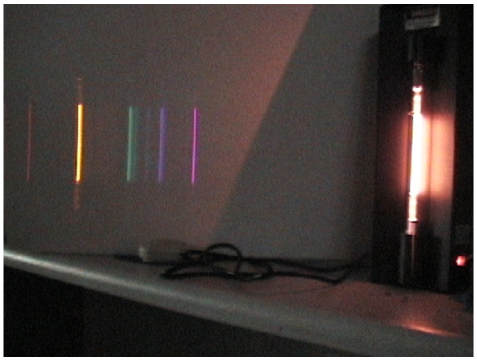
CA2 2B.4: *Identification of Elements: Lab*

Purpose: To identify elements using their spectra, and to make specific spectrum wavelength measurements by calibrating the spectrum produced by a diffraction grating.

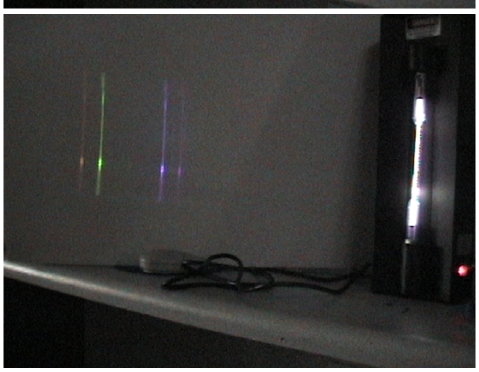


Equipment needed: several discharge tubes, digital camera, Image J, spectroscope or diffraction grating material.

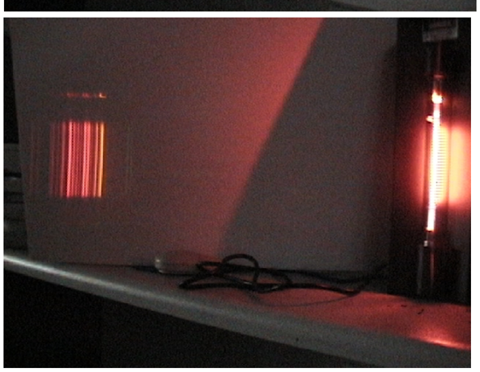
Part 1. Qualitative comparison.

Procedure:
Use the spectrum observations you did earlier (if you did not do them, please complete the *Observing Spectra* activity before beginning this activity). Make sure you observe the spectra of hydrogen, helium, and mercury.

The photos below were made very easily by using a standard discharge tube, like a fluorescent light without paint inside the glass tubing. A diffraction grating was placed in front of a digital camera lens, and then the resulting spectra was photographed. As you can see, each image is different. Using your notes, try to identify which spectrum is which.



1. List which one is which below, from top to bottom.



Part 2. Quantitative measurement of emission lines.
It is possible to identify spectrum lines *precisely* and assign wavelength numbers to them. These numbers are recorded in any number of standard references. In this part of the lab, you will measure the wavelength of a standard color of mercury, and then use this to determine the wavelength of other elements in the spectrum of mercury and other elements.

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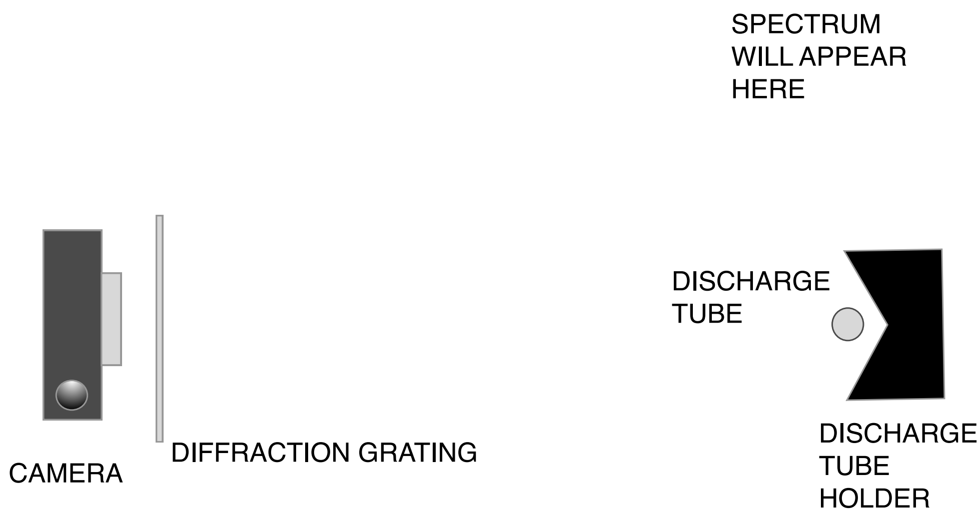
CA2 2B.4: Identification of Elements: Lab

Procedure:

2. Set up the camera, diffraction grating, and spectrum tube as shown. It is important to put the camera on a tripod so it cannot move during the experiment, and to tape the spectrum tube holder in place so it cannot move. Make sure the diffraction grating is oriented so the spectrum appears to the left or right of the tube, not above or below it. The diagram below is an overhead view.



3. Put the mercury vapor tube in the tube holder with the power OFF. **CAUTION: The spectrum discharge tube holder has approximately 5000 Volts between the terminals. Make sure the power is off when changing tubes, and never stick anything into the terminals where the tube rests other than a discharge tube.** Use a dry cloth to handle the discharge tubes as the residue left by your fingers might damage them.

4. Look through the camera and verify that the spectrum you see is from the mercury lamp. All other room lights should be off and the room as dark as possible. It might help to put something dark behind the apparent location of the spectrum. Take a photograph of the spectrum. (If no cameras or computers are available, place a meterstick in the image between the lamp (located at position zero) and observe the location of the spectrum lines against the ruler positions. Your teacher has some alternate directions in case that is necessary.)

5. Take pictures of all the spectrum tubes you have available.

6. Upload the pictures to a computer that has Image J available. This may involve software or memory card usage unique to your situation at your school site, and your teacher may need to assist you.

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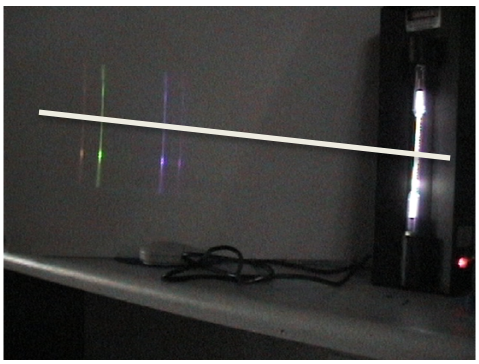
CA2 2B.4: Identification of Elements: Lab

7. Open the mercury picture with Image J. This is usually done by choosing File>Open rather than double-clicking. Most computers will attempt to open the jpegs from a camera using the operating system's preferred image display program such as Preview or a web browser, so be sure to open the file from the Image J menus instead.

8. The mercury picture will resemble the picture below. Use the line tool to draw a line between the image of the bulb and the the spectrum lines shown in the spectrum picture. You should keep the measurement line perpendicular to the bulb orientation as you draw it.



Record the number of pixels between the bulb and the green line here:

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9. The wavelength of the green line of mercury is 546 nanometers (nm). This information will enable you to set the **plate scale** of the equipment you have by comparing this wavelength to the number of pixels seen in the picture. Compute the plate scale below.

$$\text{Plate scale} = \frac{546 \text{ nm}}{\text{Pixels between bulb and green line}} =$$

10. Now examine the yellow line in the Mercury image and compute its wavelength using this formula:

$$\lambda = \text{plate scale} \bullet \text{pixel measurement}$$

Show your work here. Make sure you state the pixel measurement and then show the wavelength calculation (don't just write down the wavelength answer and nothing else.)

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CA2 2B.4: Identification of Elements: Lab

Record your observations and calculation results in the table below, for as many lamps and lines as your teacher assigns. Use more paper if needed.

Element and color	Pixel value observed	Wavelength λ (computed)

11. A record of these specific wavelengths is needed to evaluate spectrum graphs. A spectrum graph is a graph of the brightness measured by a pixel in a CCD vs. its wavelength. To make a spectrum graph in Image J, use the line tool to draw a horizontal line crosscutting the lamp and as many of the emission lines as you can see. Then choose Analyze>Plot Profile to see a spectrum graph of the line you drew. Essentially Image J simply plots the pixel values you see as you follow the line. Sketch the spectrum graph for mercury below.

Your teacher may ask you to create other spectrum graphs and record the results in your observation book.

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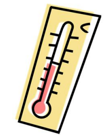
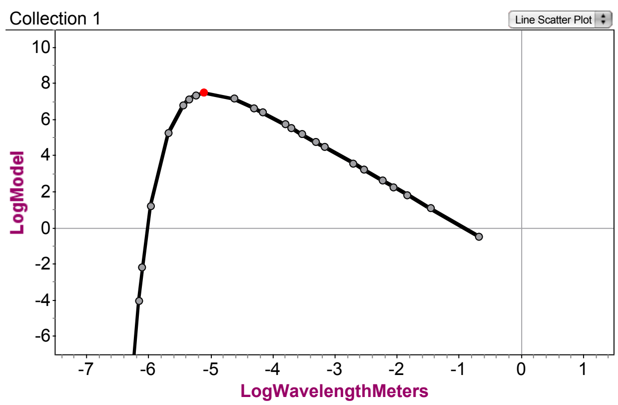
CA2 2B.5: Blackbody Radiation and Wien's Law: Activity



Purpose: To see how astronomers measure the temperatures of stars.

Background: Stars are examples of **blackbodies**, which are objects that do not reflect light, but absorb it and re-emit it due to internal heat. An example of a blackbody might be a box, painted black, with a small hole in the side to allow light to enter. Black paint absorbs light, so as light enters the box it is eventually absorbed by one of the sides of the box before it can be re-emitted. This makes the box grow gradually warmer as more light enters the hole.



Surprisingly, stars are pretty good blackbodies. It is not required to be black in color to be a blackbody—all that is required is that the object absorb light without reflecting, and glow only due to internal heat and not reflection. The sun qualifies on both of these conditions.

One of the properties of blackbodies is a characteristic shape of a **brightness vs. wavelength** graph, as shown at left. The brightness always goes on the y-axis and the wavelength goes on the x-axis, with long wavelengths such as red farther to the right as compared to shorter wavelengths like blue.

There is always a single peak, and the data to the right of the peak falls off more slowly than it rises to the left of the peak. The illustration shows a simulated blackbody curve for an object at 555 Kelvins. The dot at the peak indicates the **brightest color** in the graph.

In simpler language, what we see from a blackbody curve is a clue about its temperature. Objects that behave like blackbodies (poor reflectors, absorb radiation, emit radiation based on internal temperature) will have a single brightest color that controls their overall hue. This is why there are red stars and blue stars, for example. The peak color determines which color dominates when we look at the star.

It turns out that blackbodies have two properties related to their temperatures, which are shown in the simulation on the next page. The family of curves shown are for blackbodies at several different temperatures. Label the diagram and answer the questions about the graph on the next page.

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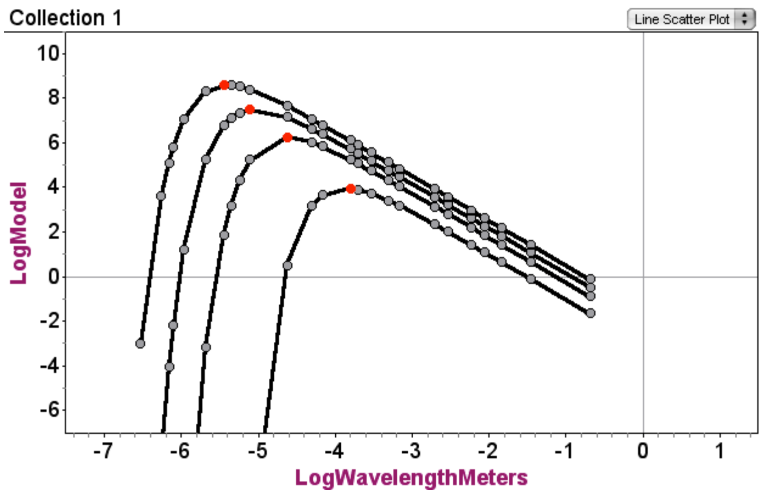
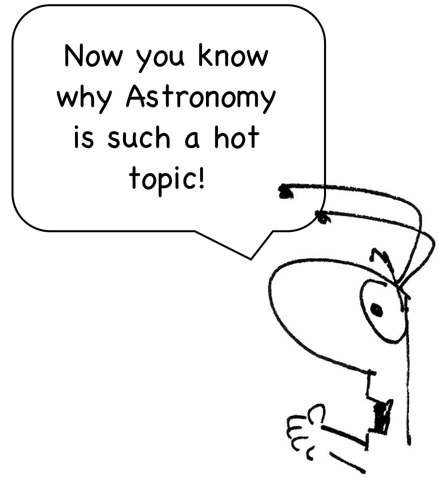
CA2 2B.5: Blackbody Radiation and Wien's Law: Activity





Conceptual Questions

1. First, if a blackbody gets hotter, or two blackbodies are compared, every color the hotter one emits is brighter. Every dot gets higher up (brighter) for a blackbody that is hotter. Which curve in the collection represents the hottest blackbody?

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2. Second, if a blackbody gets hotter, or two blackbodies are compared, the hotter blackbody will have a shorter peak wavelength. How does the diagram show this effect?

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3. Mark the highest point on each individual curve and connect them. It is this relationship that is interesting for today's activity. The peak wavelength of a blackbody is **inversely** related to the temperature of the surface of the blackbody. This rule is known as Wien's Law (pronounced 'Veen's').

Quantitative Questions

Since it is an inverse relationship, the rule will be of the form: $T \,\alpha\, \dfrac{1}{\lambda_{\text{peak}}}$

Which means, in English: "The longer the wavelength, the cooler the temperature." Or even more simply, "Red is cool. Blue is hot."

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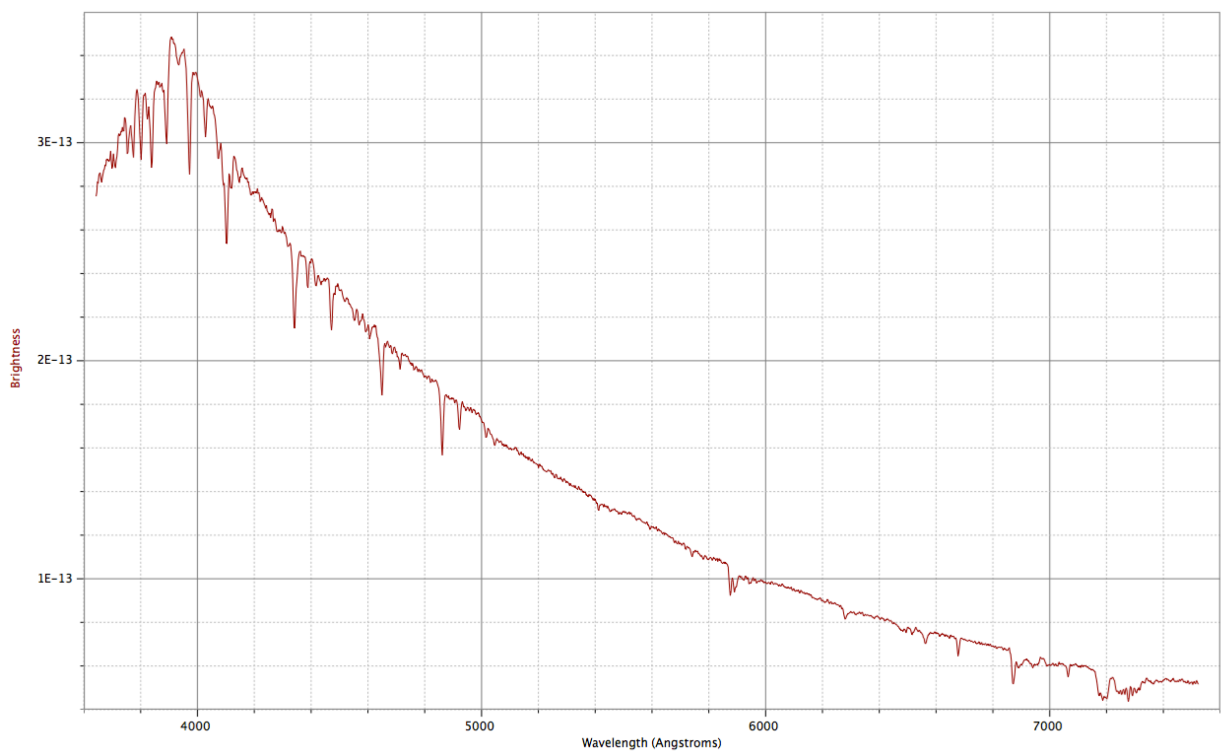
CA2 2B.5: Blackbody Radiation and Wien's Law: Activity

$$T = \frac{2.9x10^6}{\lambda_{peak}}$$

Experiments reveal that there is a proportionality constant making this an equation.

The units on the constant are nanometers•Kelvins, so when it is used to compute temperature, the wavelength must be entered in nanometers and the temperature will therefore be computed in Kelvins.

4. The graph below is the *actual* spectrum of a star called 69 Cygnii. The data was collected by the National Optical Astronomy Observatory and is used with permission. In the graph below, read the value of the peak wavelength. (Find the highest point, and then read its position on the x-axis. Mark the point and write the value on the graph.)



5. The value of the peak wavelength in the graph is in *Angstroms*(**Å**), which is a non-metric unit of length. 10 **Å** is 1 nanometer, so to find the number of nanometers, divide by 10. Peak wavelength in nanometers =

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5. Compute the temperature of this star using Wien's Law.

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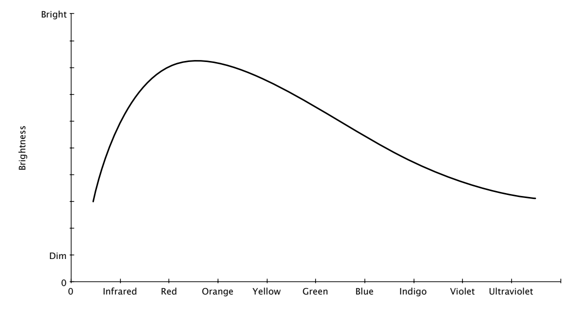
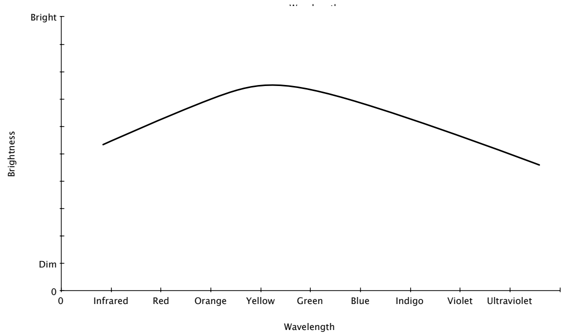
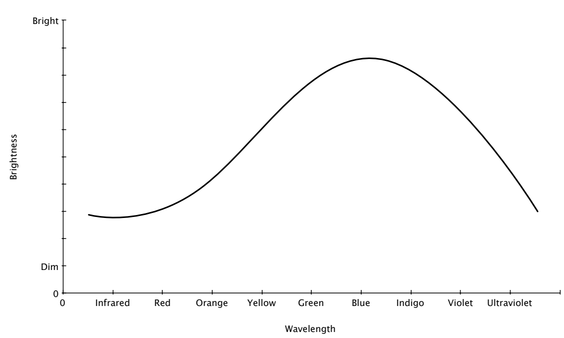
CA2 2B.5: Blackbody Radiation and Wien's Law: Activity

6. What would be the peak wavelength for a star with a temperature of 4000 K? (Solve for the peak wavelength. Show your work.)

7. Consider the following blackbody sketches. The top one has a peak wavelength in red; the middle one, in yellow; and the bottom one peaks in blue. Recall white light is the combination of all colors. Wien's Law explains why there are blue stars and red stars, but no green stars. If a star has a peak wavelength in blue, it will not have much red. If it peaks in red, it will have little blue. Why doesn't a star that peaks in yellow look yellow?







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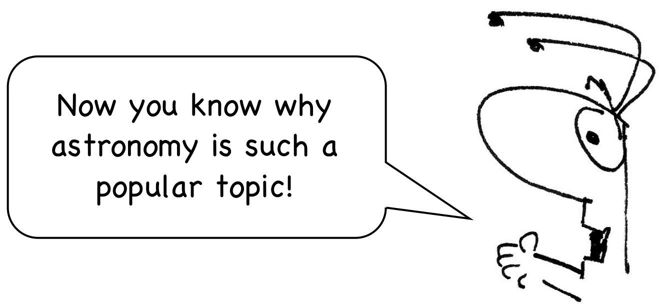
CA2 2B.6: Analyzing Stellar Spectra: Lab

Purpose: To extract information from a real stellar spectrum including stellar composition and temperature.

Background: This activity is based on *Analyzing Stellar Spectra,* developed by the National Optical Astronomy Observatory and used with permission.

Observations of stars using telescopes and spectroscopes reveal that individual stars mostly exhibit absorption spectra. Early observations of the spectra showed that they fell into patterns. After several different schemes were tried, around the year 1900 **Annie Jump Cannon** developed the current system, originally based on the alphabet, but now reorganized in terms of the surface temperature of the star. The spectral classifications range from O to M, and are usually presented to students in the form of a mnemonic phrase such as

Oh
Be
A
Fine
Girl (or **G**uy)
Kiss
Me



Where O is hottest, at around 30,000 K, and M is the coolest, around 2000K. These temperatures are determined via Wien's Law. A table of stellar spectral classes and typical temperatures of each class is given in the Appendices.

In this activity, we are going to examine the spectra of several stars, obtained by the National Optical Astronomy Observatory. The spectra are displayed as graphs, similar to the spectrum graph you may have made earlier in this unit. These graphs have been carefully calibrated to displace the values of the brightness plotted against the wavelength. The graphs displayed in the workbook contain everything you need, but more precise measurements are possible if you open the data and examine it with a computer. The data can be displayed in any graphing program such as Graphical Analysis by Vernier Software, Excel by Microsoft, or Fathom by Key Curriculum Press, and are included with the disk your teacher received with the teacher's guide.

For each spectrum graph, we are going to do two activities. First, we will identify key elements in the star's spectrum by noting the position of absorption lines. Second, we will estimate the temperature of the stars using Wien's Law.

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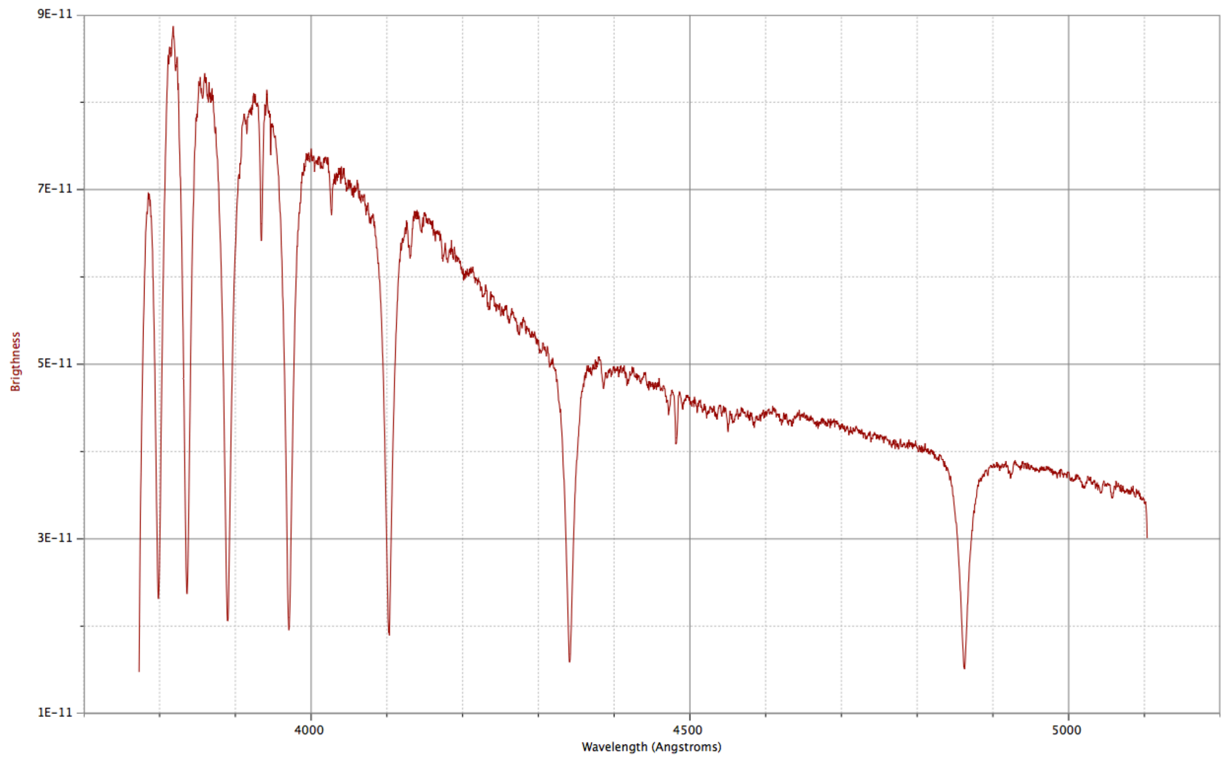
CA2 2B.6: Analyzing Stellar Spectra: Lab

Star Name: 15 Draco



1. First pretend to smooth over the top of the graph, as if you were applying icing to a cake. Draw a smooth line over the top edge of the data, jumping over the gaps as if they were not there. Interpolate, (estimate between) where the highest point would be if there were no absorption lines. This is not always the largest value in the data table or the location of the tallest spike in the graph, but it might be close. This is called the **peak wavelength.** The graphs are calibrated in Angstroms. Recall 10 Angstrom is 1 nanometers or 1 Angstrom $=1\text{x}10^{-10}$ meters. Mark the peak wavelength and write down your estimate for the value of the wavelength here.

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2. Calculate the temperature of the surface of the star using Wien's Law.

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CA2 2B.6: Analysing Stellar Spectra: Lab

3. Now look at the deepest absorption lines displayed. Using the graph scale, estimate the wavelength of the first absorption line to the right of 4000 Angstroms.

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4. Use the table at right to identify which element this line is caused by. Note: not every absorption line is identified in this table.

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5. Identify several lines and see which elements they represent. In the table, the elements may be ionized (missing an electron) or doubly ionized (missing two electrons) and so on. These atoms have slightly different spectra than intact atoms. In the table this is indicated by a Roman numeral**.** **Iron II** would therefore be doubly ionized Iron. For the purposes of this activity, you can simply identify it as Iron (Fe).
Bold face elements such as Hydrogen and Helium tend to be more prominent.

Wavelength observed	Element

The spectral class of the star can be determined based on the temperature. Using the table in the appendix, verify that 15 Draco is spectral class A.

6-8. Now repeat these steps for the 3 stars shown on the next page, or for the 10 stars in the computer files if you are doing this on the computer. Record the data in the table underneath each picture.

In each graph the y- axis is always brightness, and the x-axis is always wavelength measured in Angstroms. Label the axes appropriately.

Element	**λ (Å)**
Calcium II	3933
Calcium II	3968
H-epsilon	**3970**
Helium I	**4026**
Iron I	4045
Nitrogen IV	4058
Silicon IV	4089
Nitrogen III	4097
H-delta	**4101**
Iron II	4175
Calcium I	4226
Iron II	4233
Carbon II	4267
Iron I	4325
Helium II	**4339**
H-gamma	**4340**
Helium I	**4388**
Helium I	**4471**
Magnesium II	4481
Helium II	**4542**
Silicon III	4552
Nitrogen V	4605
Nitrogen III	4634
Carbon III	4649
Carbon IV	4658
Helium II	**4686**
H-Beta	**4861**
Oxygen V	5592
Carbon III	5696
Carbon IV	5805
Sodium I	5890
H-alpha	**6563**
Helium I	**7065**
Nitrogen IV	7100

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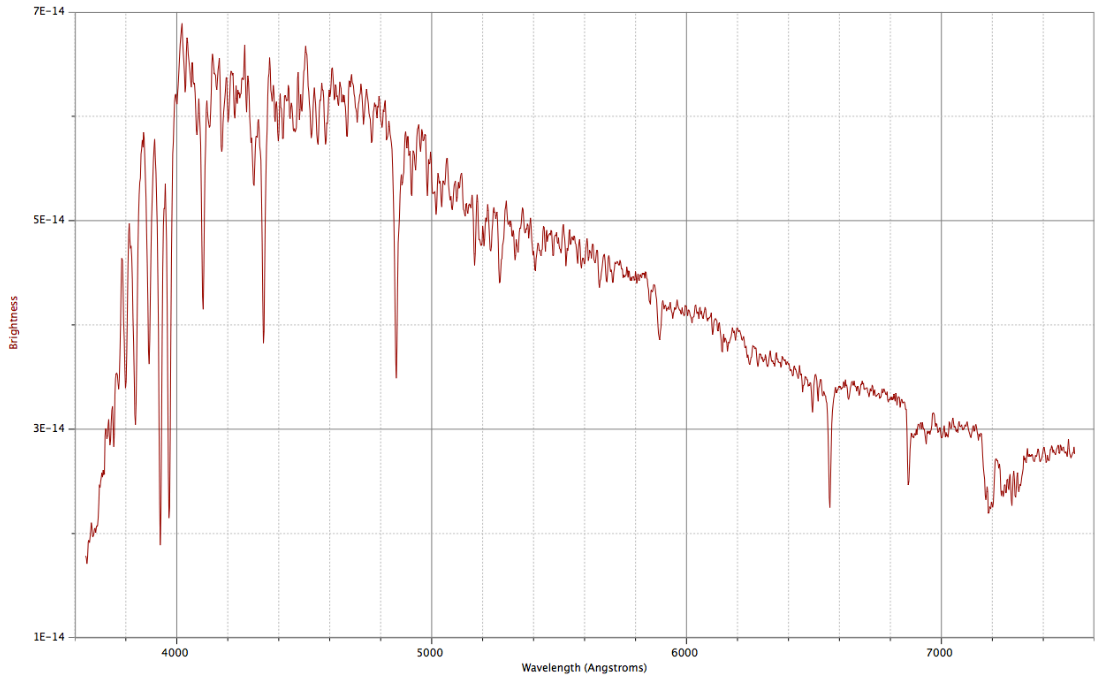
CA2 2B.6: Analyzing Stellar Spectra: Lab



6. Star name:41 Cygnus

Wavelength observed	Element

Peak wavelength:

Computed temperature (show your work):

Spectral Class:

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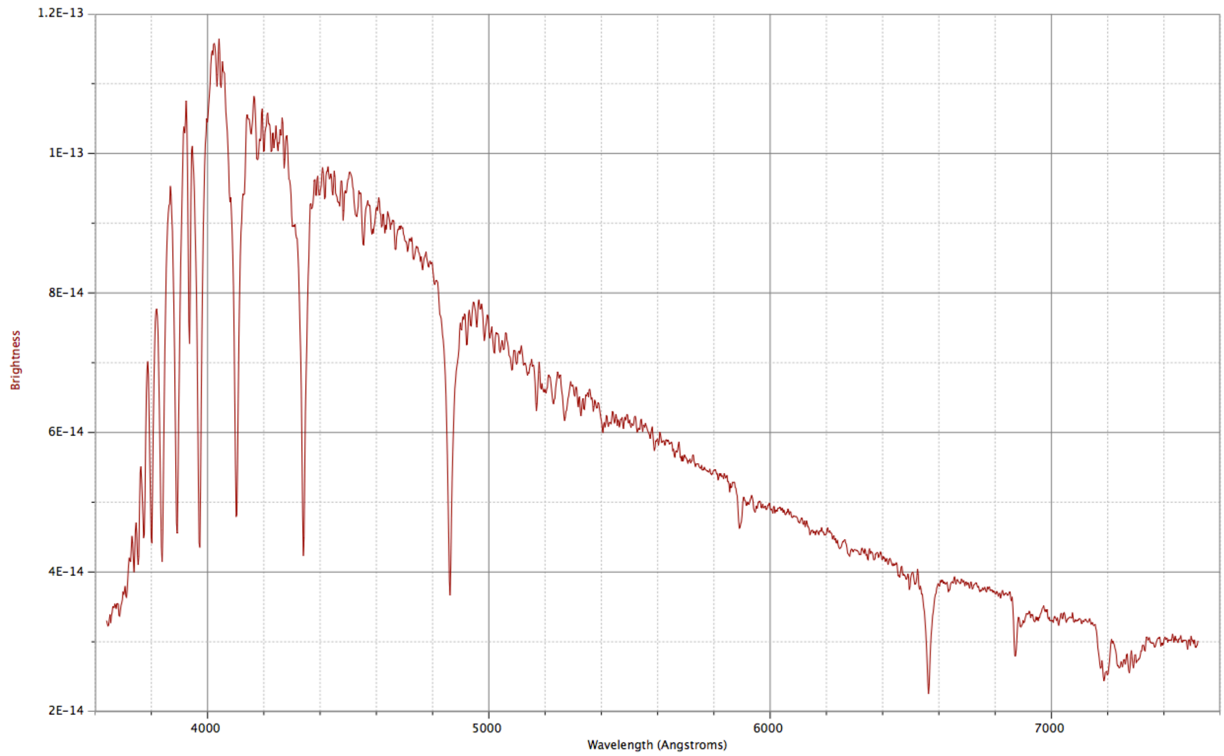
CA2 2B.6: Analyzing Stellar Spectra: Lab



7. Star name:HD 331063

Wavelength observed	Element

Peak wavelength:

Computed temperature (show your work):

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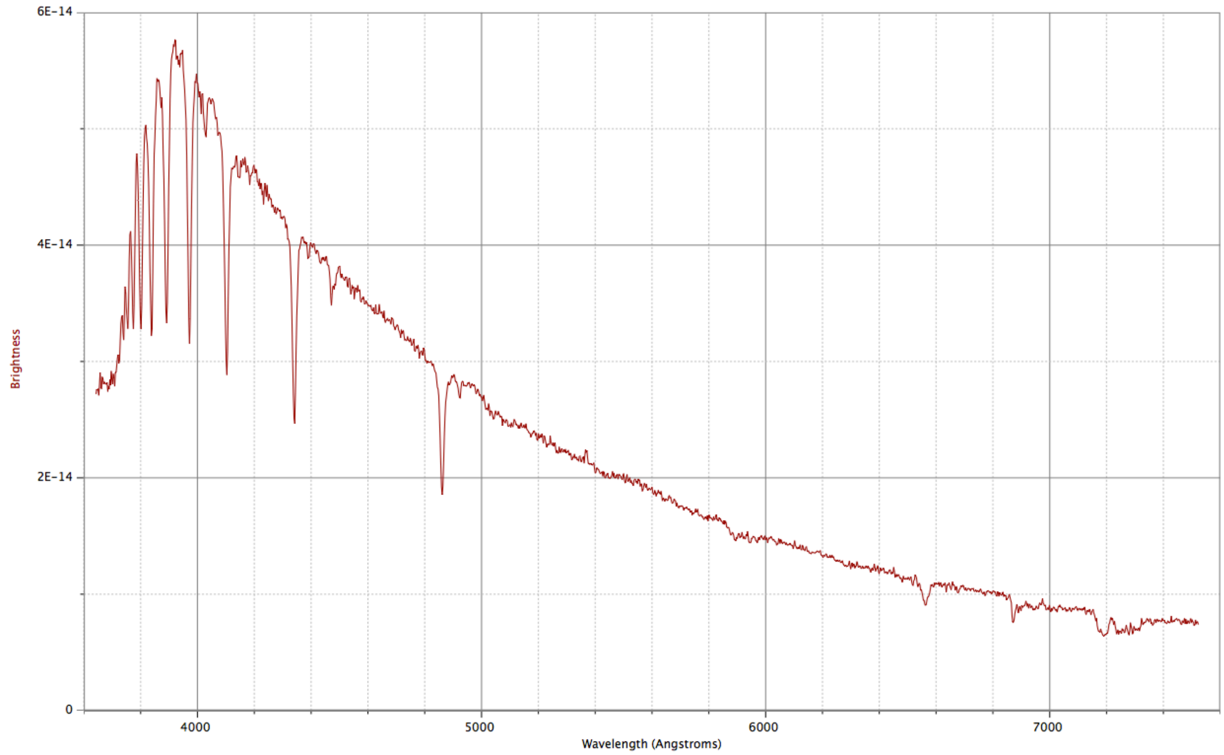
CA2 2B.6: Analyzing Stellar Spectra: Lab



8. Star name: Lambda Cygnus

Wavelength observed	Element

Peak wavelength:

Computed temperature (show your work):

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CA2 2B.6: Analyzing Stellar Spectra: Lab

Questions:

9. Are you observing the composition of the star's photosphere, or the star's chromosphere and coronas? How do you know? Do you expect these compositions to be different?

10. Annie Jump Cannon classified thousands of star spectrum graphs, and got so good at it she could distinguish them visually without plotting the data. In addition to inventing the system, she created subtle sub-categories of each star, running from 0 to 9, appended to each letter, such as B2, A6, and 09. What is the specific category for the sun?

11. Look at the table of *Brightest* stars and the table of *Nearest* stars in the appendix. Do you notice any patterns in the spectral classes?

12. Based on its spectral class of G2, the sun's temperature is 5800 K. Calculate the sun's peak wavelength.

13. What elements in the table do not appear in this collection of stars?

14. What element(s) always appear?

15. How would you describe a star that has a peak wavelength of 1200 nm?

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Famous Astronomers

Neil deGrasse Tyson (1958-)

Director of the Hayden Planetarium

The author (left) with Neil deGrasse Tyson (center) with students and teachers attending the American Astronomical Society conference in 2009. Photo provided by the author.

Neil deGrasse Tyson is an astrophysicist most known for his science communication efforts. He was the host of several television programs including *400 Years of the Telescope* before being asked to host the revival of the *Cosmos* science documentary on PBS. He is the host of the weekly radio and television show *StarTalk*, and appears on television programs regularly to explain science to the public. His research interests tend to focus on galactic and cosmological topics including stars in the galactic bulge, supernovas in other galaxies, and the mass density of the universe.

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CA2 2B.7: The Doppler Effect: Activity

Purpose: to understand the Doppler Effect and how it applies to stars.

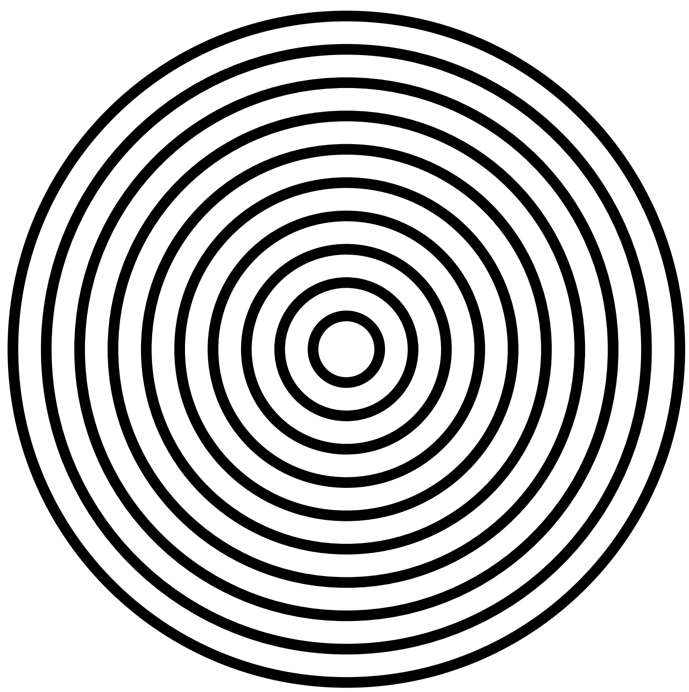
Background: So far, we have examined two aspects of colors in stars that yield information about them. For example, we have learned you can use the spectra of a star to find out its *composition*, and also to find out its *temperature*. The third kind of information you can extract from a star is called its **radial velocity**, or the velocity it has towards or away from the observer. This is determined by an effect known as the **Doppler Effect.**

You may have heard of the Doppler effect through news reports about the weather. The Doppler effect occurs because of one of the properties of a wave. It is:

The velocity of the wave is independent of the velocity of the source or observer.

This means that if you are emitting a sound wave while sitting in a stationary car, the sound will leave you at approximately 340 m/s. If you then drive the car at 40 m/s, and blow the horn again, it will still emit sound travelling at 340 m/s. Thus, it is theoretically possible to catch up the sounds you make. Doing so is called **breaking the sound barrier**. That is a topic best investigated in an introductory physics class, so we're going to have to let that go for now.

To understand the consequences of our simple statement above, consider a bug hopping on the surface of a quiet pond. If the bug hops up and down and does not move, a series of concentric ripples are formed like this:



All the circles will be evenly spaced if the bug does hops at a constant rate because the waves will depart its vicinity at a constant speed.

On the other hand, if the bug moves to the right as it hops, it will leave a series of waves that are not concentric, as shown.

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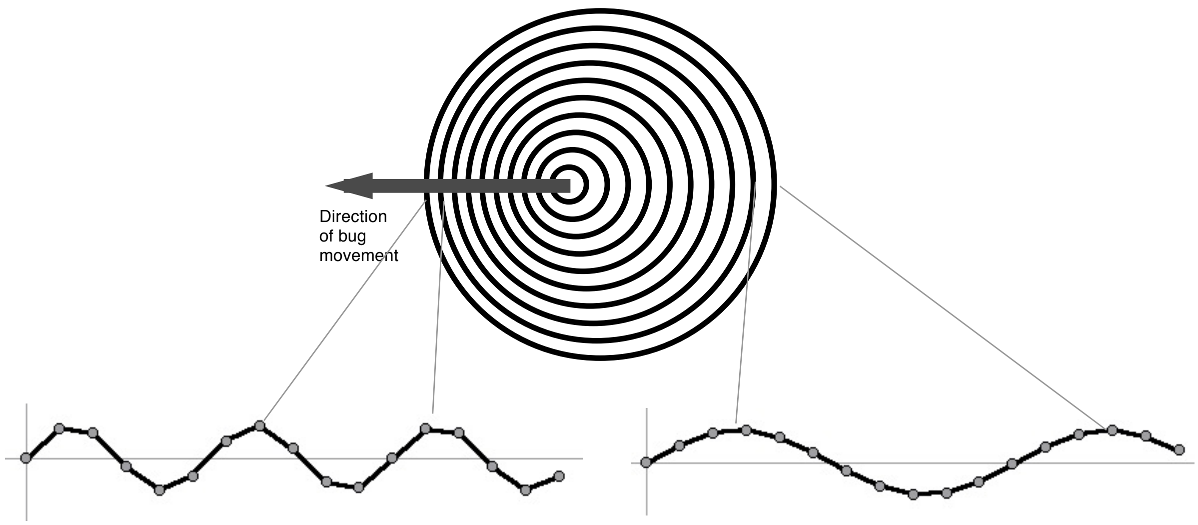
CA2 2B.7: The Doppler Effect: Activity

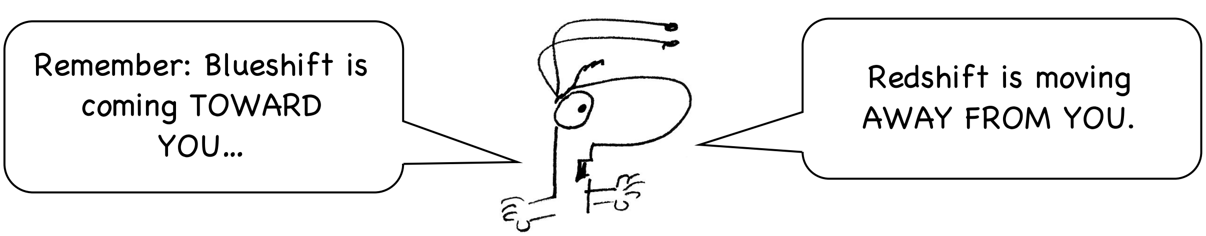


An observer on the shore will note that the waves are bunched up in the direction of the bug's movement, to the left, and will arrive more frequently than normal, increasing the frequency and shortening the wavelength of the waves observed. An observer to the right of the bug's original position, on the other hand, will see waves stretched out more.

This effect is called the **Doppler effect.** It is the change in the wavelength of a wave due to the motion of the source. (A similar effect happens if the source is stationary and the observer moves towards or away from it.)

If the source moves ***towards*** the observer, the wavelength is ***shortened***. In terms of sound, this would cause the pitch to rise. This causes the familiar *Weeeeee-Wooooo* sound a siren makes as it passes you. After the source passes, the wavelength is lengthened and the pitch is lowered.

The same thing happens with light, but with light, the wavelength changes cause a change in **color**. If the source of light approaches you, the wavelength is shortened. Any color changes observed require either extremely sensitive equipment or enormous velocities. If the color shift is caused by an approaching light source, the color moves towards the blue end of the spectrum, which is called a **blueshift**. If the source is moving away, the wavelengths are lengthened and colors move towards the other end, called a **redshift.**



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CA2 2B.7: The Doppler Effect: Activity

The greater the shift, the greater the velocity change. The Doppler Effect only happens when the movement is toward or away from the observer, not when the object is moving at right angles. Movement at right angles to the line of sight is called **transverse**. Movement toward or away from the observer is called **radial.** The Doppler effect only measures radial velocities.

In the activity that follows, some simulated spectra have been made in comparison to the sun's spectra. You will use the Doppler Effect to estimate the velocity of the object in question. You can also calculate the velocity of objects with a formula:

$$\lambda_{observed} = \frac{\lambda_{emitted} c}{(c - v)}$$

In this formula v is the radial velocity of the source, observed is what you see in your telescope and spectroscope, and *emit* is what the source would look like if it was stationary. If v is approaching you it is negative; if v is moving away it is positive. Lowercase "c" is the speed of light, 300,000,000 m/s. The equation is an approximation; a more sophisticated version is needed if the objects are moving near the speed of light, but for the purposes of this exercise, this formula will do.

EXAMPLE:

A star has an absorption line at 5400 nm. The star is approaching the solar system at 30,000 m/s. Calculate the wavelength of the observed absorption line. Because the star is approaching the solar system, the velocity is negative.

$$\lambda_{observed} = \frac{\lambda_{emitted} c}{(c - v)}$$

$$\lambda_{observed} = \frac{5400(300,000,000)}{(300,000,000 - 30,000)}$$

$$\lambda_{observed} = 5400.54 nm$$

In the case of a redshift, v is negative, in which case you would use c+v in the denominator. Notice that the shift in wavelength is very small. Nevertheless, with the best instruments we have available, we are able to detect Doppler shifts caused by just a few meters per second. Indeed, Doppler radar used by meteorologists can detect the direction and the speed of nearby rain clouds using this principle.

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CA2 2B.7: The Doppler Effect: Activity

Conceptual Questions:

1. What are the two things that the Doppler effect can reveal about an object that emits light?

2. What is the difference between a red shift and a blue shift?

3. When the shift is larger, what does that tell you about the speed?

4. The sun has an H-epsilon absorption line at 3970 nm. A certain distant star is observed to have an H-epsilon absorption line at 3975 nm. Is the star redshifted or blueshifted?

5. If the star were moving towards us, what would its H-epsilon absorption line wavelength be?

6. What might it mean if you observe a star's Doppler shift over time and observe that for part of the time it is redshifted, then blueshifted, then redshifted again, over and over?

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CA2 2B.7: The Doppler Effect: Activity

Quantitative Questions

7. What velocity would be required to cause a wavelength shift of +10 nm in a 500 nm absorption line?

8. According to the formula, for relatively low earthbound speeds, will a Doppler effect cause a visible change in color to the human eye?

9. Suppose a telescope is used to analyze the spectra of sunlight reflecting off of Saturn's rings. What result would you expect to find?

10. A distant spacecraft emits a radio signal at 1000 m (but by the time it arrives at earth we receive it at 1001 meters wavelength. Is the spacecraft approaching or receding from the earth? How fast is the spacecraft moving relative to the earth?

11. Discuss how fast an object in space would have to move in order to make it appear to be a different color visually. Why don't we see cars change color as they approach us and drive away?

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CA2 2B.7: The Doppler Effect: Activity

12. In which of the following astronomical situations would you expect the Doppler Effect to yield useful information? (Mark the ones you choose with a √.)Explain your reasoning.

___A galaxy moving away from the Earth

___An exoplanet rotating

___An asteroid moving perpendicular to our line of sight

___Tiny, but rapid movements on the surface of the sun (like bubbling)

___The rotation of Mercury

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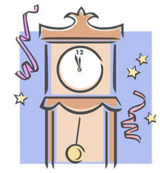
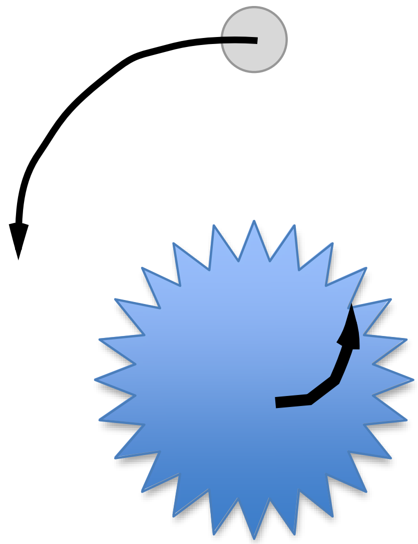
CA2 2B.8: Doppler Wobble: Lab



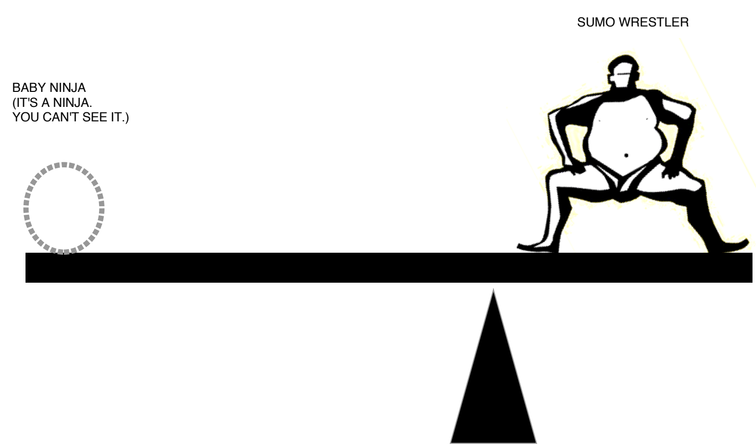
Purpose: To show how the Doppler Effect and Kepler's Laws can reveal the presence of an exoplanet you cannot even see.



Background:

Suppose a star has a large, yet unseen planet. It is difficult to observe such planets because the glare of the star's light makes it hard to see the planet. (There are some exceptions, usually giant planets in large orbits.) In general, we see very few exoplanets. Most of them are detected either with the transit method or the **Doppler Wobble.**

If a star has an unseen planetary companion that is large enough, it will cause the planet to wobble as it moves through space. Because of Newton's third law of motion, if a star's gravity pulls on a planet, the planet's gravity must necessarily pull on the star. This makes the star wobble back and forth at the same rate the planet orbits the star. Think of the star and planet at children sitting on a seesaw. The larger child is closer to the balancing point and doesn't move as much as the smaller child… but he larger child does in fact move.



Think of it as observing a sumo wrestler square dancing on a seesaw with a baby ninja. Let that image just sit there and percolate for a while.

The sumo wrestler is the star and has most of the mass of the system. The baby ninja is small, and hard to see because of the ninja costume. Nevertheless, if the sumo wrestler swings the baby in a circle, it will cause the wrestler to sway back and forth slightly. This is what we observe with the Doppler Wobble.

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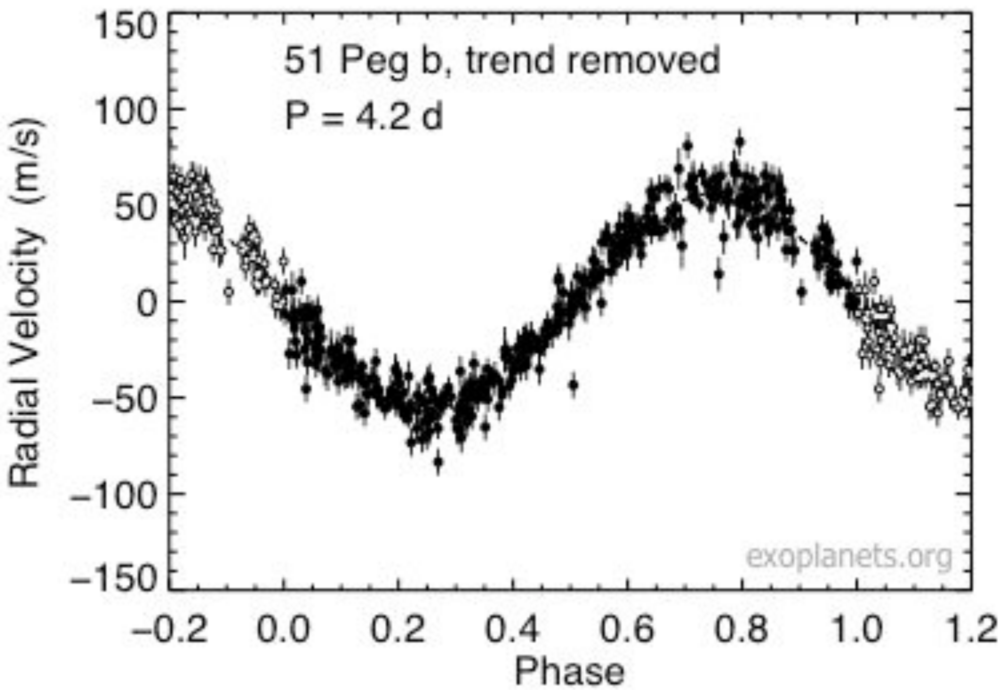
CA2 2B.8: Doppler Wobble: Lab

We can observe this effect if the orbit of the planet is tilted even a little towards the line of sight we have with the planet. The only time it doesn't work at all is if the plane of the orbit is perpendicular to the line of sight. In that case, we cannot detect the radial back-and-forth wobbling of the star due to the influence of the smaller planet.

Here is some data from the actual Doppler wobble of a real star, 51 Pegasi. In the diagram below, the Doppler-Effect calculated velocity of the star is plotted on the y-axis, and the difference between the data and a theoretical model driven by a planet with a 4.2 day period (called the *phase*) is plotted on the x-axis. The diagram shows that the star 51 Pegasi has a Doppler shift caused by a Doppler wobble.



This plot was retrieved from the Exoplanet Orbit Database and the Exoplanet Data Explorer at exoplanets.org, maintained by Dr. Jason Wright, Dr. Geoff Marcy, and the California Planet Survey consortium.

1. According to this data the star wobbles how often?

____

2. Therefore according to this data the planet's orbit takes how long?

____

____

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CA2 2B.8: Doppler Wobble: Lab

3. Assuming this is the orbital period of the planet, we can determine information about the system using the same methods we did in the Locating Exoplanets lab. 51 Peg is a spectral class G5. Use the Spectral Class table in the Appendix to estimate the mass of the star. First, write down the mass in solar masses as given in the table.

4. Next, multiply the mass by the mass of the sun in kg. This value can also be found in the appendix.

5. Now use Newton's version of Kepler's Third Law to compute the orbital radius of the planet's orbit.

$$P^2 = \frac{4\pi^2 r^3}{GM}$$

6. Search for this planet on the internet (51 Peg b) and tell what is special about it.

7a. What would be the effect of having more than 1 planet in a system?

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CA2 2B.8: Doppler Wobble: Lab

7b. Sketch the Doppler wobble (Velocity vs. time) graph that might result.

8. Is there a way to find the orbital radius from the Doppler Wobble if the mass of the parent star is unknown?

9. Which kind of stars are more likely to have easy-to-measure Doppler Wobbles, given identical planets and orbits?

10. Compare and contrast the Doppler wobble method of exoplanet discovery with the transit method.

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CA2 2B.9: Color Puzzle

Fill in the terms at the bottom of the puzzle. Then write the same letter in the box with the corresponding number. A quotation or phrase will be spelled out in the grid at top.

1	2	3		4	5	6	7	8		9	10		11	12		13	14	15	16
17		18	19		20	21	22	23	24		25	26		27	28	29	30	31	.
		32	H	33		H	34	35	A	36		37	Y	38		39	A	40	
41	42	43		44	45	46		47	48	49	A	V	50	'	51		L	52	53
H	54	,		55	56	57		T	H	58	59	60		T	H	A	T		61
62	A	63		64	A	65	T		V	66	67	L	68	T		A	69	O	U
70	71	-	A	72	73		O	74	T	A	V	75	S		S	T	76	L	L
	77	X	78	S	T	,		T	H	O	U	79	H		N	O	T		T
O		S	80	G	H	T	,		B	E	L	O	81		T	H	E		82
E	D	.		-	V	I	83	G	I	N	I	A		84	I	N	E	85	

1. _ _ _ _ _ _ _ _ (10, 20, 33, 4, 11, 8, 29, 35) RAINBOW
2. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ (37, 2, 38, 23, 17, 63, 5, 84, 1, 15, 30, 42, 22, 9, 39) COMBINATION OF E & M
3. _ _ _ _ _ _ F _ _ _ _ _ (19, 64, 43, 46, 31, 7, F, 3, 14, 53, 16, 25) THREE HUNDRED MILLION M/S (3 WORDS)
4. _ M _ _ _ _ _ _ (50, M, 21, 27, 41, 52, 12, 36) SPECTRA WITH ONLY CERTAIN COLORS
5. _ _ _ _ _ P _ _ _ _ (18, 55, 51, 26, 82, P, 32, 66, 28, 40) CONTINUOUS - EMISSION
6. _ _ _ _ _ _ _ _ _ _ (48, 44, 45, 49, 76, 70, 34, 47, 56, 59) ALL THE COLORS; OPAQUE GLOWING THING
7. _ _ _ _ _ (81, 78, 60, 72, 61) LAW THAT TELLS TEMPERATURE BASED ON COLOR
8. _ _ _ _ _ _ _ _ _ _ _ _ _ _ (69, 83, 80, 79, 24, 54, 68, 65, 57, 74, 58, 6, 62, 85) PEAK WAVELENGTH (2 WORDS)
9. _ _ P P _ _ R (71, 67, P, P, 13, 75, R) EFFECT SEEN WHEN WAVE SOURCE OR OBSERVER MOVES
10. R _ _ (R, 77, 73) THESE STARS ARE COOLER THAN BLUE ONES

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CA2 2B.9: Color Puzzle

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Conceptual Astronomy 2 Unit 2C: Position

In the previous Unit 2 sections, we learned about how brightness and color can be used to extract information about stars. Now we will learn how the *position* of a star in an image can be used to find out information about a star.

Under normal circumstances, a star's position does not appear to change. If a star's RA and dec does appear to move, there can only be two causes. Either

a. The star itself is moving
and/or
b. The earth is moving.

If the star itself is moving, this is called **proper motion**. Only the nearest stars exhibit this. Since the proper motion is only visible when the star is moving at right angles to our line of sight, it is complementary to radial motion. With both proper motion and radial motion data you can estimate the star's movement in 3 dimensional space.

If the earth's movement is causing the star to move, this is much more common and useful. This is usually detected as a small wobble in the star's position that takes exactly 365 days to repeat. That is usually the major clue that the movement is due to the earth's orbit around the sun. Most of the activities in this section are related to this effect, called **parallax.**

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Famous Astronomers

Benjamin Banneker (1731-1806)

African American Astronomer and Almanac Writer

Bemjamin Banneker was a noted astronomical almanac writer from the eighteenth century. An almanac is a book containing calculated lists of predictions such as sunrise and sunset times, eclipses, and so on. Self-taught as a free black man, Banneker corresponded with Thomas Jefferson and scolded him for being a slave-owner while promoting freedom.

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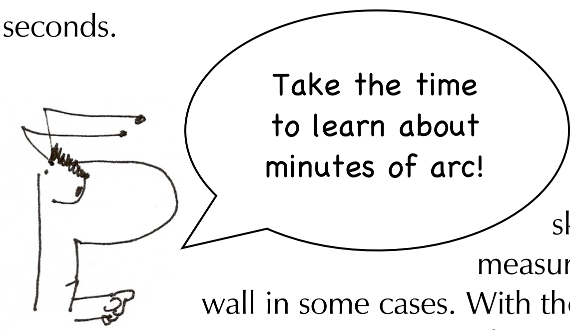
CA2 2C.1: Arc Seconds: Activity

Purpose: To learn about arc seconds as an angular measurement.

Background: Astronomers measure angles in the sky using a system that is based on degrees that is called the sexagesimal system. This means it is based not on tenths (which would be decimal) but instead is based on sixtieths. As was discussed in Volume 1, ordinary degrees are subdivided by astronomers into 60 smaller segments called *minutes of arc*, or sometimes called **arc minutes** or just *minutes*. Each minute of arc is subdivided into 60 **arc seconds**, or just *seconds*. The symbols for arc minutes and arc seconds are ' and ", respectively. Beginners will sometimes think these represent feet and inches, which they can in ordinary linear measurement. In astronomy, however, they are used for arc minutes and seconds.



Tycho Brahe was noted for being one of the sharpest visual observers in history. This was partly due to his excellent eyesight and observing skills and partly due to his large and carefully made measuring equipment, including protractors as large as a wall in some cases. With these, he could routinely make observations as sharp as one arc minute with just his eyes.

The telescope enabled us to see more than the human eye can alone, increasing the resolution of observations to the point where less than an arc second of separation can be seen by giant telescopes.

1. How many arc seconds are there in an arc minute?

___

2. How many arc minutes are there in a degree?

___

3. How many arc seconds are there in a degree?

___

4. The moon appears one half of a degree wide in the sky. How many arc minutes is this?

___

___

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CA2 2C.1: Arc Seconds: Activity

5. Another unit of angular measure is the *radian*. A radian is defined in such a way that 2π radians is equivalent to an entire circle or 360 degrees. How many degrees are in one radian?

6. Use the factor-label method of conversion to convert 34 arc seconds into radians.

7. Convert 0.7 arc seconds into radians.

8. Astronomer use different systems of indicating degrees, minutes, and seconds when referring to angles as opposed to time. How would you write 12 hours, 13 minutes, 5 seconds in time units (but abbreviated?

9. How would an astronomer write 12 degrees, 13 minutes, 5 seconds in symbols representing angular measure for say, declination?

10. Convert 12 degrees, 13 minutes, 5 seconds of angular measure into radians. Show your work. Hint: convert everything to degrees first; add together, then convert to radians.

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CA2 2C.2: Parallax of a Flagpole: Lab

Purpose:
To measure the distance to a nearby flagpole without walking over to it. To show how to measure distances without actually traversing the distance between objects using geometry.

Materials needed: Photos of flagpole from two locations (with a far more distant object in the background); photo of object of known size and distance at the same plate scale; cm ruler

Procedure:
Examine the photos of the flagpole and water tower on this page.

These two photos were taken from positions 4.0 meters apart on a balcony some distance away from a flagpole across campus from the author's classroom.

Note that the water tower in the distance is much farther away with intervening hills between the flagpole and the tower.

A position shift of 4 meters caused the flagpole to move in front of the water tower compared to what was seen originally.

Notice the flags are slightly different in the breeze. While only moments apart, these photos were not taken simultaneously.

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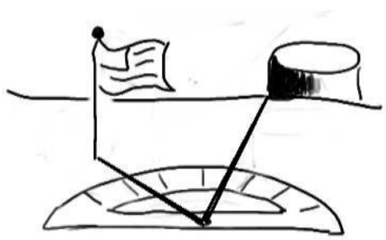
CA2 2C.2: Parallax of a Flagpole: Lab

The apparent position shift in the flagpole's position compared to the water tower is called its **parallax** shift, defined as an angle of position shift due to motion of the observer. It is relatively easy to measure how far the flagpole shifted in the picture (you can do it with a ruler) but to express this observation as an angle is somewhat more complex.

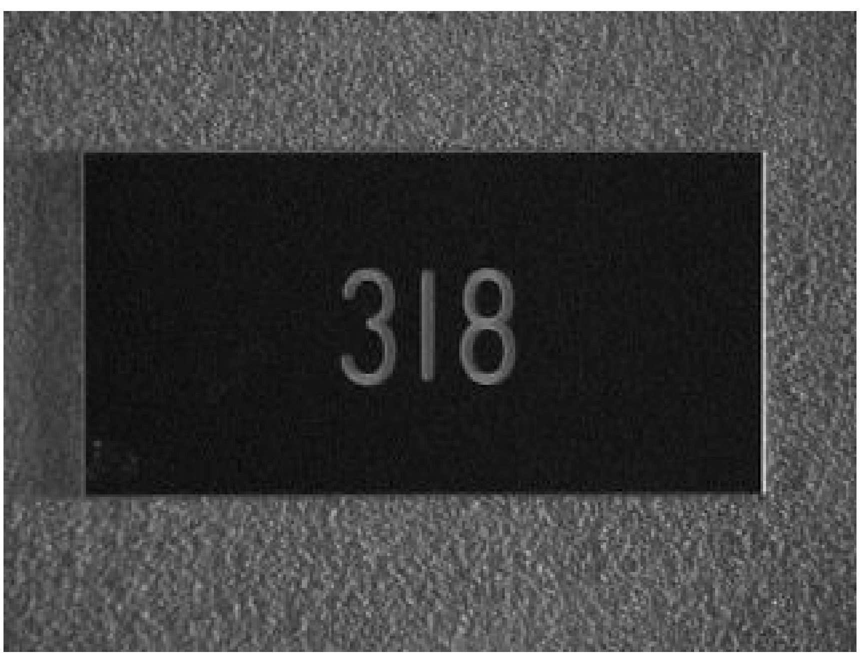


Actually, using a protractor for this purpose is conceptually correct, but imprecise. Astronomers measure angles in pictures by establishing the **plate scale**, which is how many degrees of angle are covered by one pixel in the image. (Millimeters work too, if you're doing this on paper instead of a computer. Just use *millimeters* everywhere the instructions say *pixels*.)

In order to judge the plate scale, at least one picture must be taken that establishes everything that is needed at once.

Determining the Plate Scale of the Photos

The photo on this page shows the room sign outside the author's classroom. When this picture was taken, the same exact settings were used on the same camera as for the flagpole. However, in this case we know how far away the camera is from the subject, and how large the subject is.



The room sign is 30.0 cm wide, and the camera was 2.00 meters away from it when this photo was taken.

Using this information, you can determine how many degrees wide the sign appears, and how many millimeters of the photo it takes to represent one degree. The instructions begin on the next page.

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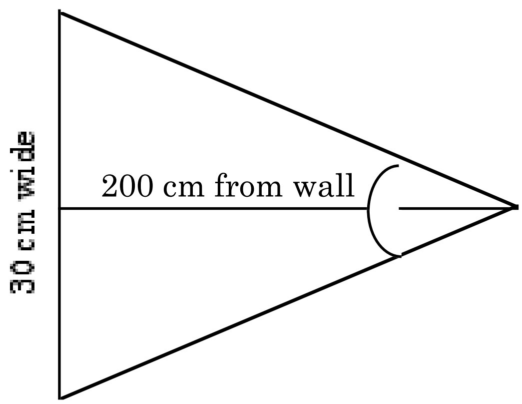
CA2 2C.2: Parallax of a Flagpole: Lab



Consider the diagram at left. To find the plate scale, we need the angle shown with the small arc symbol. There are two ways to get it: Draw the picture to scale and measure with a protractor, or use a trig function. (The diagram on this page is NOT to scale.)

1. Determine which method you will use, and measure the angle shown. Describe your method and state the angle below.

____

____

____

____

____

____

The plate scale is the number of degrees per the number of millimeters.

2. How many millimeters wide is the photo of the room sign? ______________________

3. What is the *plate scale* of the photos taken? (All of the photos were taken with the same zoom setting, using the same camera; so the plate scale is the same for all of them.)

Compute using: $\text{plate scale} = \dfrac{\text{how degrees wide the room sign is}}{\text{how many mm wide the room sign is}} =$ ___________

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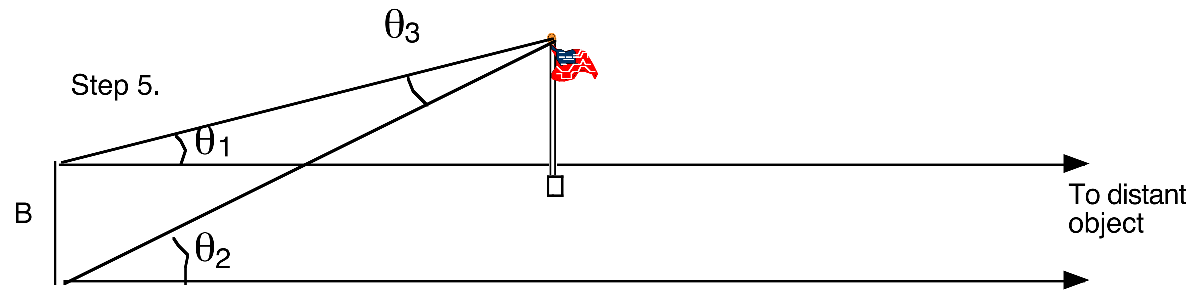
CA2 2C.2: Parallax of a Flagpole: Lab

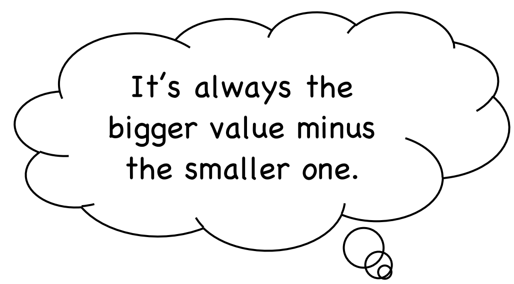
Finding the Parallax Shift

To understand the parallax shift, consider the following diagram as seen from overhead.



$$\theta_3 = \theta_2 - \theta_1$$

In this diagram B (the *baseline*) is the distance between the two positions where the pictures were taken. Theta (θ) is a variable that stands for the angles involved. θ_3 is the parallax shift of the flag compared to the water tower. It can be found by subtracting the angular separation of the flag and water tower in each position.



Now we will find the angular separation. It is the number of degrees two objects would appear to be apart, if you held a protractor to your eye (with your eye at the vertex) and let the two objects fall on the protractor scale. In the illustration the angular separation is the angle between the left side of the water tank and the pole. The separation in this case is θ_1. A few steps away, and a similar observation yields θ_2. Subtracting these yields the parallax angle θ_3.

4. Now we determine the two angles in the photos with the flag and water tank. In the first photo, measure the distance between the flag pole and the left edge of the water tank in pixels (or millimeters). Then convert this measurement to degrees by multiplying by the plate scale. This is θ_1.

____

____

____

5. Do the same calculation for the second photo. This is θ_2.

____

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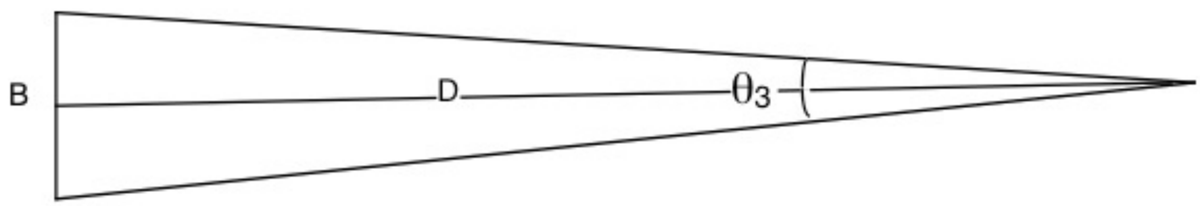
CA2 2C.2: Parallax of a Flagpole: Lab

6. *Subtract* the two to determine the *parallax angle,* θ_3.

Finding the Distance to the Flagpole

7. Now that we have the parallax angle and the baseline, we can determine the distance to the flagpole. This can be done with a scale drawing without the use of trigonometry, or by using a simple trig relation as shown in the diagram below.



To do a scale drawing, draw a line representing B to scale. Remember B is 4.0 meters, so you could draw a 4.0 cm line on a sheet of paper. Then draw a triangle that has a parallax angle equal to what you measured. This may take a large sheet of paper and some trial and error.

8. To use trig, first convert the angle to radians :

$$\text{angle in degrees} \times \frac{\pi}{180} = \underline{\hspace{4cm}}$$

9. Then use this simple relationship to find the distance to the flagpole: $D = \frac{B}{\theta_3} = \underline{\hspace{2cm}}$

The explanation of this formula is covered in detail in the teacher's guide. It depends on a property of radians and tangents called the ***small angle approximation,*** which tells us the tangent of a small angle equals the angle when measured in radians. How accurate is this value? Overhead maps of the campus where these pictures were taken show that the distance between the flagpole and the classroom where this was taken is several hundred feet away. A comparison value is in the teacher's guide.

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CA2 2C.2: Parallax of a Flagpole: Lab

Questions

10. This entire process is an analogy to what astronomers do to measure the distance to stars. What part of this analogy represents a nearby star?

11. What represents the distant background stars?

12. What represents the distance between the positions of the earth 6 months apart, when the observations are made?

13. Describe what you would expect to see if you had two photographs of nearby stars, one of which exhibits significant parallax.

14. What are the limitations of this method? Under what circumstances would it not work well?

15. The Hipparcos satellite was launched in 1989 to measure parallaxes of nearby stars and greatly extended the distance measurements we were able to make because the space probe could measure smaller angles than ground-based telescopes. The satellite orbited the earth when it operated, in a geosynchronous transfer orbit that kept it fairly close to the earth most of the time. What would the baseline for parallax measurements have been for this satellite?

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CA2 2C.3: Parallax of Stars: Activity

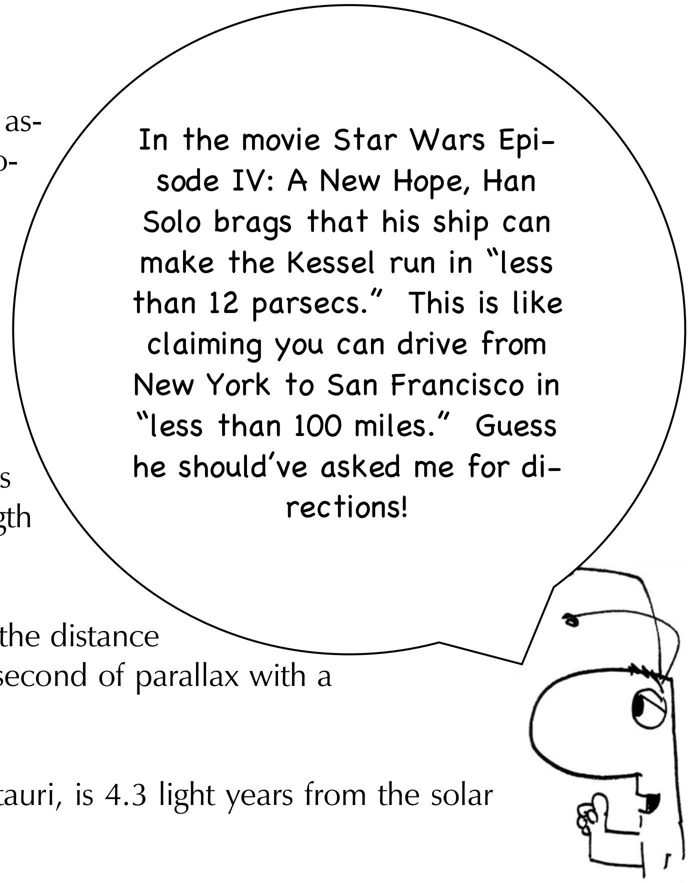
Purpose: To learn how astronomers apply parallax methods to measure the distances to stars.

Materials needed: calculator

When doing parallax calculations for stars, astronomers use a baseline of 1 AU for the motion of the earth. Then the equation becomes even simpler:

$$D = 1/p$$

Where p is the parallax angle. If the parallax angle is measured in arc seconds instead of degrees, D comes out in a unit known as **parsecs**, (parallax-seconds) a unit of length which turns out to be 3.26 light years.



A parsec is a unit of *length*. Its definition is the distance an object would have if it exhibits one arc-second of parallax with a baseline of one AU.

1. The nearest star to the earth, Alpha Centauri, is 4.3 light years from the solar system. What is its parallax?

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2. The smallest angle that is typically measured by earthbound telescopes for parallax is approximately 0.025 arc seconds. How many parsecs does this correspond to?

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3. How many light years is this?

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CA2 2C.3: Parallax of Stars: Activity

4. Certain space-based parallax systems such as the Hipparcos mission have extended parallax measurements to enable geometry based measurements much farther than ground-based telescopes. If Hipparcos measured a parallax of 0.002 arc seconds, how far away is such an object?

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5. Parallax is measured due to the motion of the earth around the sun. Thus, any parallax shift repeats over the course of a year is probably due to the earth's movement. However, the method fails when measuring double-star systems that orbit each other with a period of one year. Why?

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6. Suppose we set up an observatory on Mars to measure parallaxes. Would the results be better or worse than they are on Earth? Why?

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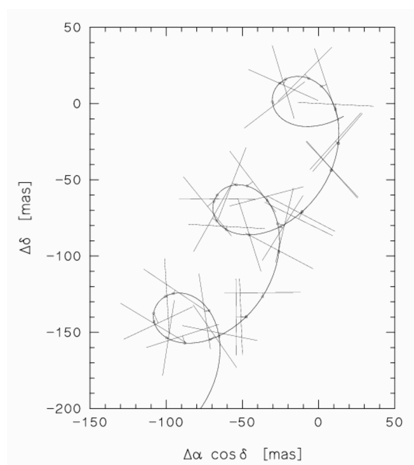
7. The position of stars being measured via parallax, if measured continuously, describe a little circle that takes 365 days to complete, as shown in this illustration by Michael Perryman. The loops are caused by parallax due to the Earth going around the sun. The diagonal motion is caused by the star's proper motion. If the star did not have proper motion, the figure would be a circle.



What do you think the star positions would look like if the star had even larger proper motion?

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CA2 2C.4: Position: Applications

Purpose: To review and practice applications of the positions of stars.

1. How many arc seconds wide is the moon? On the average the moon appears roughly one half of one degree wide in the sky.

2. How many arc seconds are there in a complete circle?

3. Suppose we increase the distance between the observations in the flag pole activity. How will this affect the parallax angle?

4. Surveyors are attempting to measure the distance across a river. The observation stations are 50 meters apart and with a surveyor's transit they measure the parallax angle of a tree across the river as 2 degrees as compared to a distant mountain. How far away is this tree?

5. Why do astronomers use arcseconds rather than degrees or radians to measure parallax?

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CA2 2C.4: Position: Applications

6. Suppose a star system is 3.26 light years away. What is its parallax? (Convert to parsecs first.)

7. Suppose the parallax of a star is 0.020 arc seconds. How many parsecs away is the star?

8. Why is there a limit to how far away parallax can be used to measure the distance to a star?

9. Why is it difficult to measure the parallax of a double star that has an orbital period close to 365 days?

10. What would the advantage of having an observatory on Mars be for parallax measurements?

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CA2 2C.4: Position Puzzle

Fill in the terms at the bottom of the puzzle. Then write the same letter in the box with the corresponding number. A quotation or phrase will be spelled out in the grid at top.

1	2	3	4	5		6	7	8	9	G	10		U	11		12	13	W	14
	15	F		T	H	16		U	N	I	V	17	18	19	20	.	-	S	I
21		W	I	22	23	I	24	M		B	25	26	G	G		T	H	27	
U	N	I	V	28	29	S	E		30	F		31	I	G	H	T			

1. P _ (24) _ (7) _ (26) _ (1) _ (22) A X — POSITION BY TRIANGULATION
2. P A _ (18) _ (10) _ (13) C — PARALLAX SECOND = 3.26 LIGHT YEARS
3. _ (23) _ (2) _ (3) _ (4) _ (5) Y _ (16) A _ (21) — DISTANCE LIGHT TRAVELS IN A YEAR (2 WORDS)
4. _ (6) A _ (11) _ (17) _ (31) _ (8) _ (9) _ (20) — DISTANCE BETWEEN 2 SEPARATED OBSERVING POINTS
5. P _ (25) _ (15) P _ (27) _ (29) — INTRINSIC MOTION
6. A R C _ (14) _ (28) C _ (30) _ (12) D _ (19) — 3600 OF THESE EQUAL ONE DEGREE

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CA2 2C.4: Position Puzzle

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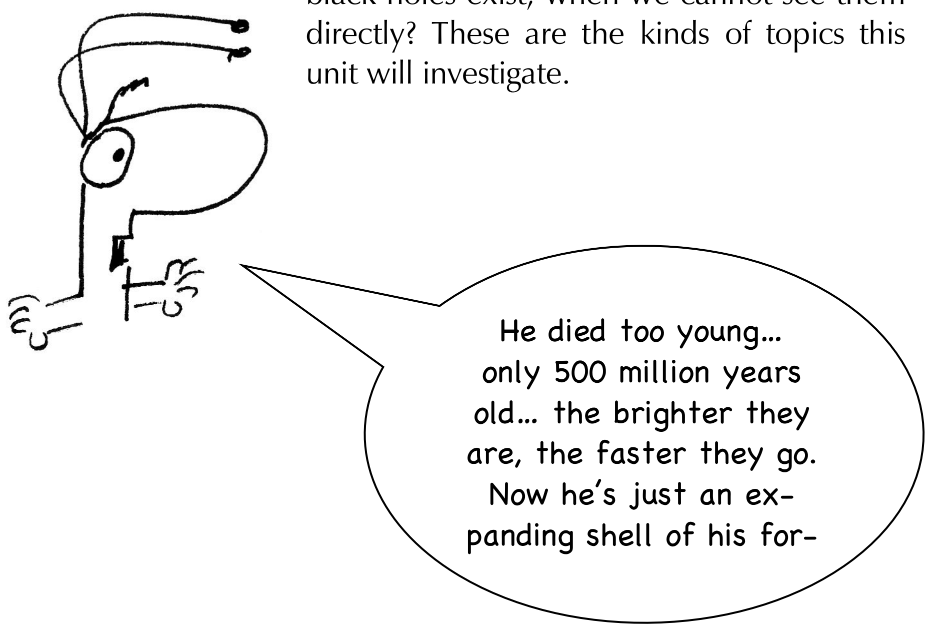
Conceptual Astronomy 2 Unit 3: Lives & Deaths of Stars

This unit collects what we have learned about how to *measure* stars, and draws conclusions from the patterns of the measurements. In what ways are giant stars alike? In what ways do we expect stars to die? What are neutron stars and black holes? How do we know black holes exist, when we cannot see them directly? These are the kinds of topics this unit will investigate.



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CA2 3.0: Lives and Deaths of Stars Objectives

At the end of this unit, students will be able to:

1. State the effect mass has on the evolution of a star.
2. Sketch an H-R diagram and identify the main sequence, giants, dwarfs, the location of the sun and white dwarfs.
3. Roughly describe the behavior of a star as it leaves the main sequence.
4. Describe the stages of evolution of a star smaller than the sun, a star about the size of the sun, and stars that are giant and supergiant with respect to the sun.
5. Visually identify basic stages of stellar evolution in photographs.
6. Use the HR diagram to argue for the existence of giants and dwarf stars.
7. Describe escape velocity and solve problems about it given the formula.
8. Estimate the age of a cluster of stars based on its H-R diagram.
9. Distinguish between novas, type Ia supernovas, and type II supernovas.
10. Explain the process used to create a light curve for a variable star.
11. Describe the various kinds of light curves.
12. State the Stefan-Boltzmann law.
13. Describe what happens in a classical nova.
14. Discuss conceptually how astronomers perform spectroscopic parallax.
15. List the spectral classes in order of decreasing temperature.
16. Discuss the concept of the cosmic distance ladder.
17. Describe the event horizon of a black hole.
18. State the relationship of the four fundamental forces of nature to the formation of black holes, neutron stars, white dwarfs, and normal stars.
19. State what evidence leads us to believe supernovas are rare.
20. Define the following terms:

Binary system
Black dwarf
Black Hole
Cepheid variable
Dark nebula
Electromagnetic force
Electron degeneracy pressure
Emission nebula
Escape Velocity
extrapolate
Field star
Flowchart
Giant
Gravitational force
H-R diagram
Interpolate
Magnetar
Main sequence star
Neutron star
Nova (classic)
Open (Galactic) Cluster
Period luminosity relationship
Planetary nebula
Protostar
Pulsar
Red Giant
Spectral class
Standard Candle
Standard star
Stefan-Boltzmann Law
Stellar evolution
Stellar nursery
Strong nuclear force
Subraster
Supergiant
Supernova remnant
Type Ia Supernova
Type II Supernova
Weak nuclear force
White dwarf

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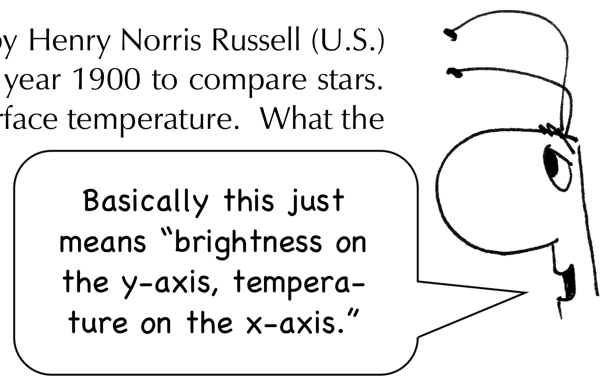
CA2 3.1: The Jewel Box: Lab

Purpose: To plot a basic Hertzprung-Russell diagram and note its features, as well as estimate the age of the Jewel Box cluster.

Background:
This activity is based on the "Jewel Box Cluster" activity developed by the National Optical Astronomy Observatory and is used with permission. The National Optical Astronomy Observatories web site for this project in its original version is located here: http://www.noao.edu/education/jewels/home.html. Color images of the cluster and measurement scales are required to complete this activity and can be found on the Teacher's Guide binder and can be downloaded from the site above.

H-R diagrams were independently invented by Henry Norris Russell (U.S.) and Ejnar Hertzprung (Denmark) around the year 1900 to compare stars. Basically they are a graph of luminosity vs. surface temperature. What the periodic table is to chemistry, the H-R diagram is to astronomy. They show the relationship between a star's intrinsic luminosity (how much light it emits) and its spectral class, color, and temperature. They are so informative and generally useful it is important you understand them thoroughly.



In this exercise, you will plot the color and brightness of a sample of stars from the Jewel Box Cluster to determine its approximate age.

Equipment needed: For this activity you will need:

- Color print of the Jewel box Cluster in a page protector (must be printed in color)
- washable or erasable marker
- Star Gauge (must be printed in color)
- graph sheet
- student answer sheet

Procedure:

1. Examine the print of the Jewel Box Cluster provided by your teacher. Do all the stars appear to be the same color?

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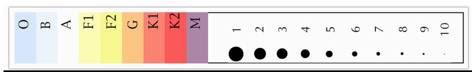
CA2 3.1: The Jewel Box: Lab

2. Estimate where the edge of the cluster lies. Make sure the color print of the cluster is inside a page protector so it can be used again. Outline (on the page protector) where you think the boundaries of the cluster are with the marker.

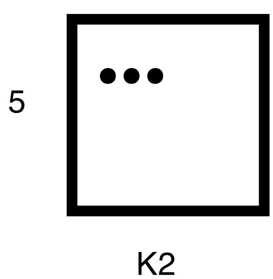
3. Place an "X" where you estimate the center of the cluster of stars to be and use a ruler to draw a 4 cm square about this center point. Measure the brightness of the star closest to the upper left hand corner of your square from its size in the image in comparison to the dots on the Star Gauge. Have your lab partner estimate the star's color using the color portion of the Star Gauge and place a filled-in dot on the graph provided in the box that corresponds to the brightness and color you have measured for your first star.



The Jewel Box Cluster. This is the picture you will be analyzing, but you must use a color version provided by your teacher.

Estimate how many stars are in the box.

Please note: you are not *plotting* the stars here. You are placing them in categorical *bins*. Each box on the chart corresponds to a star of a particular brightness and a specific color. The boxes are *containers* and you are putting a dot, representing a star, in a box. Thus, each box can hold several stars, and they should be drawn as separate dots so you can keep track of how many you have identified. For example, here is the box on the answer grid representing a star of color K2 (red) and size 5, containing 3 stars of that size and color you have located and classified so far.



Place a dot with your marker on the star you have just measured and then proceed in some systematic fashion to **measure and mark on your chart (on the last page of this activity) the brightness and color of every star within your 4 cm square.**

4. Do the Jewel box stars on your graph appear to be randomly scattered or do they fall in any kind of pattern?

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CA2 3.1: The Jewel Box: Lab

5. The reason astronomers like to analyze clusters is that it eliminates interfering variables when comparing stars. Presumably, all the stars in the cluster (not including the field stars) are at the same distance from us. What does that tell us about the bright stars in the image compared to the dim stars?

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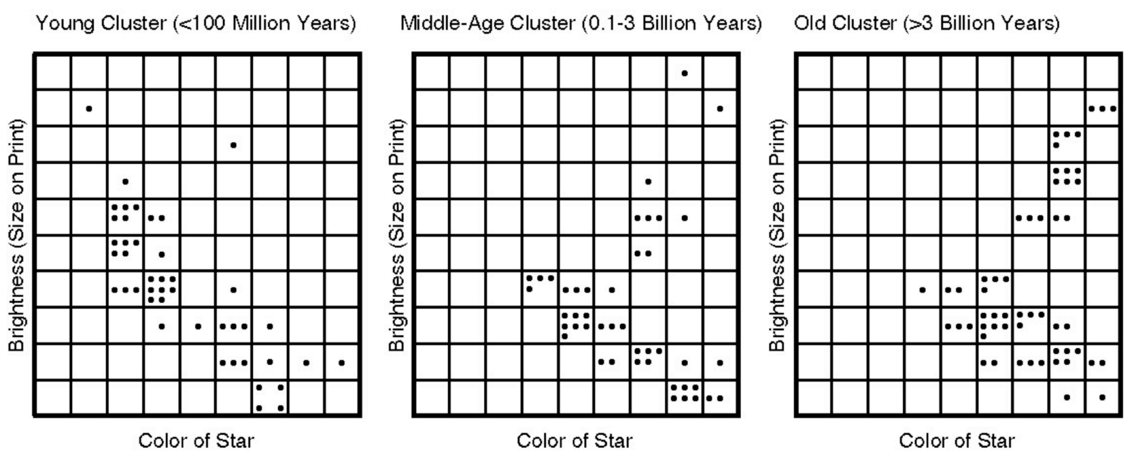
Another interfering variable that clusters control is *age*. The theory is all the stars in the cluster were formed more or less at the same time from the same nebula. Thus, differences between the stars are due to their intrinsic structural differences rather than distance from us or age. This includes things like the spectral class of the stars, their temperatures, overall luminosity, and so on.

Estimating the Age of the Jewel Box Cluster

Newly formed stars occupy a band in your graph from the upper left corner to the lower right corner. The most massive stars are hot (blue) and bright. The least massive stars are cooler (red) and dim. This band of stars is called the **main sequence.** Main sequence stars fuse hydrogen and are relatively stable. The sun is a main sequence star. Stars spend most of their "lives" on the main sequence.

The diagram below shows how the shape of the H-R diagram will change based on the age of the cluster.



When stars live out their lives and become old, the gravitational forces tend to collapse the star and internal heat forces that tend to expand a star get out of balance. This imbalance leads to the "death" of the star. When the most massive stars (the blue, giant stars) die, they will expand and cool, changing color and leaving the main sequence. The stars "peel off"

CA2 3.1: The Jewel Box: Lab

the main sequence from upper left, to lower right, in order. This forms an “elbow” on the diagram. The stars in the pointy corner of the elbow are about to die. If all the stars in the cluster were formed together, the “elbow” corresponds to the cluster’s age.

6. Using the sample graphs on the graph worksheet, estimate the age of the Jewel Box Cluster.

7. Describe the visual appearance of a very old cluster.

8. What kind of diagram would result if we plotted stars selected randomly from all over the sky, and why?

Field Stars (Optional)

9. Stars in front or behind the Jewel Box that are not part of the cluster also appear in the image. Astronomers call these **field stars.** If time allows, estimate how many of these stars are included in your measurements by drawing a 4 cm square near the edge of the print and measure the color and brightness of the stars within this square. Mark these stars on your brightness-color diagram using an "x" instead of a dot.

Do the field stars appear to fall randomly on your diagram or do they appear to fall in any kind of pattern?

10. Compare your answer to Question 4 and Question 5. Why do you think the similarities or differences between the two star patterns exist?

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CA2 2C.3: Parallax of Stars: Activity

Plot your data on this chart.

Brightness (Size on Print)

1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
	O	B	A	F1	F2	G	K1	K2	M

Color of Star

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CA2 3.2: Near vs. Bright Stars: Lab

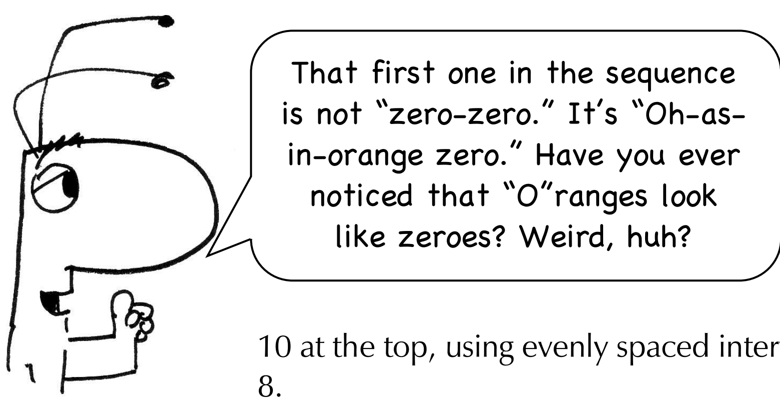
Purpose: To plot a Hertzprung-Russell diagram for the twenty nearest stars, the twenty brightest stars, and compare them; to learn about the relationship between luminosity and

Materials needed: Distance-luminosity data table for the nearest and brightest stars, H-R diagram graph grid, pencil, and a scientific calculator with a log function key.

This lab is adapted from the Distances and Properties of Stars activity, Ch. 12 of Modern Astronomy by M.K. Hemenway and R. Robert Robbins.

Plotting the H-R diagram:

1. On the chart provided on the last page, label the axes as follows:
   a. On the horizontal (x) axis write "Spectral Class: temperature". Label the scale O through M, leaving space for 5 or 10 divisions between letters. O should be on the left, M on the right. By tradition, H-R diagrams proceed from hot to cold. That will look like this:
   O0…O2…O4…O6…O8…B0…B2…B4…B6…B8…A0…etc. out to M9.



Make the entire scale from O0 to M9 fit in your graph. It will probably work better if you go by 2s.

b. On the vertical (y) scale write "Absolute Magnitude". Label the scale from 20 at the **bottom** to -10 at the top, using evenly spaced intervals such as 20, 18, 16, 14....-4,-6,-8.

2. Plot the "Absolute visual magnitude" of each star vs. the spectral class for the twenty closest stars. Use a nice, *small* clean point "•" for each star plotted. Also include the sun, which has an absolute magnitude of 4.6 and is spectral class G2. Use a star shape for the sun. 

Note: the Roman numerals next to each spectral class (I-V, usually) refer to special zones on the chart and for the purposes of this activity, you can ignore them.

3. Plot the absolute magnitude and spectral classes of the twenty brightest stars, but this time use a small "**x**" for each point plotted. Answer the questions on the following page.

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CA2 3.2: Near vs. Bright Stars: Lab

Questions

1. Which set of points is a better representation of average stars? How do you know?

2. As far as *local* stars are concerned, is the sun very bright?

3. As far as the *brightest* stars are concerned, is the sun very bright?

4. What kinds of stars are more common? Explain carefully.

5. Why are the magnitude numbers in reverse order compared to a normal graph?

6. In the diagram it should be obvious that there is a band of stars moving from the upper left to lower right. This is called the MAIN SEQUENCE. Label it on your diagram.

Are most of the stars you plotted on or near the main sequence?

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CA2 3.2: Near vs. Bright Stars: Lab

Notice the *brightest* stars. Some are main sequence, some are not. Note in spectral class K, there are some stars which are M=0 and some which are M=7. The first star is about 600 times brighter than the second. Both stars have about the same surface temperature (since they are in the same spectral class) so this means, square meter for square meter, they are about the same brightness at their surfaces. For one of them to be brighter, therefore, it must be LARGER. About 600 times the surface area, in fact. This works out to be about 25 times the sun's radius in the case of the red giant Aldebaran.

Therefore you can see that the H-R diagram implies that there must be *Gigantic* Stars.
even more extreme cases exist. M class stars can have an absolute magnitude of 10, and also as small as -5. This is a factor of 1,000,000 in luminosity, so the brighter star must have that much more surface area, and is therefore called a SUPERGIANT. The star Antares is wider than the diameter of Mars' orbit!

7. The corners of the H-R diagram represent four different domains where stars could lie. Note on your axes where HOT, COOL, DIM, and BRIGHT stars must reside. Also on your graph, note where Supergiants, Giants, Main Sequence, and White dwarf stars reside. Here is a guide:

Main Sequence – stars which are fusing hydrogen in their cores like the sun does. These stars appear in the H-R diagram in a diagonal running from extremely HOT BRIGHT stars in the upper left corner to extremely COOL DIM stars in the lower right.

White Dwarfs – these stars have ended their lives by running out of fuel and are glowing mainly by residual heat. While small, they are also extremely bright because in their condensed state, their surfaces concentrate the remaining heat and glow white-hot. They are DIM and HOT.

Giants – Stars which are in the giant phase are nearing the end of their life by expanding and becoming what is known as **Red Giants.** They are larger, and COOLER than average main sequence stars, yet their immense size makes them overall emit more light, thus they are BRIGHT. GIANTS can be either Red (right side) or Blue (left side).

Supergiants – Supergiant stars are even HOTTER and BRIGHTER than giants, having formed from a larger star to begin with.

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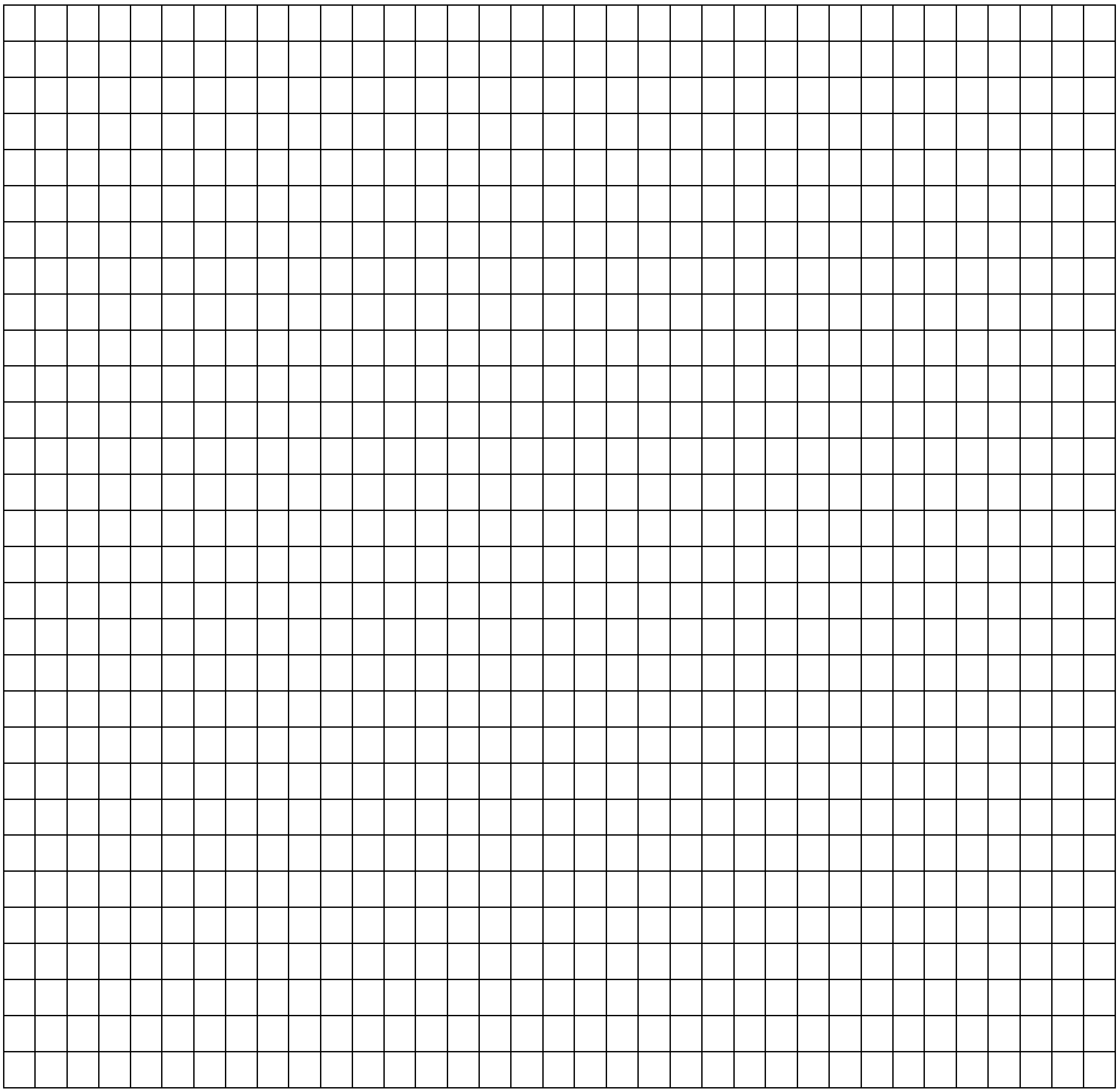
CA2 3.2: Near vs. Bright Stars: Lab

Grid for plotting HR diagram



Label Checklist (all of these things should be somewhere on the chart:
__Main Sequence__ White Dwarf __ Blue Giants__ Red Giants __ Supergiants __ Sun __ OBAFGKM __ Absolute magnitudes -20 to +10 ___ HOT/COLD __ DIM/BRIGHT

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CA2 3.3 The Stefan-Boltzmann Law: Activity

Purpose: to investigate relationships in the H-R diagram quantitatively using the Stefan-Boltzmann Law to learn how big stars and how small stars can be.

Materials needed: H-R diagram from previous activity, or from a text. Calculator.

Background:

The Stefan Boltzmann Law

We learned earlier when discussing Wien's Law that when a star is hotter, its peak wavelength shifts towards the blue. This makes blue stars hot and cool stars red. We noted at the time, without details, that it is also true that when two stars are compared, the hotter one will be brighter in *every* color. However, we did not discuss the reason for this difference. The explanation lies in the **Stefan-Boltzmann Law**, which says that the brightness of a star at a particular wavelength is brighter when it is hotter.

The exact relationship between luminosity, radius, and temperature of a star is equal to the energy output per square meter times the surface area of a star in square meters, or

$$L = 4\pi r^2 \sigma T^4$$

Where L is the luminosity or brightness, r is the radius of the star, pi=3.14, sigma (σ)= a constant known as the Stefan-Boltzmann constant, and T is the temperature of the star in Kelvins.

We will only be using this law to *compare* stars, so in setting up ratios the sigma constant will always cancel out. All questions you may be asked about will therefore be solved using this ratio, comparing star A to star B:

$$\frac{L_A}{L_B} = \frac{4\pi r_A^2 \sigma T_A^4}{4\pi r_B^2 \sigma T_B^4} = \frac{r_A^2 T_A^4}{r_B^2 T_B^4} = \left(\frac{r_A}{r_B}\right)^2 \left(\frac{T_A}{T_B}\right)^4$$

These ratios can be interpreted as: L_A/L_B = how many times brighter is A than B; r_A/r_B = how many times larger is A than B, and T_A/T_B= how many times hotter is A than B.

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CA2 3.3 The Stefan-Boltzmann Law: Activity

Conceptual Questions

1. Which kinds of stars are intrinsically brighter? Circle the right answer.

Larger stars	Smaller stars	(same temp)
Hotter Stars	Cooler stars	(same size)
Large hot stars	Small cool stars	

2. Which variable causes the greatest amount of brightness increase with the smallest amount of change?

Size (radius)   Temperature

3. The Stefan-Boltzmann Law teaches us that if two stars are the same temperature, yet one is brighter, it must be

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4. The Law also tells us if two stars are the same size, yet one is hotter, it must be

____

5. Use the Stefan-Boltzmann law and the H-R diagram to argue that giant stars MUST exist. Specifically address the existence of stars on the far right of the diagram at the top right and the bottom right.

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Quantitative Questions

6. What is the ratio of brightness of the smallest and largest magnitudes on the chart? This indicates that stars come in an enormous range of brightnesses.

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CA2 3.3 The Stefan-Boltzmann Law: Activity

7. If two stars have the same temperature but star A is twice as large in radius as star B, how much brighter will the larger star be? Show your reasoning.

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8. If two stars have the same radius but differ in temperature by a factor of two, how much brighter will the hotter star be?

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9. If two stars have the same radius but differ in temperature as follows, compare their brightness.
Star A = 2000K; Star B = 5500 K

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10. If two stars have the same temperature, but differ in radius as shown, compare their brightness ratio:

Star A = 1,000,000,000 m radius
Star B = 1,250,000,000 m radius

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11. What the H-R diagram tells us is that if you compare stars at the top and bottom of the H-R diagram but with the same spectral class (say M), then they will be the same ___________________ but different ______________________.

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CA2 3.3 The Stefan-Boltzmann Law: Activity

12. If two stars have the same spectral class but vary different by temperatures, then which star is larger? How do you know?

13. Use a similar line of argument as you used to show giant stars must exist to explain how we know dwarf stars must exist.

Challenge:

14. Look up the spectral class of Betelgeuse and its temperature in the appendix in the back of the book. Next look up the temperature of the sun (spectral class G2.) Next, look up the absolute magnitude of Betelgeuse and the sun and compute their Brightness (or Luminosity) ratio. With this information, you can calculate the size of Betelgeuse compared to the sun.

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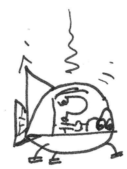
CA2 3.4: *Are Stars Alive? Activity*

Purpose: To draw an analogy between the life cycles of stars and people.

Background: We often speak of stars as if they are alive. We refer to star birth, star death, and the lives of stars. They are not alive, of course; they simply have a beginning and and ending, and thus the "life" comments are just an analogy.

This is a useful analogy. It also helps us understand the dilemma that astronomers face when trying to piece together the story of a star's life, because we humans do not live long enough to witness the entire cycle of a star's evolution.

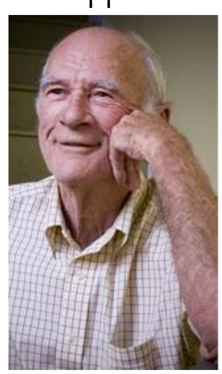


Imagine the problem faced by an alien who visits the earth, tasked with learning the life cycle of humans, but given only a short amount of time to figure it out—say, fifteen minutes.

The logical approach would be to scan the planet for a large group of humans to examine, with the goal of sorting them into groups. Luckily, upon approach to our planet, the aliens discover thousands of humans all grouped together in an open-air structure, easily photographable for later analysis. (We call this "a sports stadium.")

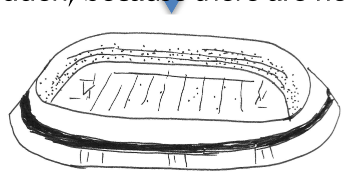
Now, armed with a large collection of human faces, the aliens attempt to sort them into chronological order.

From this sorting they determine there are large numbers of humans that vary in outward appearance (skin color/hair/clothes) but are all about the same size. A few humans are tiny, and exist in a continuum of sizes but beginning with a certain minimum size.



Other humans are probably aged, because of various infirmities as shown by aids such as wheelchairs and, perhaps (incorrectly) glasses.

By comparing the number of children to adults, the aliens could conclude the youthful state of human growth is short, and the adult phase is very long (explaining why there are more adults than children.) Similarly, the decay of humans must be relatively sudden, because there are not many extremely aged-looking humans in the collection. The assumption that the humans are naturally sorted into a representative sample of the larger society is not 100% certain; so there would be discussion of some unseen and as yet undiscovered phase of human life.



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CA2 3.4: Are Stars Alive? Activity

This is exactly the same problem astronomers face when looking at stars. We do not (even our civilization does not) live long enough to see a star form, live, and die, so we can keep records of it. Instead, we must look at samples of stars in various stages of their lives and attempt to sort them into developmental order based on logic, what we understand of nuclear physics, and the occasional event that shows a transition such as a supernova or the formation of a black hole.

That being said, we have snapshots of what we believe to be stars in every stage of evolution.

Use what you have learned from class lectures or the internet to match the descriptions below to the examples given.

Stage	**What happens (depends on initial mass)**	**Example(s)**
Prior to starbirth	Dark nebulas condense under internal gravity	
Protostar formation	Within emission nebulas, "pil-lars" with protostars form	
Star "Birth"	Stars ignite with nuclear fusion	
Star "Life"	Stars sit on the main sequence, burning hydrogen	
Star "Near Death"	Hydrogen runs out; star burns helium and turns into red giant or supergiant	
Supernova "Death"	Supernova, Planetary Nebula, or white dwarf	
After-Death stage	Neutron star/pulsar forms; black holes; white dwarfs grad-ually fade	

Examples: (sort and fill in the table above)

T-tauri star, Pillars of Creation, Orion Nebula, Cygnus X-1, Pleiades, Antares, the Sun, The Coal Sack nebula, the Horsehead Nebula, The Lagoon Nebula, globular clusters, The Ring Nebula, Betelguese, the Eskimo Nebula, Sirius B, Crab Nebula, the Saturn Nebula

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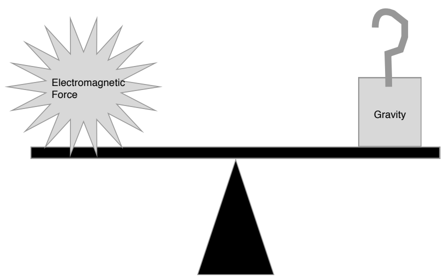
CA2 3.5: Star Death: Activity

Purpose: To provide an overview of the kinds of way a star can die.

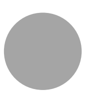
Background: The mass of a star completely determines the fate of a star. Small stars die quietly; large stars die violently.

Let's begin by looking at the process by which stars die in the first place. Stars create energy through nuclear fusion, combining hydrogen atoms to make helium and releasing energy in the process. While the star is fusing hydrogen, it resides on the main sequence of the H-R diagram, and the electromagnetic forces (radiation) trying to cause the star to expand are balanced by the contraction caused by gravity. However, since stars are finite in size, they will eventually run out of fuel.



The death stage of a star begins with the loss of energy in the core of the star. Just like a hot-air balloon, the star's heat *inflates* it. Later, when the heat source is gone, the star responds by *contracting* at first due to the loss of heat, which causes the interior of the star to compress. The compression squeezes together the helium ash in the core of the star.

In stars smaller than 0.7 times the mass of the sun, this is more or less the end of the star. The compression of a lightweight star is not sufficient to cause further nuclear reactions in the core, so the star simply shrinks, gradually cools off, and dies.



As it reaches its new state of equilibrium, the material in the star is under tremendous gravitational pressure. Stars with up to 1.4 times the mass of the sun will shrink to become approximately the size of the earth; under this compression normal matter cannot exist as regular atoms and it becomes what is known as **degenerate matter,** in which the atomic structure of atoms in normal matter is lost, with nuclei swimming in a sea of disassociated electrons. The electrons cannot occupy the same space at the same time, so they support the mass of what is known as a **white dwarf** through what is known as **electron degeneracy pressure.**

Eventually, the heat of the white dwarf will radiate into space, but this process takes a long time. Theoretically white dwarfs will eventually turn into a **black dwarf**, but astronomers do not think that any black dwarfs have had time to cool off.

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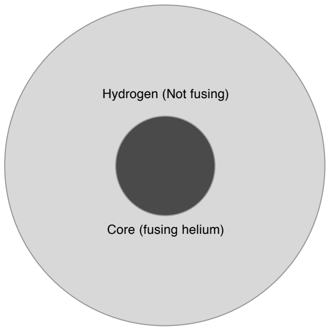
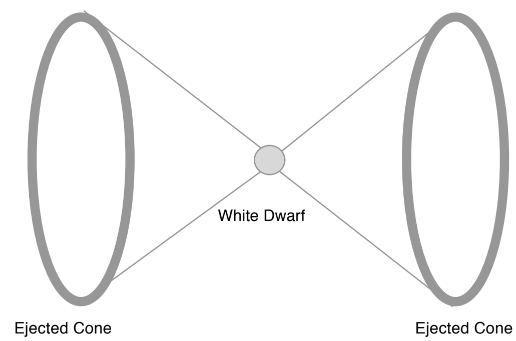
CA2 3.5: Star Death: Activity



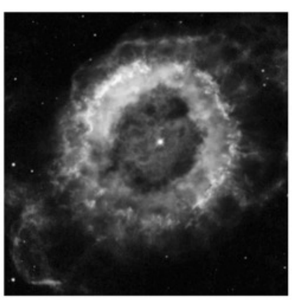
Stars that are slightly smaller than the size of the sun and somewhat larger, up to about 7-8 times the mass of the sun, will die in a slightly more spectacular fashion. After the initial collapse phase, the star can cause the core to reignite with additional nuclear fusion. This time, helium fuses into carbon. Helium fuses *hotter* than hydrogen, causing the star to re-inflate to be even larger than it was before, turning into a **red giant**.

The red giant phase of the star's life is short; there are fewer helium atoms in the core of the star than there were hydrogen atoms (recall it takes 4 Hydrogen to make 1Helium).

Helium fusion is unstable. Small changes in temperature can greatly affect the rate of reaction. Eventually, the reaction rate grows so much that the star essentially overheats and blows off its outer layer, forming what is known as a **planetary nebula.** Planetary nebulas eject material typically in cone-shaped arrangements with an increase in density and emission at the leading edges, making them appear as rings, overlapping circles, or bow-ties seen from the side. The photo shows a planetary nebula called the Ghost Nebula, seen from one end, as taken by the Hubble Space Telescope.



Side View of Planetary Nebula



Meanwhile, in the interior of the star (which still exists), the reduced mass causes a white dwarf to form, unable to sustain further fusion events. Most planetary nebulae have a small, visible white dwarf in their centers.

Stars which are 8 times the mass of the sun or larger will die a more spectacular death. After the helium core is formed, the fuel runs out eventually, and the star collapses. Unlike the planetary nebulae formed by smaller stars, the second collapse can trigger a new round of nuclear fusion in which helium forms carbon. Subsequently the carbon fuel runs out, and the star undergoes yet another round of expansion and contraction, this time triggering the formation of a carbon core, which fuses to form neon, followed by oxygen, silicon, and eventually, iron. When the core becomes iron, then the star is truly about to die. This is because iron does not give off energy when it fuses. Instead, energy is required to put into the system to make Iron fuse. Thus, a star cannot sustain itself by fusing iron.

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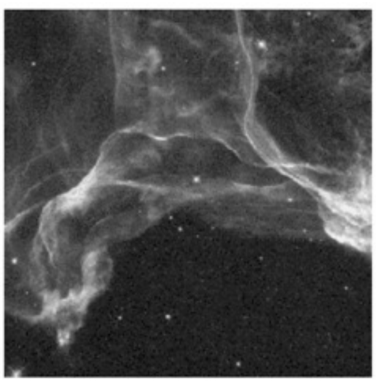
CA2 3.5: Star Death: Activity

This triggers a final collapse of the giant star. Stars from 8-25 times the mass of the sun will collapse in a final cataclysm, which takes the form of a giant shock wave from the core of the star and propagating outward, creating fusion in the elements that surround the core. The shock wave can even trigger fusion in the low-density outer regions of the star. All of this energy given off at once, caused by the core collapse of a giant star, is called a **Type II supernova**. Far more powerful than the novas or even the **Type 1a supernovas** formed in binary systems, giant star core-collapse supernovas are one of the brightest events in the universe. Such explosions may cause the star to temporarily become brighter than all the other stars in the galaxy combined.

Note, however, that the explosion does not actually occur in the core. The explosion happens in the layers above it, where elements may still fuse and generate energy to feed the explosion. The core itself is therefore subjected to an *implosion*, exploding inward, forming along the way an object that cannot be held up by electron degeneracy pressure.



In the competition between gravity and the various forces of nature, the battle rages in a supernova core. The exploding gas form a nebula, called a **supernova remnant**, which recycles elements formed in the explosion, some far beyond Iron in the periodic table, and scatters them throughout the galaxy to be recycled in a second generation star. The photo shows a section of the Cygnus Loop supernova remnant photographed by the Hubble Space Telescope.

But what about the core? In a giant star, the electron degeneracy force (essentially, this is the weak nuclear force) fails, and the core collapses until the electrons are impressed into neighboring protons. Note the following nuclear reaction:

$$p^+ + e^- = n$$

Which means that a proton, with a charge of +1, plus an electron, with a charge of -1, can combine to make a neutron, with a charge of zero.

Essentially, then, the core of such stars become giant atomic nuclei, consisting of a huge ball of neutrons. Such objects are called **neutron stars**. The strong nuclear force, regulating the adherence of nuclear particles to each other in atomic nuclei, holds these particles in place, balancing the tremendous pull of gravity.

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CA2 3.5: Star Death: Activity

As they collapse, stars retain **angular momentum**, which essentially means they have a certain amount of spin. Just like an ice skater spinning faster when she pulls in her arms, a collapsing stellar core spins faster and faster. If any charged particles remain, the spinning charges can rotate around the core (which can be as small as 20 miles across) so fast that a radio signal is generated. If we pick up this radio signal on earth, we refer to such neutron stars as **pulsars** because our radio telescopes pick up repetitive "ticks" each time the star rotates. Most neutron stars are not pulsars (at least, for us) because the alignment has to be more or less aimed at the earth for us to detect the signal.

On the other hand, giant stars that are 25 times the mass of the sun or larger (depending on the exact composition of of the star's interior prior to collapse) an even more dramatic event occurs.

In such stars the shrinking surface increases the force of gravity because each particle gets closer and closer and the force intensifies. If it overwhelms the strong nuclear force, then the star collapses further—from 20 miles across, to the size of a building—then to the size of a basketball—and even smaller, smaller than a head of a pin—until what is known as a **black hole** forms.

A black hole has so much gravity even light cannot escape it (hence it is black) and since nothing can travel faster than light, nothing material can escape either (hence it is a hole). We will explain a bit more about black holes in a later activity.

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CA2 3.6: Sorting Pictures: Activity

Purpose: To sort images of stellar evolution chronologically and learn to recognize specific stages of stellar evolution in example photographs.

Materials needed: This activity requires color images, which at the time of this writing are located at this address:

http://chandra.harvard.edu/edu/formal/stellar_cycle/image_set.pdf

The material was developed by the Education and Public Outreach office of NASA's Chandra X-ray telescope mission, and is public domain. The link will lead you to a color version of the document, which is reproduced here in black and white.

Procedure: Look at all the images and read the caption descriptions. Decide whether or not you are going to describe the life of a low-mass star, a sunlike star, or a giant star. Different people in your class may be assigned to different stellar sequences.

Use the pictures to illustrate the life cycle of a star. Decide the proper order to display the images chronologically. (They are in no particular order on the pages that follow.) Record the order you selected here. You do not need to use every card. If you are using a card set printed from the original source above, set aside the cards that have graphs on them. Record the card number and the name of the object on the card below.

Note: There is a matching activity on the last page of this handout. Make sure you do not skip it.

Mass of star you are describing: ______________________

Card Sequence: ___________________________________

Description:

Print Name ______________________________ Period __________ Date ________________

CA2 3.6: Sorting Pictures: Activity

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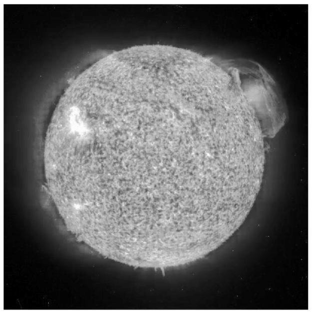

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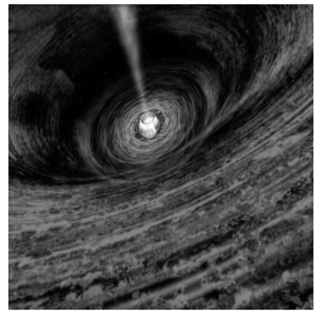

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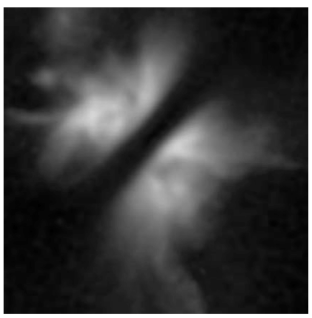

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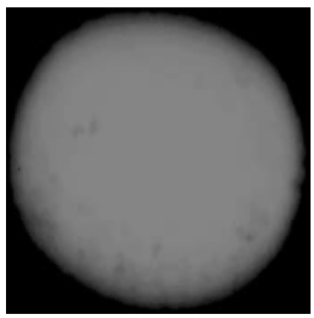

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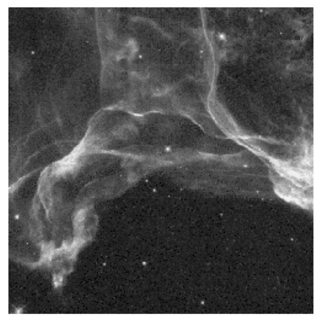

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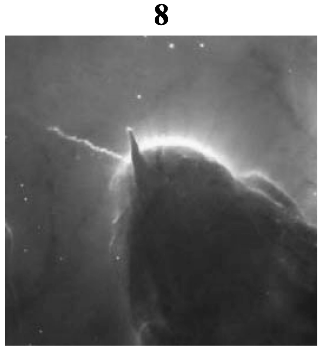

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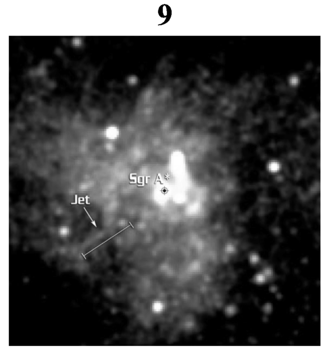

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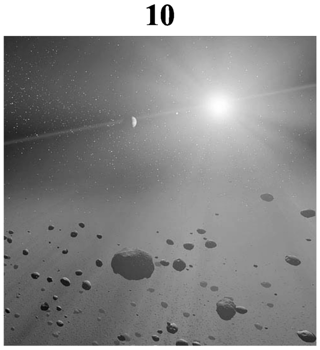

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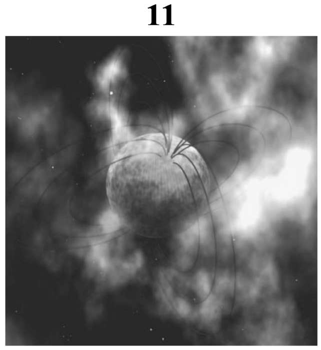

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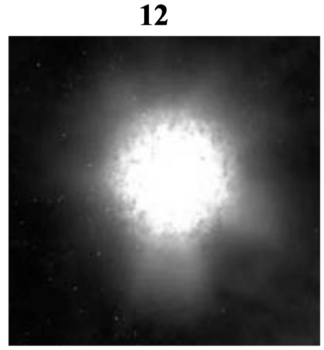

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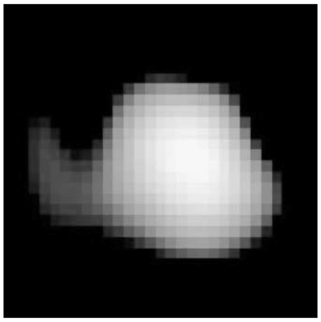

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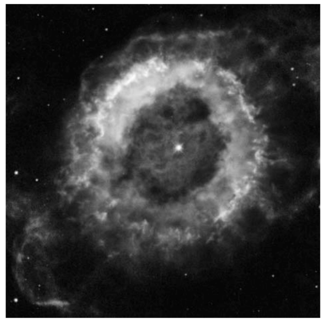

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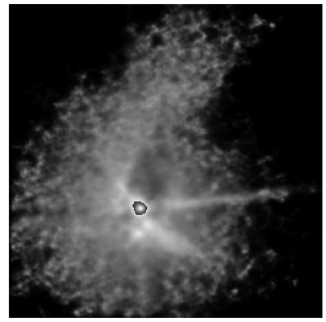

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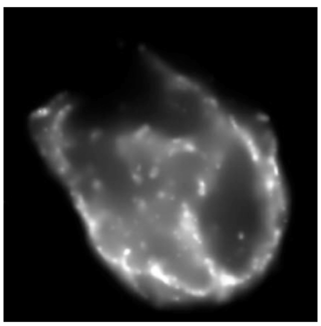

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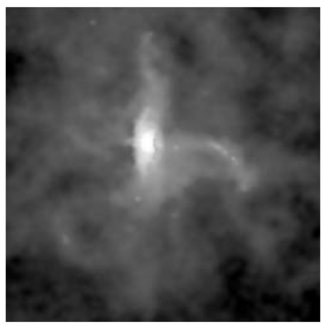

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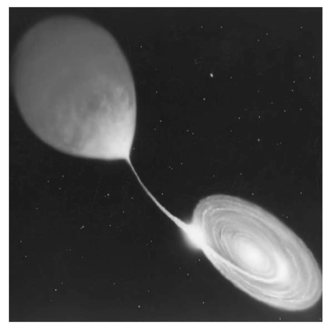

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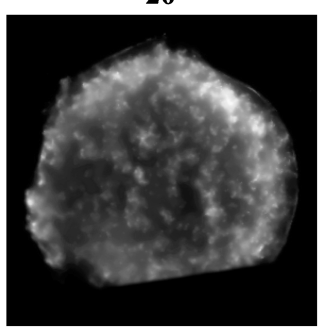

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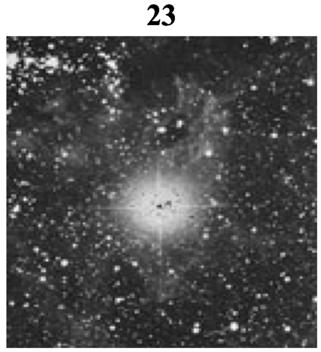

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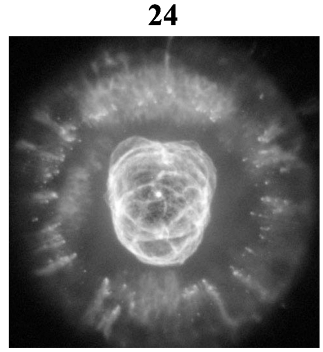

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CA2 3.6: Sorting Pictures: Activity

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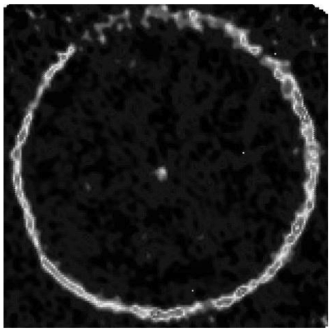

26

1. The Sun is a mid-sized main sequence star. [Solar and Heliospheric Observatory (SOHO) image] http://antwrp.gsfc.nasa.gov/apod/ap981212.html
2. Sirius B (dim object in the background) is a white dwarf in a binary system with Sirius A (bright object in the foreground) - a 2 solar mass main sequence star. [McDonald Observatory image] http://antwrp.gsfc.nasa.gov/apod/ap960902.html
3. Artist illustration of a black hole. [April Hobart, Chandra X-Ray Center]
4. Protoplanetary disk in the constellation of Taurus. [Hubble Space Telescope image] http://www.spacetelescope.org/images/html/opo9905q.html
5. Artist Dana Berry illustration used for the red supergiant stage.
6. The Cygnus Loop is the expanding debris from a supernova remnant. [Hubble Space Telescope image] http://antwrp.gsfc.nasa.gov/apod/ap010623.html
7. Massive blue stars; the Butterfly open cluster of young massive stars. [NOAO image] http://antwrp.gsfc.nasa.gov/apod/ap990106.html
8. Close-up of stellar nursery in the Trifid Nebula. [Hubble Space Telescope image] http://antwrp.gsfc.nasa.gov/apod/ap010812.html
9. The Sagittarius A black hole in the center of the Milky Way Galaxy. *NOTE: This image is included for a specific reason, to address a common misconception that all black holes are the end result of the collapse of a massive star. Sagittarius A is the massive black hole at the center of the Milky Way Galaxy. This type of black hole is not involved with stellar evolution. You can use this image as an assessment of student understanding of different types of black holes, or simply for discussion.* [Chandra X-Ray Observatory image] http://chandra.harvard.edu/photo/2003/0203long/more.html
10. NASA Artist illustration of young planetary system. [NASA, T. Pyle] http://www.spitzer.caltech.edu/images/1350-ssc2004-22a-A-Distant-Solar-System
11. Artist illustration of a magnetar - a neutron star with a super strong magnetic field. [Dr. Robert Mallozzi/University of Alabama in Huntsville, and Marshall Space Flight Center] http://chandra.harvard.edu/photo/2002/1132/index.html
12. Artist illustration used to represent a Type Ia supernova explosion. [D. Berry, Chandra X-Ray Observatory]

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CA2 3.6: Sorting Pictures: Activity

13. Mira is a red giant star. [Hubble Space Telescope image] http://antwrp.gsfc.nasa.gov/apod/ap010121.html
14. The Ghost Nebula is a white dwarf with an expanding planetary nebula. [Hubble Space Telescope image] http://antwrp.gsfc.nasa.gov/apod/ap040207.html
15. a T-Tauri star system. These protostars have violently active surfaces and will soon become main sequence stars. [Canada-France-Hawaii Telescope image] http://antwrp.gsfc.nasa.gov/apod/ap010604.html
16. N132D is a Type II supernova remnant. [Chandra X-Ray Observatory image] http://chandra.harvard.edu/photo/2002/0050/index.html
17. 3C58 is a pulsar. [Chandra X-Ray Observatory image] http://chandra.harvard.edu/photo/2004/3c58/
18. Dana Berry illustration of a red giant and white dwarf in a binary system.
19. The Omega stellar nursery (M17). [Hubble Space Telescope image] http://antwrp.gsfc.nasa.gov/apod/ap040828.html
20. The Tycho supernova Type Ia supernova remnant. [The Chandra X-Ray Observatory image] http://chandra.harvard.edu/photo/2002/0005/index.html
21. Artist Ralf Schoofs' image of the red giant stage of a Sun-sized star. www.ralfschoofs.de
22. Antares is a red supergiant star. [David Malin, Anglo-Australian Observatory image] http://antwrp.gsfc.nasa.gov/apod/ap980726.html
23. SN1987a is a Type II supernova remnant. http://www.seds.org/messier/xtra/ngc/lmc_sn1987A.html
24. The Eskimo nebula is a planetary nebula. [Hubble Space Telescope image] http://antwrp.gsfc.nasa.gov/apod/ap031207.html
25. TT Cygni is an unstable red giant star. [H. Olofsson, Stockholm Observatory image] http://antwrp.gsfc.nasa.gov/apod/ap010304.html
26. W49B is a Type II supernova remnant from a massive star that collapsed into a black hole. [Chandra X-Ray Observatory image] http://chandra.harvard.edu/photo/2004/w49b/

All images and descriptions are from the Chandra X-Ray education and public outreach page. This particular batch is located here:
http://chandra.harvard.edu/edu/formal/stellar_cycle/index.html

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CA2 3.6: Sorting Pictures: Activity

Matching Activity

As a final step, use the card descriptions to map this vocabulary list of terms related to stellar evolution with their definitions. Some of these terms will appear on the puzzle at the end of the unit.

	1. Binary system
	2. Black hole
	3. Cepheid variable
	4. Magnetar
	5. Neutron star
	6. Planetary nebula
	7. Pulsar
	8. Red giant
	9. Stellar nursery
	10. Supernova remnant
	11. T-Tauri star
	12. Type Ia Supernova
	13. Type II Supernova
	14. White dwarf

A. Big star, explodes alone
B. Collapsed stellar corpse that traps light.
C. Leftovers after an explosion.
D. Nebula that appears circular with white dwarf near center.
E. Place where stars are born.
F. Protostar about to "turn on"
G. Pulsing star that pulses faster if it is smaller
H. Red giant dumps fuel on white dwarf
I. Slowly cooling dead sun-sized star
J. Spinning neutron star.
K. Spinning pulsar with a powerful magnetic field.
L. Star made of neutrons
M. Star system with 2 suns.
N. Giant star nearing death stage

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CA2 3.7: Stellar Evolution Flowchart: Activity

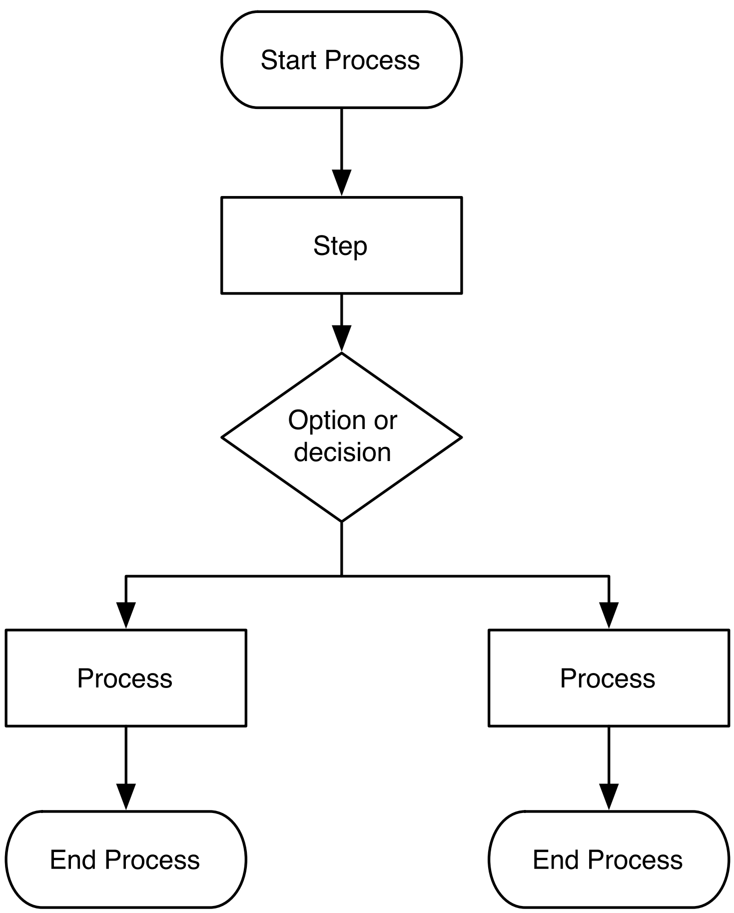
Purpose: To construct a flowchart showing the evolution of stars. Also, to distinguish the evolution of low-mass stars from medium and high mass stars.

Equipment needed: Large format paper.

Background information:

A ***flowchart*** is a diagram showing the steps in a procedure or process. The symbols below show you an example of how a flowchart is used.

Your task is to create a flowchart (or a set of flowcharts) to illustrate the stages of stellar evolution for: a low-mass star, a star with the approximate masses of the sun, a star which is larger than the mass of the sun, and a giant star far larger than the sun.



Each chart should begin with a dark nebula, and end with a stage of evolution based on its mass.

Use the following terms in your flowchart as needed. Base the sequence on the results of your analysis of stellar evolution picture sequence activity.

Dark Nebula
Emission Nebula
Protostar
Main Sequence star
Red Giant
Planetary Nebula
White Dwarf
Supernova
Neutron Star
Black Hole
Brown Dwarf

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CA2 3.7: Stellar Evolution Flowchart: Activity

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CA2 3.8: Measuring the Light Curve of a Nova: Lab

Purpose: To measure the light curve of an exploding star.

Equipment needed: Computer, set of 109 images from Nova Lab hosted by NOAO, Image J with photometry plug-in (See Appendix for instructions).

Background:
This activity is based on the Nova Search activity developed by the National Optical Astronomy Observatory. The project was developed by Travis Rector, Jeff Lockwood, and George Jacoby. Images from that project are included on the teacher's resource disk and are used with permission.

The source of the images and original instructions for this project are located here: http://www.noao.edu/education/arbse/arpd/ns.

Images were taken of the Andromeda Galaxy using the WIYN 0.9 meter telescope at Kitt Peak National Observatory near Tucson, Arizona. Approximately 109 images of the same exact section of the center of the galaxy were taken, at high resolution. (The original project slices up the galaxy into 16 *subrasters* and covers the entire galaxy. This exercise only examines one section, labeled subraster 6.)

Within these 109 images, there are several pictures of novae, or stars that explode. The exact nature of novas can vary, but typically they occur in systems with one giant star and one white dwarf star. In a classical nova, the stars are not destroyed. The giant star dumps material on the white dwarf until the material on the surface explodes. In a type Ia supernova, the explosion is more violent and destroys the stars in the system. In the images provided for this project, classical novas simply get brighter temporarily. Then they fade away. Your task is to locate a nova, measure it in comparison to several standard stars, and eventually plot a light curve.

Materials needed: Subraster 6 of Nova Search data from NOAO, Image J with astronomy package installed, computer.

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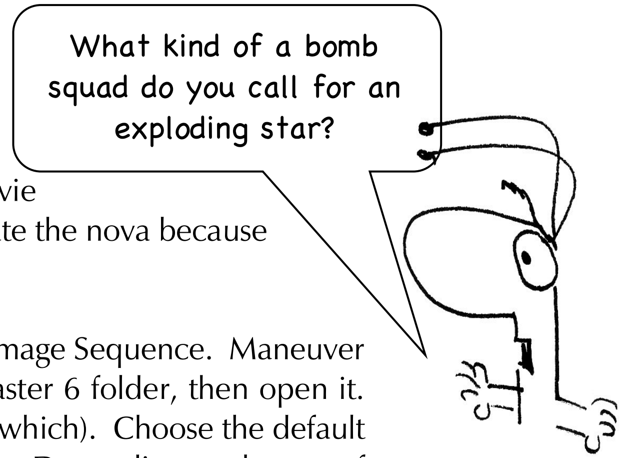
CA2 3.8: Measuring the Light Curve of a Nova: Lab

Locating a Nova



The task of locating a nova is relatively straightforward. You will load all 109 images into the Image J software and then create a movie from them. The movie will enable you to locate the nova because its brightness will visibly change.

1. From the File menu, select Image>Import Image Sequence. Maneuver through your file directory to locate the subraster 6 folder, then open it. Select any image in the folder (doesn't matter which). Choose the default setting on the computer to load all 109 images. Depending on the age of your computer this might take a few seconds to a minute or two.

2. Next, you will adjust the brightness and contrast of these images so the novas are easier to see. Use these functions:

    a. Image>Window/Level (click "Auto") and/or

    b. then Image>Adjust>Brightness and Contrast (click "Auto")

3. Now start the animation by pressing "\" (no quotes).

4. Novas can be located by observing a spot that appears suddenly, and fades away over several frames. They will look like any other star, bright in the center and not quite sharp on the edges. Other transient events on the images are due to bad pixels, cosmic rays, and so on. These will only appear once, have sharp edges, and are not good candidates for novas. Can you find the nova in the sample images on this page?

Once you have located a nova in the image sequence (if it is really close to the edge it will be difficult to measure—pick another) then stop the animation and use the slider at the bottom of the window to find it again. Then use the left and right arrow keys on your keyboard to find out exactly where the nova begins and ends. If the nova appears in less than 4 frames, it is not a good candidate for this lab (although it may very well have been a nova).

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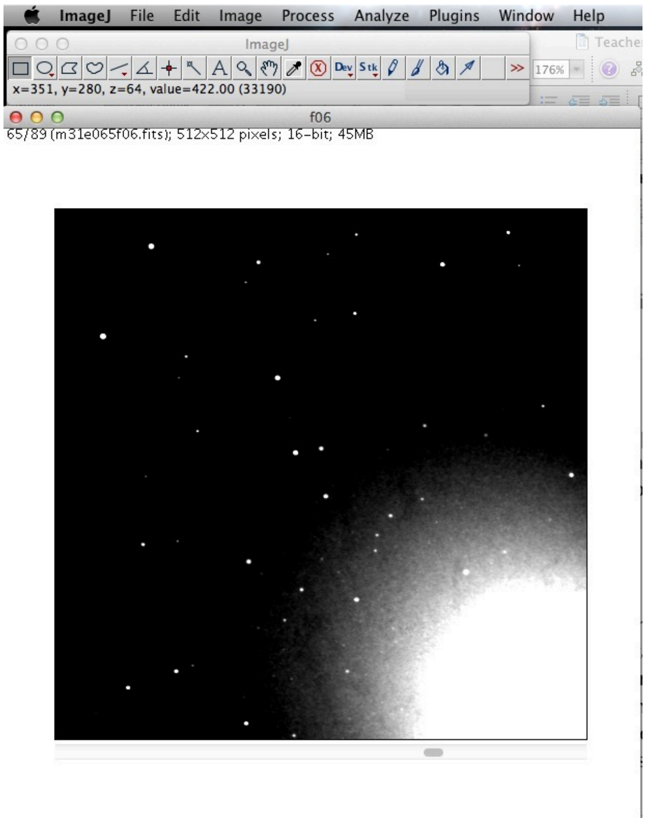

5. There is a data table for you to use on the last page of this section of the workbook.

Record the frame numbers, one in each row, where the nova appears. Also, point your cursor at the nova and note the x,y coordinates displayed under the button bar. You only have to record the x,y coordinates of the nova once, since it does not move.

About the Standard Stars

We cannot measure the magnitude of a star directly with a digital image. The magnitude must be computed in comparison to a known, standard star. In this image, there are several pre-measured, standard stars. They are shown on the reference page on the next page.

You will need to locate and measure each these standard stars as you measure the nova. Note that the magnitudes of the standard stars are given. You won't need the coordinates or the +/- values on this activity, but you will need the standard star's number and its magnitude.

Record the magnitudes of the standard stars in the Table 1.

Measure the Nova and Standard Stars

Now, in the button bar, you will see a double greater-than symbol like this: >>. Pick it and choose "Astronomy tools." The buttons will change. You will be using the one that looks like a bulls-eye, immediately to the right of the eye dropper. Select it by clicking on it once.

6. For each image in which the nova appears, do the following.

a. Click (using the Aperture tool described above) on the Nova and record its brightness ("source – sky") in Table 2. The values appear in a pop-up table that appears after the first click.

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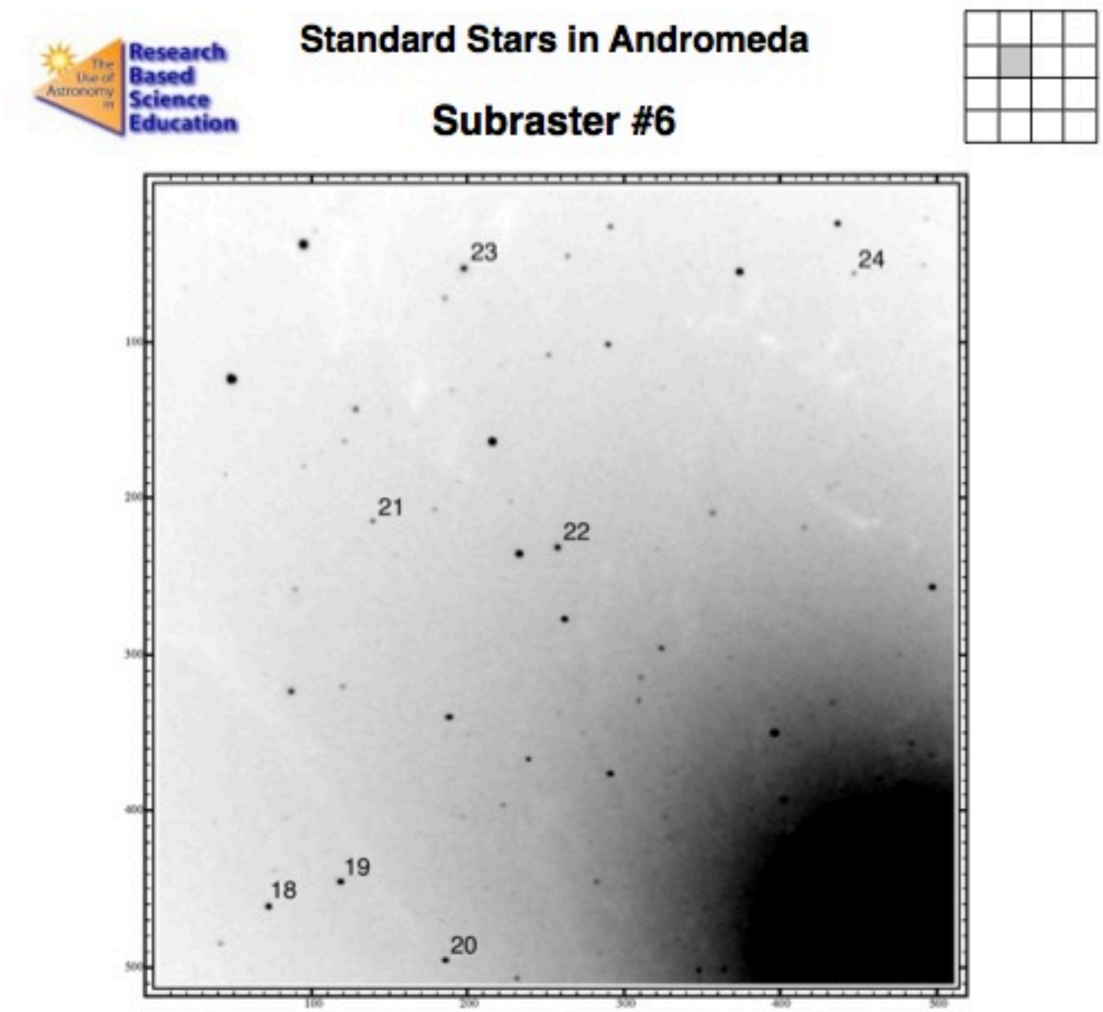
CA2 3.8: Measuring the Light Curve of a Nova: Lab

b. Click on EACH standard star and record its brightness as well. One row of the table is needed for each picture. If the nova appears in 3 pictures, you will use 3 rows.

c. Use the arrow keys on your keyboard to advance to the next image, and repeat until the nova no longer appears. Then stop.



Star #	X	Y	RA (2000)	Dec	Magnitude
18	71.1	462.5	00:43:10.83	41:16:41.3	15.14 ± 0.05
19	117.5	446.5	00:43:08.03	41:16:52.3	15.09 ± 0.04
20	184.9	497.0	00:43:03.97	41:16:17.9	15.29 ± 0.02
21	138.1	214.6	00:43:06.82	41:19:30.2	16.55 ± 0.04
22	257.1	231.4	00:42:59.61	41:19:18.8	15.45 ± 0.04
23	196.7	51.5	00:43:03.27	41:21:21.2	15.22 ± 0.06
24	447.8	54.7	00:42:48.08	41:21:19.2	16.70 ± 0.06

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CA2 3.8: Measuring the Light Curve of a Nova: Lab

Convert the Brightness Counts into Magnitudes

7. For each brightness count you measured, you will need to convert the brightness of the nova into a magnitude and record it in Table 3, the magnitude data table. Here is an example of how to compute the magnitude. We will use the formula we derived earlier for this purpose:

$$(m_{unknown}) = 2.5\log\left(\frac{BrightnessCounts_{known}}{BrightnessCounts_{unknown}}\right) + m_{known}$$

In this particular lab, it may help to relabel the equation as follows:

$$(m_{nova}) = 2.5\log\left(\frac{BrightnessCounts_{\text{standard}}}{BrightnessCounts_{nova}}\right) + m_{\text{standard}}$$

Let's suppose you measure a nova in one of the frames and determine the following, and record it in your data table:

In frame 67, standard star 23 has a brightness of ("source-sky") 150961.
The nova in the same picture has a brightness of 23046.
The magnitude of standard star 23 is 15.22 (taken from the finder chart).
The magnitude of the nova is therefore

$$(m_{nova}) = 2.5\log\left(\frac{150961}{23046}\right) + 15.22$$

$$m_{nova} = 17.26$$

Then you would record this in row 67, column "standard star 23" in your magnitude table (Table 3).
Then repeat for each standard star in the image.
Then change images, and repeat for each image.

Date Each Image, and Record the Average Magnitudes

8. Now compute the average magnitude for each frame, and record it in Table 3 at the end of the row.

9. Finally, (Finally!) look up the date each image was taken as follows. Consult the list below, and compare it to your frame numbers. Each frame of the movie you made was photographed on a different day. Record the dates in table 3 as well.

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CA2 3.8: Measuring the Light Curve of a Nova: Lab

Dates and Frames

e001: 3 Sep 1995
e002: 18 Jun 1997
e003: 23 Jul 1997
e004: 24 Jul 1997
e005: 25 Jul 1997
e006: 31 Jul 1997
e007: 1 Aug 1997
e008: 18 Nov 1997
e009: 6 Jun 1998
e010: 24 Jul 1998
e011: 25 Jul 1998
e012: 26 Aug 1998
e013: 5 Sep 1998
e014: 14 Oct 1998
e015: 30 Oct 1998
e016: 11 Nov 1998
e017: 27 Jan 1999
e018: 24 Jun 1999
e019: 20 Jul 1999
e020: 14 Jun 2000
e021: 17 Jul 2000
e022: 13 Sep 2000
e023: 14 Sep 2000
e024: 15 Oct 2000
e025: 10 Nov 2000
e026: 12 Jan 2001
e027: 15 Jan 2001
e028: 2 Nov 2001
e029: 22 Nov 2001
e030: 23 Dec 2001
e031: 25 Jun 2002
e032: 21 Jul 2002
e033: 14 Aug 2002
e034: 17 Sep 2002
e035: 20 Sep 2002
e036: 21 Sep 2002
e037: 23 Oct 2002
e038: 10 Nov 2002
e039: 11 Nov 2002
e040: 11 Jun 2003
e041: 13 Jun 2003
e042: 14 Jun 2003
e043: 15 Jun 2003
e044: 16 Jun 2003
e045: 17 Jun 2003
e046: 18 Jun 2003
e047: 4 Jul 2003
e048: 5 Jul 2003
e049: 6 Jul 2003
e050: 7 Jul 2003
e051: 8 Jul 2003
e052: 9 Jul 2003
e053: 2 Aug 2003
e054: 3 Aug 2003
e055: 30 Aug 2003
e056: 31 Aug 2003
e057: 17 Sep 2003
e058: 18 Sep 2003
e059: 19 Sep 2003
e060: 20 Sep 2003
e061: 21 Sep 2003
e062: 9 Oct 2003
e063: 13 Oct 2003
e064: 6 Nov 2003
e065: 5 Dec 2003
e066: 9 Dec 2003
e067: 10 Dec 2003
e068: 11 Dec 2003
e069: 13 Dec 2003
e070: 3 Jan 2004
e071: 6 Jan 2004
e072: 31 Jan 2004
e073: 2 Feb 2004
e074: 3 Feb 2004
e075: 24 Jun 2004
e076: 25 Jun 2004
e077: 26 Jun 2004
e078: 27 Jun 2004
e079: 30 Sep 2004
e080: 1 Oct 2004
e081: 2 Oct 2004
e082: 23 Oct 2004
e083: 24 Oct 2004
e084: 17 Nov 2004
e085: 20 Nov 2004
e086: 28 Jun 2005
e087: 29 Jun 2005
e088: 30 Jun 2005
e089: 1 Jul 2005
e090: 29 Jul 2005
e091: 27 Sep 2005
e092: 28 Sep 2005
e093: 29 Sep 2005
e094: 21 Oct 2005
e095: 22 Oct 2005
e096: 23 Oct 2005
e097: 14 Nov 2005
e098: 15 Nov 2005
e099: 16 Nov 2005
e100: 16 Dec 2005
e101: 17 Dec 2005
e102: 18 Dec 2005
e103: 20 Dec 2005

10. Next, graph the nova's **light curve** by plotting magnitude on the y-axis and the date on the x-axis. Your teacher may instruct you to convert the dates to **Julian dates** first. Make sure the dates are spaced proportionally to the time between them: A gap of two months should be twice as wide as a gap of one month. One way to do this is to type in the dates and average magnitudes into a computer program such as Excel and plot them. You can also use the grid provided in this workbook after the data tables. The use of Julian dates is optional; a modern version of Excel will plot dates correctly, spacing them according to the amount of time that has elapsed. Or you can use the graph grid provided.

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CA2 3.8: Measuring the Light Curve of a Nova: Lab

Questions:

1. Based on the classic definition of a light curve for a nova, is what you found a nova? That is, does it have a dramatic change in brightness that does not recur in a short time interval?

2. How long did your nova last, in days?

3. Could it have actually been longer? Why?

4. What is the difference between the brightest and dimmest magnitudes your nova reached?

5. What is the dimmest magnitude you can measure in this image, and how did you get this number?

6. Why is it likely you failed to capture the brightening of the nova, and only saw it getting dimmer?

7. Based on the magnitude of this nova, is it something you could have seen without a telescope? How do you know?

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CA2 3.8: Measuring the Light Curve of a Nova: Lab

MASTER DATA TABLE FOR NOVA LAB.

Table 1. Standard Star Data

Star Number	Magnitude

Subraster: 6
X,Y coordinates of Nova (these don't change):_____,_____

Table 2. Brightness Count Measurements of standard stars and nova

	Brightness counts							
Frame	Standard Star 18	Standard Star 19	Standard Star 20	Standard Star 21	Standard Star 22	Standard Star 23	Standard Star 24	Nova

Table 3. The Magnitude Data Table

	The magnitude of the nova based on the brightness of …								
Frame	Date	Standard Star 18	Standard Star 19	Standard Star 20	Standard Star 21	Standard Star 22	Standard Star 23	Standard Star 24	Nova's average

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CA2 3.8: Measuring the Light Curve of a Nova: Lab

Graph the light curve.

Notes:

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CA2 3.9: Standard Candles

Purpose: To conduct analysis to show how supernovas or Cepheid variables can be used as distance measuring tools.

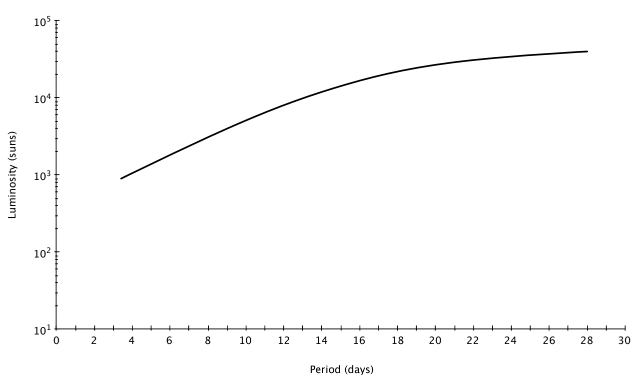
Equipment needed: Ruler; Small light bulb, power supply and light sensor OR data from brightness vs. distance lab OR camera flash and digital camera with video capability.

Background: The discovery that supernovas that are of the same type have the same maximum brightness enabled astronomers such as Edwin Hubble to measure the distance to nearby galaxies by comparing the brightness of supernovas in those galaxies to those closer to the Earth.

If we plan to investigate the effect of distance on the brightness of a target, we must first establish two facts:

1. The object we are investigating must be the same brightness everywhere it occurs in the universe.
2. The relationship between distance and brightness (the inverse square law). Presumably when you did the brightness vs. distance lab earlier in the course you verified that the inverse square law works.

With respect to #1, there are two kinds of stars that typically are used as standard candles. One is called a **Cepheid** (sef-e-edd) **variable**, a specific kind of variable star that has a special property: The larger they are, the more slowly they respond to changes inside them. Also, the larger and brighter they are on average, the slower they pulsate. Studies of nearby Cepheids have shown that there is a strong relationship between the overall luminosity of the Cepheid and its pulsation rate. This is called the **period-luminosity relationship** and was originally discovered by Henrietta Leavitt. Basically this relationship says that the brighter the star (due to increasing mass) the slower it pulsates. A slower pulsation rate is a larger period of time.



A similar rule holds for Type 1a supernovas: They have a consistent brightness because they are triggered by the white dwarf in the system accumulating a specific, known amount of mass from their red giant companions.

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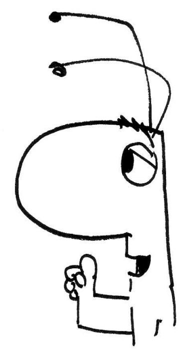
CA2 3.9: Standard Candles

The trick then, is to have a determination of how bright an object is *supposed to be* intrinsically, measure it as an *apparent* brightness and use the inverse square law to determine the distance.



Procedure:
For the purposes of this activity, the "light source" referred to below will either be the candle, small light bulb, or flash that you choose to use as described above.

Get some data:
Using the equipment listed, or old data obtained from another lab, collect data about the brightness of your light source at a variety of distances.

In the space below, explain either how you got the fresh data or how the old data was obtained. Include how the equipment worked, interfering variables controlled, etc. Describe the procedure here:

2. In this experiment, what was the

Independent variable?____

Dependent variable? ____

3. Basic hypothesis?

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CA2 3.9: Standard Candles

4. Attach at the end of this document the data table you used before (a copy is fine) or the data you collected specifically for this activity. If you are using previously measured data, *leave out the last data point you measured.*

5. Next comes the part where we apply the standard candle concept. If you are using data from a previous lab, use the brightness of the last measured data point (the one you left off from #4.) If you are using fresh data, move your sensor or camera farther away from the light than your farthest data point. Measure the brightness using the same method you describe above, and record it here.

6. Next, use the data you measured to **extrapolate,** or estimate beyond measured values, the distance. Explain your method below. It could be sketching the graph beyond the measured values and reading the number off the graph, using some sort of modeling technique involving graph straightening, or some other method. Predict the distance.

7. We have a way of verifying the method; you could use a ruler (or look up the previously measured distance). How far was the light source, as measured by a ruler?

8. What percentage error did you get?

9. What could cause your distance estimate to vary? (Don't say human error; if you made a mistake, fix it. We are talking about errors inherent to the system used.)

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CA2 3.9: Standard Candles

10. In order for astronomers to measure cosmic distances, various methods must be used. Each method must overlap a little with some other methods. For example, it is possible to measure the distance to the nearest Cepheid variable with parallax. Why is this important?

11. **Interpolation** is the estimation of unknown values from *between* data points, whereas **extrapolation** is the estimation of unknown values from *beyond* the data. Which is more reliable, and why?

12. This idea of overlapping distance-measuring methods is called the **cosmic distance ladder** and will culminate in the Hubble law presented in the next unit. Look up some other "rungs" of the cosmic distance ladder and list and define them below.

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CA2 3.10: Black Holes and Escape Velocity

Purpose: To understand more about black holes and their characteristics.

Equipment needed: Calculator

Background:
Black holes are the end state of supergiant stars that have collapsed in upon them. They have so much gravity not even light can escape (which is why they are black.) Since nothing can travel faster than light, no physical object can escape them either (which is why they are holes.)

The collapse of a supergiant star overwhelms all the other known forces of nature. In a star, the gravity of all the particles is balanced by the radiation pressure of the electromagnetic force trying to blow the star apart. In a white dwarf, gravity is balanced by the weak nuclear force and electron degeneracy pressure of the compressed matter that remains. In a neutron star, the electron degeneracy pressure is overwhelmed and the strong nuclear force, regulating individual nucleons (protons and neutrons) resists the collapse of gravity. In a supergiant star core collapse, even this force is overwhelmed. There are no other forces of nature, so in these objects, gravity wins. The object continues shrinking, with no force in the universe to stop it. Ultimately it becomes a **singularity**, a kind of exception to the normal laws of nature. This happens because as the distance between particles in the collapsing star decreases, the force of gravity increases due to the law of gravity:

$$F = \frac{Gm_1m_2}{r^2}$$

As r becomes very very small, F becomes incredibly large. As r becomes zero, F becomes infinite. An infinite amount of gravity is more than enough to stop light. Here's why:

Whenever we drop something from the surface of the earth, it increases in speed, accelerating until it hits the ground. The higher you lift something, the more **gravitational potential energy** you give it. Near the surface of the earth, this is calculated with a simple formula that assumes gravity is constant:

$$U_g = mgh$$

Where the value of g is 9.8 m/s/s, the *acceleration of gravity near the surface of the earth*. But gravity gets weaker with increasing distance, so this value is not constant as we travel into space. It gets weaker with distance. A more universal way of writing the potential energy equation is to substitute Newton's law of gravity into the potential energy equation, which yields the following (note that g is not the same as G, the universal gravity constant).

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CA2 3.10: Black Holes and Escape Velocity

$$U_g = -m_1(\frac{Gm_2}{r})$$

Note the r is not squared due to the distance traversed. Also, for simplification reasons with later steps, we defined the gravitational potential energy to be zero at infinity, thus making all values of it negative. More potential energy will be expressed as being "less negative."

Thus, if an object is lifted from the earth to infinity, and dropped onto the surface of the earth and stops at a distance r_e, (the radius of the earth), this expression shows how much potential energy it had to begin with:

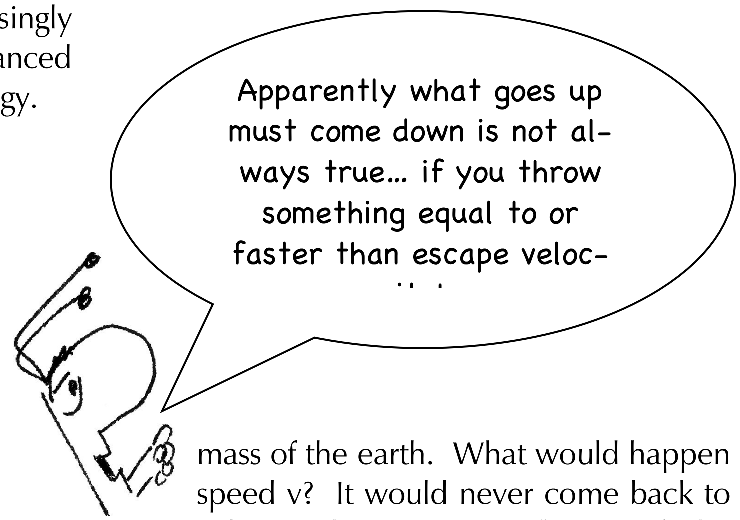
$$U_g = -m_1(\frac{Gm_2}{r_e})$$

According to the **law of conservation of energy**, energy cannot be created or destroyed but can be converted. As the object descends, its loss of potential energy will be converted into **kinetic energy**, or the energy of motion. Kinetic energy is expressed by

$$K = \tfrac{1}{2}mv^2$$

where m is the moving mass and v is its velocity. Thus, as an object gives up its potential energy through falling, it gains kinetic energy by speeding up. At infinity where the object was originally dropped, it had a total energy of zero. Just as it strikes the ground, the object has a total energy of zero (since conservation says the total cannot change) and the increasingly negative potential energy must be balanced by an increasingly positive kinetic energy.

Thus, we arrive at this condition:



This means, if we drop an object from infinity and let it strike the earth, it will not move faster than this speed v, which is not infinite and not even equal to the speed of light. M_2 in this equation is the planet's mass, or the mass of the earth. What would happen if we throw an object upward at this speed v? It would never come back to the earth. That why we call this velocity the **escape velocity** of the earth.

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CA2 3.10: Black Holes and Escape Velocity

$$U_g + K = 0$$

$$-m_1\left(\frac{Gm_2}{r_e}\right) + \tfrac{1}{2}m_1v^2 = 0$$

$$\tfrac{1}{2}m_1v^2 = m_1\left(\frac{Gm_2}{r_e}\right)$$

$$\tfrac{1}{2}v^2 = \left(\frac{Gm_2}{r_e}\right)$$

$$v^2 = \frac{2Gm_2}{r_e}$$

$$v = \sqrt{\frac{2Gm_2}{r_e}}$$

Procedure: Recall in calculations you are about to do, the following values may be useful. Look them up from the appendix and write them here:

1. a. speed of light=
   b. mass of the earth=
   c. radius of the earth=
   d. mass of the sun=
2. Calculate the **escape velocity of the earth** using the mass of the earth and radius of the earth.

____

____

____

3. Calculate the escape velocity of the sun. Use the mass and radius of the sun.

____

____

____

____

4. Calculate the escape velocity of the sun from the distance of the earth. This is the speed that must be imparted to a probe leaving the solar system from the earth.

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CA2 3.10: Black Holes and Escape Velocity

5. Now let's consider a different question. Suppose somehow, the sun turns into a black hole. (It can't, because it's too small, but it will be instructive to see how this turns out.) One definition of a black hole is an object *that has an escape velocity equal to the speed of light*. Algebraically rearrange the equation to solve for r.

6. Now consider: what would be the size of a surface where the escape velocity is the speed of light, and the mass is equal to the sun? This surface is known as the **event horizon** of the black hole. Nothing can pass over this border. It isn't a physical surface; just a location, but below this border nothing can escape. Above it, things still have a chance. Calculate r, the event horizon radius for a non-rotating naked singularity, using your equation above.

7. How large an event horizon is the black hole in the center of the Milky Way, approximately 4 million solar masses?

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CA2 3.11: Stellar Evolution Puzzle

Note: *some* of the numbered blanks from terms in this puzzle contain spaces and should be accounted for as spaces in the solution. These are marked with a grey square.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	22	23	,	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
40	41	42	43	44	45	46	47	48	,		49	H	50		51	52	53	54	
I	55		56	U	57		58	59	O	O	60	,		61	H	62		63	64
65	66	O	67		I	N		O	U	68		69	70	71	72	73		74	I
75	76		W	77	78	79		M	80	81	82		I	N		83	H	84	
I	N	T	E	85	I	O	86	87		O	F		88	O	89	90	91	92	93
I	N	94		95	T	96	97	98	.		W	E		99	100	E		M	101
102	E		O	F		103	T	104	R	105	T	U	F	F	.		–	–	
106	107	R	108		109	110	G	111	N	,		112	O	S	M	O	S		

1. _(21) _(23) _(8) K _(4) _(5) _(3) _(58) _(18) _(31) _(30) A GAS CLOUD THAT DOES NOT EMIT VISIBLE LIGHT
2. _(70) _(59) _(64) _(12) _(11) _(1) _(69) _(19) Y CIRCULAR NEBULA
3. _(76) _(34) _(71) _(27) _(42) _(15) _(9) V _(80) GIANT STAR EXPLODES
4. _(2) _(52) _(13) _(60) _(6) _(91) _(10) _(57) _(96) _(35) BRIGHTNESS VS. TEMPERATURE
5. _(65) _(45) _(81) _(16) _(94) _(14) _(99) _(22) _(7) STAR GETS LARGER BEFORE DYING
6. _(38) _(46) _(41) _(25) _(68) _(17) _(54) _(20) _(87) _(44) _(101) _(78) GIANT ATOMIC NUCLEUS- A DEAD STAR
7. _(50) _(93) _(29) _(104) _(74) _(62) _(24) V _(73) _(72) _(40) _(32) _(33) _(47) Y MINIMUM SPEED TO NEVER RETURN
8. _(66) _(89) _(107) _(63) K _(28) _(26) _(53) _(90) _(75) SO MUCH GRAVITY NOT EVEN LIGHT CAN ESCAPE
9. _(88) _(77) _(92) _(48) _(79) _(37) _(102) _(36) V _(110) _(85) _(51) _(111) B _(108) _(82) THE BIGGER THEY ARE THE SLOWER THEY PULSE
10. _(55) _(56) V A BINARY STAR TRIGGERS EXPLOSION IN WHITE DWARF
11. _(95) _(49) A _(67) D A _(86) D _(39) _(98) _(61) A _(97) COMPARISON STAR
12. _(103) P _(84) _(106) _(83) _(100) A L _(43) _(112) L A _(105) _(109) CATEGORY OF STAR BASED ON TEMPERATURE

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CA2 3.11: Stellar Evolution Puzzle

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CA2 3.12 Stellar Evolution Questions

1. What is the one factor that determines the ultimate fate of a star?

2. List the categories of stars by size and tell how each one dies.

4. Explain why, in the largest stars, gravity ultimately wins even though the strong force is stronger than gravity, particle for particle.

5. What is the difference between pulsars and neutron stars?

6. What does the rarity of giant stars tell you about the likelihood of encountering a black hole?

7. Why is it necessary to measure standard stars while measuring variable stars at the same time?

8. Suppose star A is twice as hot and twice the diameter of star B. How many times brighter is it?

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CA2 3.12 Stellar Evolution Questions

9. Describe what happens in a classical nova.

____

____

____

10. Which object do you think has the highest escape velocity: the earth or the moon? Why?

____

____

____

11. Suppose someone falls into the event horizon of a black hole. Why can't they escape?

____

____

____

12. List the three fundamental forces of nature besides gravity and the kinds of objects that are formed when they are in balance with gravity.

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13. Explain the process of measuring a variable star when standard stars are available.

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14. What is a magnetar?

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15. How does the HR diagram infer that there are giant stars?

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CA2 3.12 Stellar Evolution Questions

16. Why are Cepheids and Type Ia supernovas referred to as standard candles?

17. Of all the space objects listed in the vocabulary list at the beginning of the chapter, which one has never been observed and why?

18. Why are “emission nebulas”called “emission”?

19. How strong is the gravity in the center of a black hole?

20. Explain how supernovas are sort of like recycling centers of the universe.

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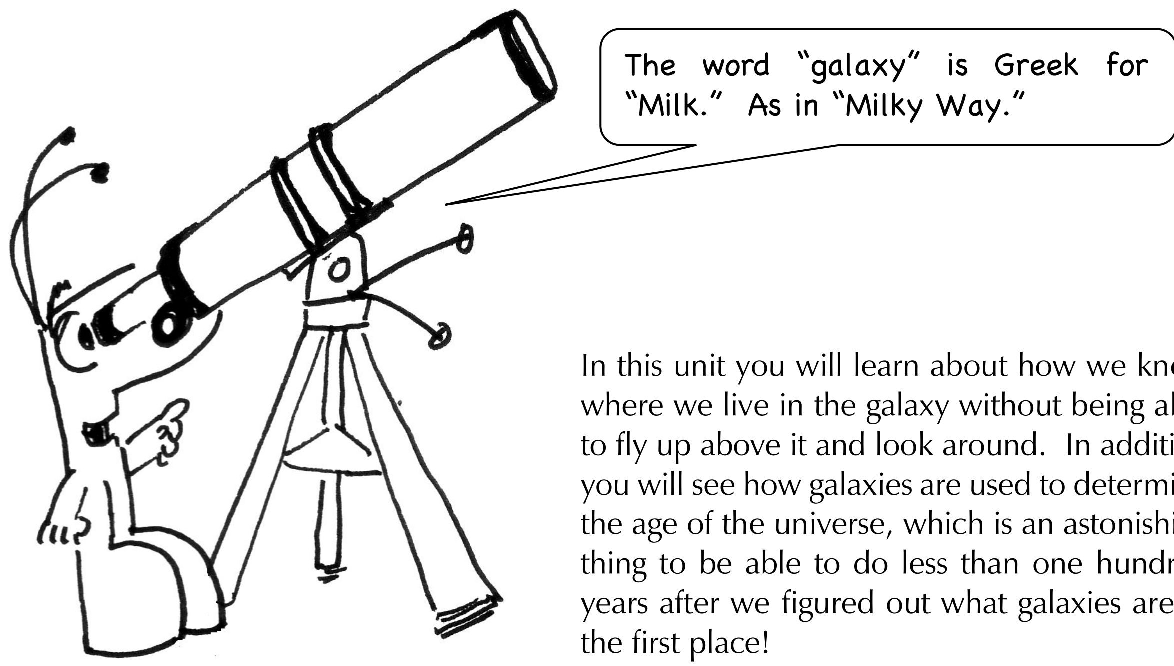
Conceptual Astronomy 2 Unit 4: Galaxies & Cosmology



In this unit you will learn about how we know where we live in the galaxy without being able to fly up above it and look around. In addition you will see how galaxies are used to determine the age of the universe, which is an astonishing thing to be able to do less than one hundred years after we figured out what galaxies are in the first place!

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CA2 4.0: Objectives: Galaxies and Cosmology

At the end of this unit, students will be able to:

1. Describe a globular cluster.
2. Describe the distribution of globular clusters around a galaxy.
3. Explain how observed globular cluster distributions around the Milky Way can be used to infer our position in the galaxy.
4. Plot locations marked in RA and dec on a graph or chart.
5. Classify galaxies according to a Hubble fork diagram.
6. Discuss the factors involved in the evolution of galaxy shapes.
7. Describe the steps needed to compute changes in position due to the gravitational influence of several objects.
8. Explain why galaxy simulations take so long to complete.
9. Explain why the 3-body problem is difficult to solve.
10. Explain how gravity, force, acceleration and velocity are used to compute movement in simulations.
11. State the mass of the black hole in the center of the Milky Way, and explain how it is found.
12. Convert arc seconds to degrees.
13. Explain how the Hubble Deep Field is used to estimate the number of galaxies in the universe.
14. Plot speed vs. time graphs for constant and accelerated motion.
15. Solve simple distance, speed and time problems.
16. Describe the rungs of the cosmic distance ladder and explain how they are dependent on each other.
17. State Hubble's Law, a modern value for the Hubble Constant, and conceptually explain how this is used to determine the age of the universe.
18. Defend the claim that we know the age of the universe; what it is based on, and how we determine the answer.
19. Describe the structure of an Active Galactic Nucleus, and what kinds of objects are explained by the unification model.

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CA2 4.0: Objectives: Galaxies and Cosmology

20. Define the following terms:

acceleration
accretion disk
active galactic nucleus
arc second
arms
barred spiral galaxy
Cepheid variable
collision (of galaxies)
declination
deep field
distance modulus
elliptical galaxy
flowchart
force
galaxy
geometric parallax
globular cluster
Hubble constant
Hubble expansion law (Hubble's Law)
Hubble fork diagram
intermediate size black holes
irregular galaxy
jet
Kepler's Third Law
mass
nucleus (of a galaxy)
plate scale
quasar
quiet galaxy
radio galaxy
redshift
right ascension
Seyfert galaxy
simulation
spaghettification
spectroscopic parallax
spiral galaxy
stellar class black holes
supermassive black holes
supernova
torus
unification model of AGN
velocity

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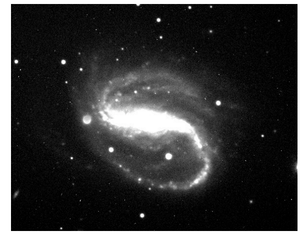
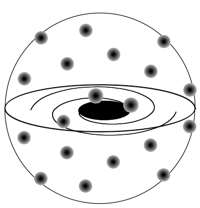
CA2 4.1: Our Position in the Milky Way: Activity



Purpose:
This activity simulates an observation of the distribution of globular clusters in the galaxy. With this simulation, students determine our relative location within our galaxy, and the direction to the center of the galaxy.

Materials:
List of Globular Cluster positions
Graph Paper
Globular Cluster photo (1 copy per student)
Globe or picture of earth (1 per class)
String (at least 8 pieces as long as your room is wide)

Background: The solar system is located in an outer edge of the disc-shaped Milky Way Galaxy which spans 100,000 light years.



Globular clusters are collections of stars which all orbit their host galaxy in a massive swarm. In a photograph such as the one shown (Photo courtesy of Robert Johnson, Kyle Hornbeck, and Barry Parker) there could be over 100,000 or more stars all in the same system. They are called globular clusters because they tend to have a spherical (or globe-like) appearance. Astronomers observing globular clusters have noted that in other galaxies like our own, the globular clusters tend to be distributed evenly around the galaxy in a sort of halo. This is observed consistently over many example galaxies.

This is hard to observe in our own galaxy, because we are unable to fly out of the galaxy and look at it from the outside. In 1914 astronomer Harlow Shapely argued that because the globular clusters are not evenly distributed in the sky, we are not located in the center of our galaxy. This activity simulates this observation.

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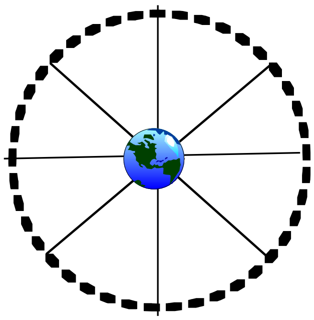
CA2 4.1: Our Position in the Milky Way: Activity

Procedures*:*

Demonstrating Our Relative Position – Part One

This demonstration is led by your teacher. Lettered items (A, B, C …) are group activities led by your teacher. Numbered items (1, 2, 3…) are questions you should answer on paper for this activity.

A. Begin by cutting off the globular cluster picture on the first page and attaching it to your clothing. The teacher will designate one student to represent the earth, and secure the image of the earth to that student.



B. Give all eight strings to the "Earth" student, and have them stand in the center of the room.

C. Have the rest of the class circle the classroom. The activity works best if it is actually a circle, but furniture may not allow that. Distribute students evenly; a good rule of thumb is that students should be arm-length apart, unable to touch anyone adjacent to them.

D. Give strings to students closest to the front, back, sides, and corners of the room, distributing them evenly so that the strings resemble a pie with equal slices.

Questions:

1. In this simulation, the angles between the strings should be approximately equal to what value?

2. Approximately how many students are between each two strings?

3. What does the classroom represent?

4. Where is the earth in this simulation?

5. Where would you have to stand to make the angles to the same globular clusters become unequal?

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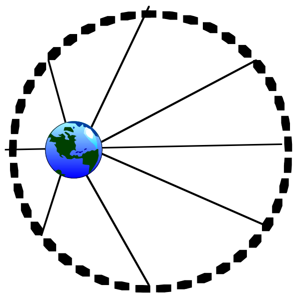
CA2 4.1: Our Position in the Milky Way: Activity



Demonstrating Our Relative Position – Part Two

E. Now have the "Earth" student move toward one edge of the circle. The eight string-holding students should continue holding the strings, playing out slack until the "Earth" is standing near the edge of the circle.

6. The angles between the strings are no longer equal. If this were a pie, the slices would not be the same size. Where would the widest slices be? (not largest in AREA; rather, the widest or largest ANGLE.)

___

7. Where are the skinniest slices (narrowest?) This implies that clusters that are farther away will appear to be…?

___

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___

___

F. Have the "Earth" student extend their arm and point to every third student. Class members should observe the student's arm moving at small angles towards students across the room, and large angles for students directly behind the "Earth."

8. Where is the greatest apparent concentration of globular clusters?

___

9. How does this compare to the direction of the center of the room?

___

10. When astronomers observe real globular clusters, it looks more like this scenario than the first one. What does that tell us about our location in the galaxy?

___

___

F. Now return to your seat and proceed to part 3.

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CA2 4.1: Our Position in the Milky Way: Activity

Part 3. Plotting the Location of Globular Clusters.

This activity is done in small groups or individually. Please refer to the list of globular clusters shown. This list is derived from Harris (1996).

ID	Name	RA	Dec	ID	Name	RA	Dec
NGC 1904	M 79	5.40	-24.52	NGC 6254	M 10	16.40	-4.08
NGC 4590	M 68	12.40	-26.73	NGC 6266	M 62	17.40	-30.10
NGC 5024	M 53	13.40	18.17	NGC 6273	M 19	17.40	-26.27
NGC 5139	omega Cen	13.40	-47.47	NGC 6341	M 92	17.40	43.13
NGC 5272	M 3	13.40	28.37	NGC 6333	M 9	17.40	-18.50
NGC 5904	M 5	15.40	2.07	NGC 6402	M 14	17.40	-3.23
NGC 6093	M 80	16.40	-22.97	NGC 6626	M 28	18.40	-24.87
NGC 6121	M 4	16.40	-26.52	NGC 6637	M 69	18.40	-32.33
NGC 6171	M 107	16.40	-13.05	NGC 6656	M 22	18.40	-23.90
NGC 6205	M 13	16.40	36.45	NGC 6681	M 70	18.40	-32.28
NGC 6218	M 12	16.40	-1.93	NGC 6715	M 54	18.40	-30.47
NGC 6779	M 56	19.40	30.18	NGC 7089	M 2	21.40	0.00
NGC 6809	M 55	19.40	-30.95	NGC 7099	M 30	21.40	-23.17
NGC 6838	M 71	19.40	18.77	NGC 6981	M 72	20.40	-12.53
NGC 6864	M 75	20.40	-21.92	NGC 7078	M 15	21.40	12.17

Harris, W.E. 1996, AJ, 112, 1487. List of Globular Clusters.
See http://www.physics.mcmaster.ca/Globular.html.

Using the grid provided on the next page, locate each globular cluster and plot it. Please note: the x-axis is in a star coordinate called Right Ascension and is plotted backward from a traditional Cartesian graph. The y-axis is called declination and is plotted in the usual fashion, although some values are negative. Right Ascension and declination are like longitude and latitude in the sky. For more details refer to volume 1 of this book.

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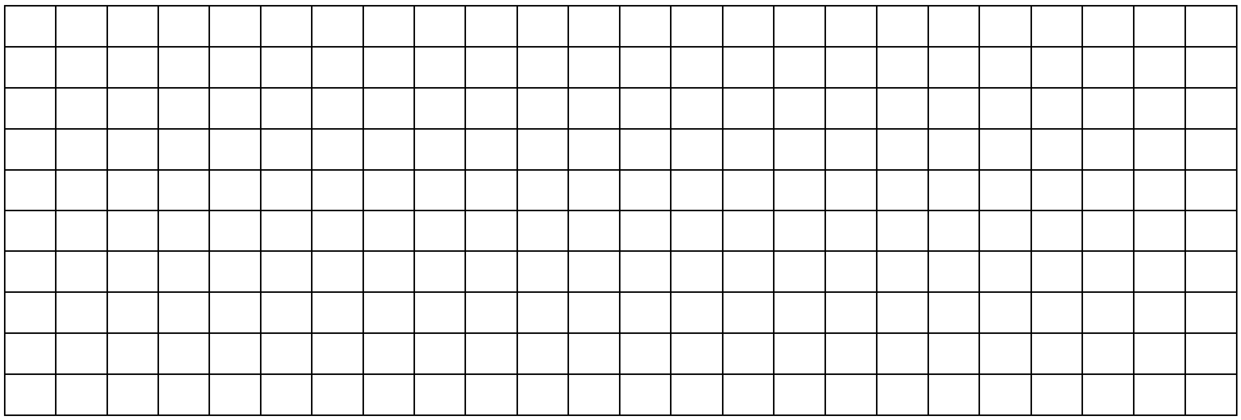
CA2 4.1: Our Position in the Milky Way: Activity



Grid for plotting globular clusters. Use 1 box =1 h RA on the x-axis, and 1 box = 10 degrees declination on the y-axis (with 0 near the center).

G. When you have plotted all the globular clusters, answer these questions:
12. Are the clusters concentrated in one area or are they evenly distributed?

13. What does this tell you about our location in the galaxy?

14. Circle the largest concentration of clusters. Using the graph coordinates system, determine the center of the cluster's location and write it here.

15. Using a star chart, or free software such as Stellarium, locate which constellation is in the direction of the coordinates you listed. Name the constellation.

16. How would your graph look if we lived near the center of the galaxy?

17. How would it look if we lived outside the galaxy?

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CA2 4.1: Our Position in the Milky Way: Activity

18. Name some strengths and weaknesses of the model we used in the demonstration.

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19. Astronomers generally agree that our solar system is located about 2/3 of the way from the center to the edge of the Milky Way, in a sort of cosmic suburb. Does this seem reasonable considering your results?

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20. If the galaxy is 100,000 light years wide, approximately how far are we from the center?

Challenges:

1. Use the references to find the more comprehensive list of globular clusters by Harris (1996). Plot all of the clusters he lists and see if your results are different.
2. The distances to globular clusters are not mentioned here, but they could potentially be important in determining our position in the galaxy. Do research to find out how we know how far away globular clusters are from us.
3. The types of stars in globular clusters would not likely have planets, and if they did, the planets' orbits would become unstable as nearby stars passed by. Nevertheless it might be possible for a planet to exist in such a place, especially one of the smaller ones. Describe what day and night would be like in such a place.
4. Photographs of globular clusters can be used to detect variable stars. They can also be used to determine the age of a star cluster using a color-magnitude diagram. Your local astronomical society may be able to assist you with such a project if you are interested.
5. All of the objects listed in the table are visible in backyard telescopes. Make observations of the clusters for your observing notebook with drawings or photographs. Photographing a cluster is not a simple task and will require expert assistance.

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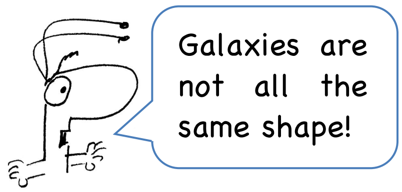
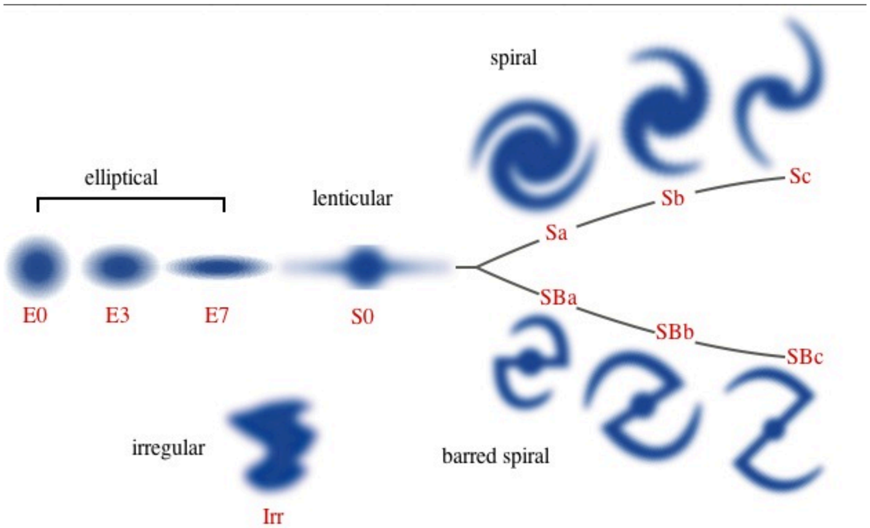
CA2 4.2: Galaxy Classification: Activity



Purpose: to observe the various types of galaxies and contribute to an ongoing project involving galaxy classification.

Equipment needed: Computer with internet access.

Background: Galaxies come in many shapes and sizes. Early on in the discovery that "island universes" were groups of billions of stars and objects similar to the Milky Way, Edwin Hubble invented a classification scheme to sort them out by shape. The so-called "fork diagram" devised by Hubble shows a progression of shapes from circular, featureless **elliptical** galaxies to the tightly-wound **spirals** and **barred spirals** shown in the diagram below. (Image credit: By Inductiveload (Own work) [Public domain], via Wikimedia Commons)



This general classification scheme originally was Hubble's attempt to explain the evolution of galaxies. He believed that galaxies naturally evolved from one type to another over time, and that the different shapes represented different ages of galaxies.

Today, we know that is not true. Galaxy arms are not formed by "winding up" like a clock spring; they are products of the waves of star formation passing through a galaxy. The galaxies are also shaped through collisions and mergers, which affects their appearance greatly.

There are billions of galaxies in the universe, and astronomers have not classified all of them yet. There are not enough astronomers to examine galaxies to get the job done. To help, projects like www.galaxyzoo.org have formed public-participation projects to classify galaxies.

Your assignment is to create a login to this site (with parent permission, and according to your school's internet policies.) After logging in, follow the tutorials and begin classifying galaxies. Galaxy Zoo's method involves clicking on the answers to some easy questions for each galaxy (Is it round? Does it have a bar? Is there anything strange about it?) as you progress through the millions of images in the database.

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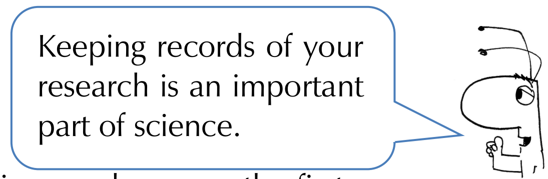
CA2 4.2: Galaxy Classification: Activity

Often several users will classify the same galaxy. The average evaluation is comparable to the evaluation of an expert astronomer. Sorting galaxies by type enables astronomers to study proportions of types of galaxies and assist in the discussion of how galaxies have changed since the formation of the universe. You will contribute in a small way to ongoing research projects if you participate.

Procedure:

For this assignment, your task is to simply keep a log of the galaxies you analyze, and report to the teacher how many galaxies you classify. In addition to classifying them using the Galaxyzoo interactive system, also describe them using the Hubble fork diagram shown on the first page. Record your answers to the interactive questions, then attempt to classify the galaxy using the fork diagram. Click on the "favorite" button so you can show your teacher how many galaxies you analyzed (it records your work this way.)



Note that irregular galaxies are not symmetrical, and are usually the result of some sort of collision between galaxies that has happened in the past.

Num-ber	Galaxy Zoo description (round, spiral arms, distinct nucleus, dust lanes, etc.)	Hubble Fork Diagram classification
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

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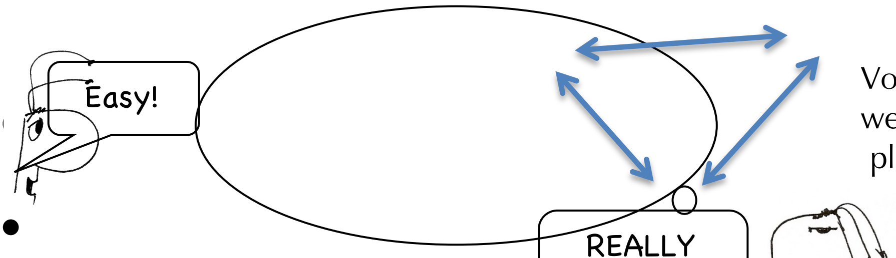
CA2 4.3: Galaxy Collision Simulations: Activity

Purpose: to show the difficulty in performing colliding galaxy simulations and characterize galaxy collisions.

Equipment needed: ruler, calculator.



Background: In Volume 1 of this work, we learned about planetary motion and how gravity governs these laws. It turns out that the mathematics of orbits with a large sun and small plan et are relatively simple, and Kepler's Laws are an excellent representation of what happens there.

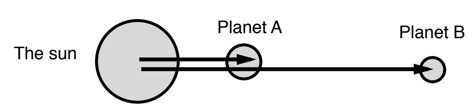
However, when a third planet is introduced, the situation is not so simple. Each of the three objects pulls on the other two. This is called the *three-body problem* and it is so complex, no one has found a simple equation like Kepler's Laws to predict its behavior far into the future. We can, however, still make predictions about three-body systems, or even systems with more objects (such as the 8 major planets in our own system). It isn't easy.

Instead of using a single, simple formula like we did with Kepler's Laws, we estimate what the planet will do by running a **simulation**. For short periods of time, Newton's Law of Gravity can predict what each planet will do. The exercise we are doing will give you an idea of how much work is required to compute these simulations.

Let us suppose there are 3 objects in our solar system, all initially at rest. The objects and locations are listed below.

Object	mass	initial position
Sun	1000	0
Planet A	50	10
Planet B	5	30

Now, to calculate what is happening to these objects, we have to calculate *three* problems. They are:
a. The force of A on the sun, plus the force of B on the sun, added together, move the Sun. (A little, because the sun is large.) This is shown to the right.



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CA2 4.3: Galaxy Collision Simulations: Activity

b. The force of B on A, and the force of the sun on A, moves A.
c. The force of A on B and the force of the sun on B, moves B.
Thus, we have to calculate *six* forces, (but only 3 calculations because each force is used twice) at a time to compute changes.

We're going to refer to that entire process (a-c) as a single STEP. First, let's calculate TWO of the six forces. In our simulated universe, gravity is computed using the following formula:

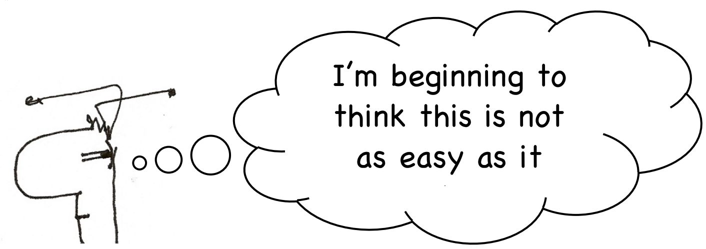
$$F_g = \frac{10 \bullet m_1 \bullet m_2}{d^2}$$

Where the universal gravity constant has been replaced with the number 10 just to make the calculation ideas easier to grasp. The actual value of the constant is 6.67×10^{-11}, but let that go for now. So here goes…
Example:
Calculate the force of gravity of planet A on the sun.

$$F_g = \frac{10 \bullet m_A \bullet m_{Sun}}{d^2}$$

$$F_g = \frac{10 \bullet 50 \bullet 1000}{10^2}$$

$$F_g = 5000$$



This will pull the sun to the right. But planet B is pulling on the sun as well, but not as hard because it is smaller and farther away. Nevertheless we have to compute it. This time use the mass and distance of planet B in the calculation and repeat it.

1. What is the force of planet B on the sun?

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____

____

____

2. What is the *total* force on the sun? (Add these together)

____

____

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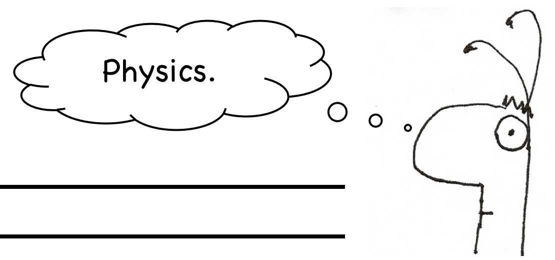
CA2 4.3: Galaxy Collision Simulations: Activity

3. What is the *acceleration* of the sun? Acceleration is found using **Newton's Second Law of Motion**, which says
s

$$\text{acceleration}=\frac{\text{Total Force}}{\text{mass}}$$



4. What is the *change in velocity* of the sun? This is calculated using the formula

$$\text{velocity change}=\text{acceleration}\bullet\text{time}$$

where time is some arbitrary (small) value. The smaller the value you use, the more precise the calculations, but then you have to do more calculations to find out values farther in the future. Calculate it with a value of 1 second.

5. This change in velocity would then be used to compute a change in position of the sun, finding out where it would move at the end of your series of calculations. This is computed using this formula:

$$\text{New position} = \text{original position}+\frac{(2\bullet\text{ original velocity + change in velocity})}{2}\bullet\text{time interval}$$

In this first computation, the original position of the sun is *zero*, and the original velocity is also *zero*. Compute the sun's new position below.

All of these steps would need to be *repeated* for the effect of gravity of Planet A and the sun on Planet B, and *again* for the effect of gravity on Planet B and the sun on Planet A. Then all three objects would be in a new position, each moved due to the gravity of the others. These 5 problems are the parts of one STEP where the forces of 2 objects act on just one that remains.

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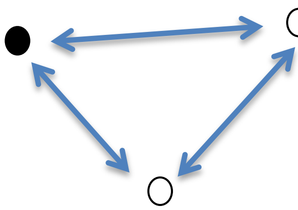
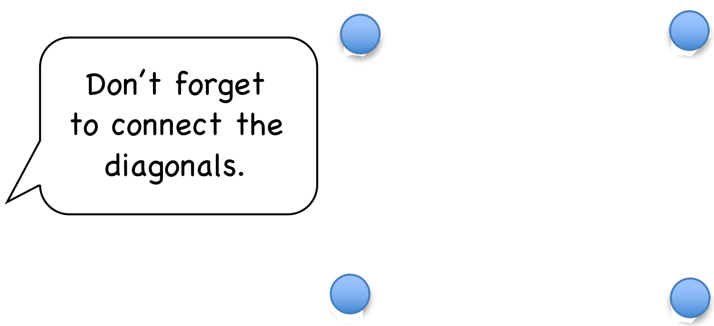
CA2 4.3: Galaxy Collision Simulations: Activity

To be clear, with 3 bodies, you could to ONE STEP which is the force of A and B on C, another STEP which is the force of C and A on B, and a third STEP which is the force of C and B on A. That's 3 separate problems with 5 sub-steps each. All of this, we call a single CYCLE of our problem. A CYCLE is 3 STEPS in this example.

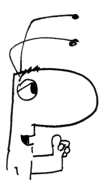


This diagram shows the relationship between the number of objects and the number of calculations. The diagram shows that THREE STEPS would be required to find out where these three objects are in the next time interval, which we will henceforth refer to as a CYCLE. Within the three STEPS there are some duplications; because the force of A on B is the same as the force of B on A, you could use the value you previously computed over again, making the total number of STEPS actually three instead of six.

6. Can you draw a diagram that would represent the number of calculations required for FOUR objects in a solar system? Hint: It's easier if you draw them as the corners of a square. Then draw lines connecting each one to each other one.



For #8 below, try using STEPS =(n(n-1))/2 Where n is the number of bodies.



7. How many STEPS would be required to complete one cycle in a four-body system? (Count the lines).

____

____

8. How many STEPS would be required for the following? Draw diagrams as necessary to figure it out.

bod-ies	2	3	4	5	6	7	8	9	n
STEPS	1	3							

Each CYCLE consists of several STEPS needed to compute all the different changes, for all the different objects.

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CA2 4.3: Galaxy Collision Simulations: Activity

9. In a galaxy simulation, a distribution of galaxy material consists of *millions* to *billions* of individually tracked stars, all pulling on each other, each one causing a complex dance of movement driven only by gravity. Suppose you ran a simulation of two galaxies colliding that required 100 stars in two galaxies total. How many STEPS would be required to do ONE CYCLE for all the possible stars in the galaxies? Warm up your calculator!

10. Now completing just ONE CYCLE just shows you what happens, say, tomorrow; it does not predict the long-term future of the system. For that you need more CYCLES. If one CYCLE is a simulation of one year of time passing, how many CYCLES would be required to complete a 250 million year simulation using the 100-star example earlier? How many STEPS?

11. If your home computer could do a thousand STEPS in one second, how long would it take to complete these calculations?

Now you begin to understand the scope of the problem in galaxy simulations. In real galaxies there are 100 billion stars. This would require 5×10^{21} calculations for a single cycle! This is why supercomputers are needed. There are just too many calculations for a small computer to handle. Even fast supercomputers take hours, days, even weeks to finish a complex galaxy simulation problem.

About Real Galaxy Collisions

In an actual "collision" between galaxies, the stars seldom actually come in physical contact. Even in a dense cluster, a star has a diameter of perhaps a million km, and is separated by billions to trillions of kilometers, making the probability of a collision higher than in the local solar neighborhood, but still low. Instead, gravity distorts the shape of the galaxies as shown on the next page.

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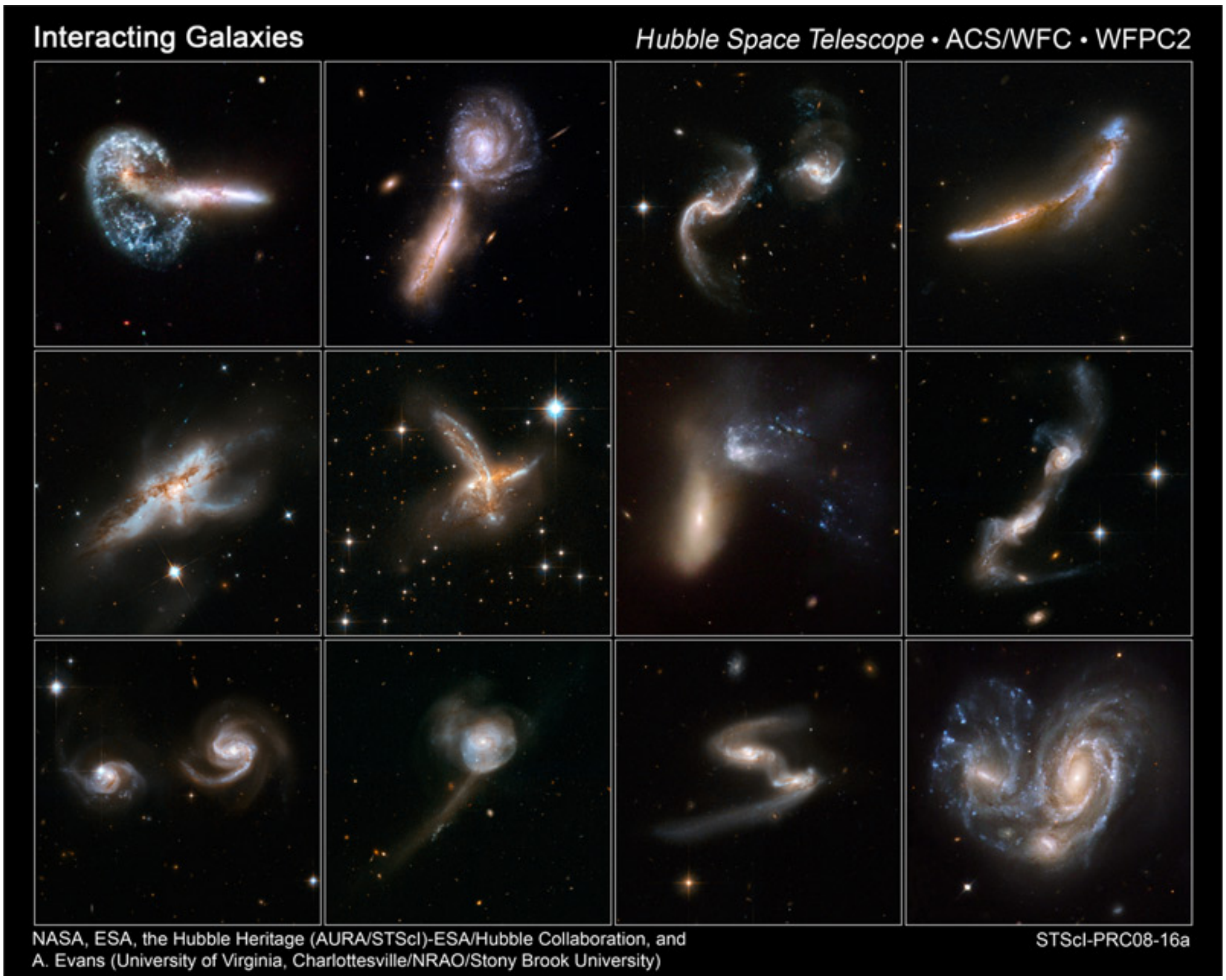
CA2 4.3: Galaxy Collision Simulations: Activity

The famous astronomer Halton Arp collected images of galaxies in the process of collision, and catalogued them. Look at the resemblance between these actual galaxies the simulations shown below.

These photographs were taken by the Hubble Space Telescope.



Such collisions take millions of years to complete and often result in the transformation of the galaxies to a different shape. Contrary to Hubble's original fork diagram, galaxy collisions are the driving engine that changes galaxies from one type to another.

Consider just the first picture. This image from the Hubble Space Telescope was recreated in simulation using a sophisticated version of what you just did. The simulation was done by Frank Summers of the Space Telescope Science Institute, Chris Mihos of CWRU, and Lars Hernquist of Harvard.

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CA2 4.3: Galaxy Collision Simulations: Activity

The picture on the left is the actual photo from the poster (albeit rotated.) The image on the right is a computer-generated simulation with billions of steps constructed to show two colliding galaxies can generate the image we see in the real sky on the left.

Astronomers cannot construct actual galaxies to perform experiments upon. These simulations are the only way we have of attempting to recreate using the laws of physics the behavior of galaxies over millions of years.

Being a competent computer programmer is a valuable skill in today's society. It is something all astronomers need at some level in their skill set to be successful.

Questions:

12. What is the difference between running an experiment and running a simulation?

____

____

____

13. Why do astronomers have to do simulations while chemists and physicists do experiments?

____

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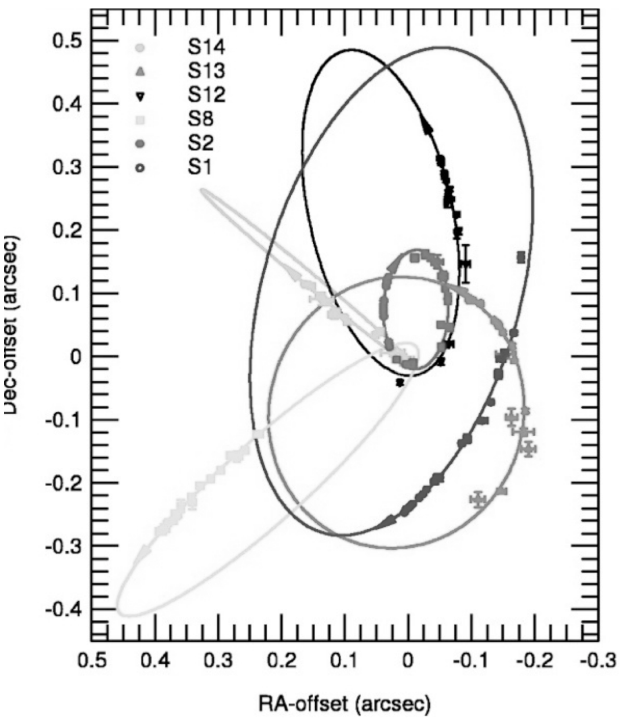
CA2 4.4: The Mass of the Black Hole in the Center of the Milky Way: Lab

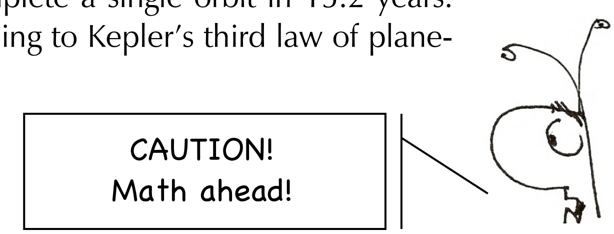


Purpose: To determine the mass of black hole in the center of the Milky Way based on observational data.

Source of image: The Astrophysical Journal, 628:246-259, 2005 July 20

Background: Some years ago data collected by Andrea Ghez and others showed that the center of the Milky Way is dominated by an enormous invisible mass. In this image based on data analyzed by Eisenhauer et. al. in a paper infrared emissions from the center of the Milky Way, the diagram at left shows several massive stars orbiting what appears to be essentially an empty spot. The points plotted are the positions of the stars measured over several years. The smooth lines are best-fit orbits that hit as many of the data points as possible.

In this activity we are going to attempt to measure the mass of whatever all these stars are orbiting. For our analysis we are going to concentrate on the smallest orbit nearest the center. This particular star has been observed to complete a single orbit in 15.2 years. Stars with larger orbits will take longer, according to Kepler's third law of planetary motion.



Equipment needed: Ruler, calculator

Procedure:

First we must establish the scale of the image. The y-axis is marked in declination units. The center of the galaxy is approximately 30,000 light years from earth. Thus, given an angular size and a distance, the size of the orbit's semi-major axis can be found. With the semi-major axis and the orbital period, the mass of the central body being orbited can be calculated.

We are making several simplifying assumptions as we begin this cosmic quest. First, we are assuming the orbital plane of the central star (called S2) is perpendicular to our line of sight. It isn't necessarily so, but the assumption is not unreasonable for a first effort at calculating

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CA2 4.4: The Mass of the Black Hole in the Center of the Milky Way: Lab

the value of the mass of the black hole in the center. Secondly the measurement of the distance to the center of the galaxy is not direct; it is inferred from our position as estimated based on the distribution of globular clusters. Given that, we can still make a reasonable estimate about the size of the object residing in the center of our Milky Way galaxy.

1. Measure the vertical height, or the major axis, of the smallest orbit in arcseconds as shown on the scale. Be as precise as possible.

---

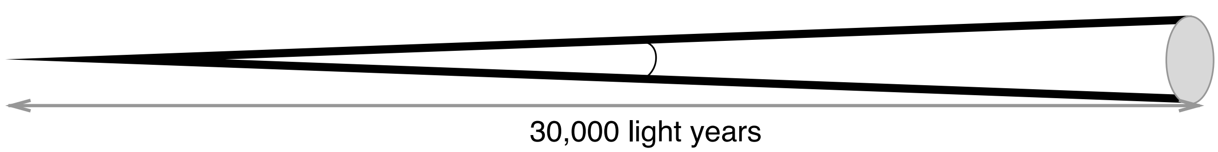
2. Convert your answer in #1 in arc seconds to degrees. Remember 3600 arc seconds = 1 degree.

---

3. Convert your answer for #2 in degrees to radians. Remember π radians = 180 degrees.

---

4. Given the distance to the center of the galaxy is 30,000 light-years, the following triangle can be set up. According to this, the tangent of the angle is equal to the diameter of the orbit divided by the distance to the center, or



$$\tan(\theta) = \frac{\text{diameter}}{\text{distance}}$$

or

$$\text{diameter} = \text{distance} \bullet \tan(\theta)$$

$$\text{but for small angles, } \tan(\theta) \approx \theta\text{, so}$$

$$\text{diameter} = \text{distance} \bullet \theta$$

Using the last formula in the derivation above, calculate the diameter of the orbit in light years. For subsequent calculations we will need the semi-major axis, which is just half of this value. Divide your answer by two.

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CA2 4.4: The Mass of the Black Hole in the Center of the Milky Way: Lab

5. We must convert the orbit diameter into meters to figure out anything physical about the planet. To convert, remember that 1 light year = 9.46 x10^{15} meters.

6. The orbital period is given in the original reference. Now we have to convert that orbital period, 15.2 years, into seconds.

5. Finally, we can apply Newton's version of Kepler's Third Law, introduced last semester, to determine the mass of the Monster in the Milky Way. The formula is $m = \frac{4\pi^2 r^3}{GT^2}$.

6. If we divide the mass of the black hole in kg by the mass of the sun, we can determine how many suns have been absorbed by the black hole at the center of the Milky Way Galaxy. The mass of the sun is 2 x 10^{30} kilograms.

7. There are many sources of uncertainty in this estimate. For example, the orbit of the star we used is tilted over somewhat. Also, due to relativistic effects the calculation we used might be oversimplified. Making corrections for these effects, astronomers usually estimate the value of the mass of the black hole in the center of the Milky Way at around 4 million solar masses. If this makes you feel like you are "way off," remember, in astronomy things are both complex and uncertain at the same time. The value you got is not bad for a simplified estimate. (And the value you get if you do the activity correctly is not 4 million. Sorry. You have to work it out.)

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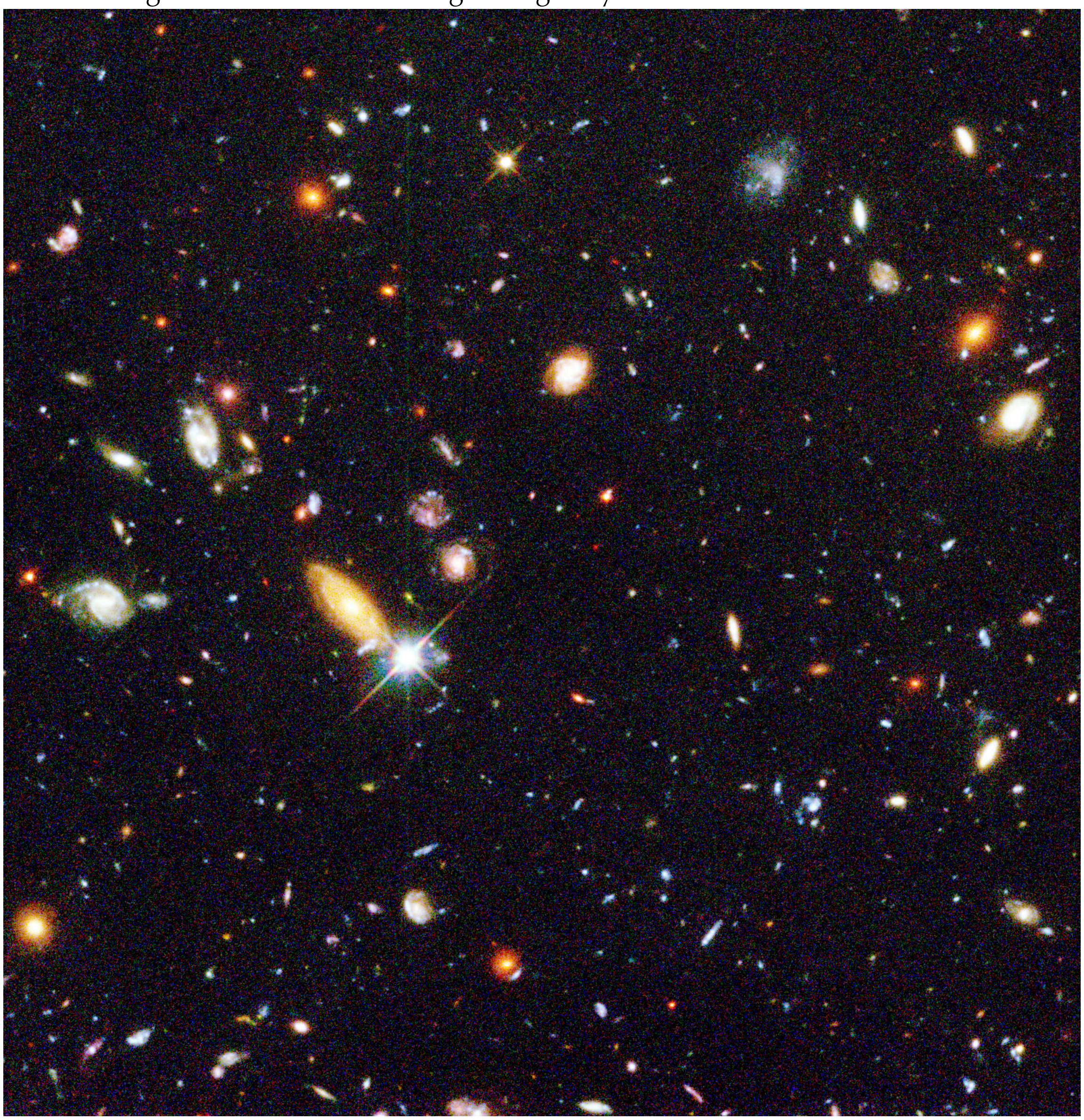
CA2 4.5: The Hubble Deep Field: Lab

Estimating the number of galaxies in the universe.

In 1996, the NASA Hubble Space Telescope took a long-exposure photo of an apparently empty part of the sky. After many hours of exposure over a ten day period, the following scene was revealed.

This image shows many galaxies that are located far beyond our own. Essentially every speck that is not background noise in this image is a galaxy.



Credit: *R. Williams (STScI), the Hubble Deep Field Team and NASA*

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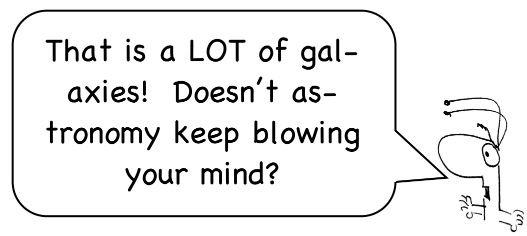
CA2 4.5: The Hubble Deep Field: Lab

Estimating how many galaxies are in this image

1. It would be challenging to count every galaxy seen in this picture. If you want to do that, go ahead, and skip to #4 and write down your answer there. However, it may not be necessary. We can get a reasonable estimate by looking at small areas and using them to calculate the number of galaxies in the entire image. Examine the numbers of galaxies seen in a small box 3 x 3 cm wide. Create a small box of this size by cutting a hole in a piece of paper and placing it over the image. Count the number of galaxies you see in the hole. Do this in three different locations of the image.



1st count:
2nd count:
3rd count:

Average of your 3 counts:

2. Now find the number of galaxies per square centimeter. This is your previous answer divided by 9. (Why is it divided by 9?)

Galaxies per square centimeter in picture:

3. Now find the number of galaxies in the entire image by measuring the area of the entire picture, and multiplying by the average number of galaxies per unit area:

Length of picture (cm):

Width of picture (cm):

Area of picture (square cm):

4. The total number of galaxies in the picture will therefore be either a) the number you got because you counted them all or b) the number you estimated using the area of the picture and the average number of galaxies per square centimeter. If you are estimating, use:

Galaxies in picture = area of entire picture x Galaxies per square centimeter in picture =

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CA2 4.5: The Hubble Deep Field: Lab

Estimating how many galaxies there are in the universe

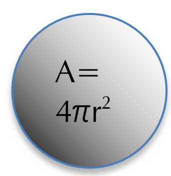
Read this quotation:

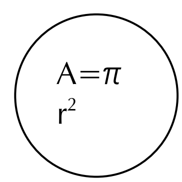
> "Representing a narrow "keyhole" view stretching to the visible horizon of the universe, the HDF image covers a speck of the sky only about the width of a dime located 75 feet away. Though the field is a very small sample of the heavens, it is considered representative of the typical distribution of galaxies in space because the universe, statistically, looks largely the same in all directions." Ray Villard, Space Telescope Science Institute

Based on this information, we can estimate how many galaxies there are in the entire universe. Assuming the distribution of galaxies everywhere is approximately the same, we would need to estimate how many dimes it would take to completely cover the sky. To do this, we are going to estimate the surface area of a sphere 75 feet in radius, then find out many dimes it would take to cover this sphere.

5. First, convert 75 feet in to centimeters (because we are going to measure the dime in centimeters.) Recall 2.54 cm = 1 inch.

6. The area for the surface of a *sphere* is





$$Area = 4\pi r^2$$

Compute the area of the sphere this large, in square centimeters. It's going to be a *large* number. "r" is the value you got in the previous question.

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CA2 4.5: The Hubble Deep Field: Lab

8. Now we need to know the surface area of a dime. It is not completely clear from the press release if we are comparing the surface area of a circular dime to the surface area of the rectangular image; as a simplifying assumption let us assume the surface area of the image is based on the *diameter* of the image representing the width and the height of the deep field image. The quote supports this because it says the picture covers the *width* of the dime. *So*: we will approximate the surface area of a dime by measuring the diameter of a dime and squaring it.

What is the diameter of a dime? (cm) ____________________________

(If you tried to Google this, you are spending too much time on the computer! Get a dime. Get a ruler. Measure. Don't round off!) **Important: The image on the first page is actually only ¼ of the original deep field. Therefore you should also divide by 4 after you find the area subtended by a time at 75 feet.**

What is the surface area of a square the same width of a dime in square centimeters?

____

____

9. Next, we need to find out how many dimes it would take to cover the size of the sphere. That's just a division problem.

$$\left(\frac{\text{Area of a sphere 75 feet in diameter}}{\text{Area of one dime}}\right) = \left(\frac{\text{Ans. for \#7}}{\text{Ans. for \#8}}\right) =$$

____

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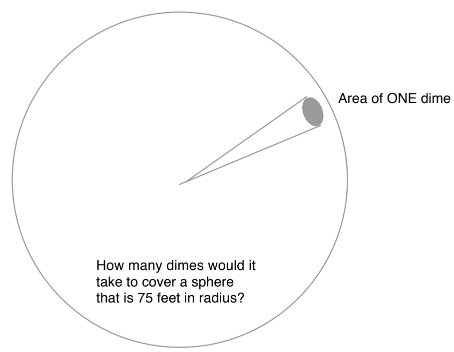

10. For each of these dimes there are at *least* as many galaxies as you estimated. Thus, a rough estimate for the number of galaxies in the universe is the *product* of the galaxies per deep field (Ans. To #4) multiplied by the number of deep fields necessary to cover the entire sky (Ans. To #9).

Total number of galaxies estimate =

Think about that. *You just estimated the number of galaxies in the entire universe.* (It's a bit low because a certain number of galaxies will overlap, hiding those behind them, and others are too dim to see, and it is difficult to distinguish the faintest galaxies in the picture with your eyes.) But as an estimate, it's not bad.

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CA2 4.5: The Hubble Deep Field: Lab

Concluding Questions

11. What were the simplifying assumptions we made?

12. Why can't we just do a deep field of the entire sky?

13. According to the press release there are approximately 1500 galaxies in the original deep field as counted by professional astronomers. How does this compare to your estimate? There are two things you need to know: First, the original picture had 4 times the area, but about ¼ of it was not exposed due to the shape of the camera CCD in the Hubble Space Telescope. So compare your estimate to roughly 500 galaxies.

14. Official estimates of the total number of galaxies range from 100 to 500 billion. How does the estimate you made based on your counting compare to this range?

15. There are approximately 100 to 400 billion stars in the Milky Way. Use 200 billion as a good estimate to calculate how many stars there are in the entire universe. (Use the estimate you made rather than the one quoted for most research.)

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CA2 4.5: The Hubble Deep Field: Lab

16. The most recent estimates of the number of planets in the galaxy is that there is approximately 1 planet for each star on the average. But are they like Earth? This means that there are as many planets in the universe (approximately) as there are stars. According to Phil Plait current estimates are that about "22 percent of sunlike stars have earthlike planets," and roughly 10 percent of all stars are sunlike. Use these values to estimate the number of earthlike planets in the universe. (Reference: http://www.slate.com/blogs/bad_astronomy/2013/11/04/earth_like_exoplanets_planets_like_ours_may_be_very_common.html)

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17. If there are 200 billion stars in the Milky Way how many in our own Milky Way might be capable of supporting life? Use the same estimate for the ratio of planets capable of supporting life.

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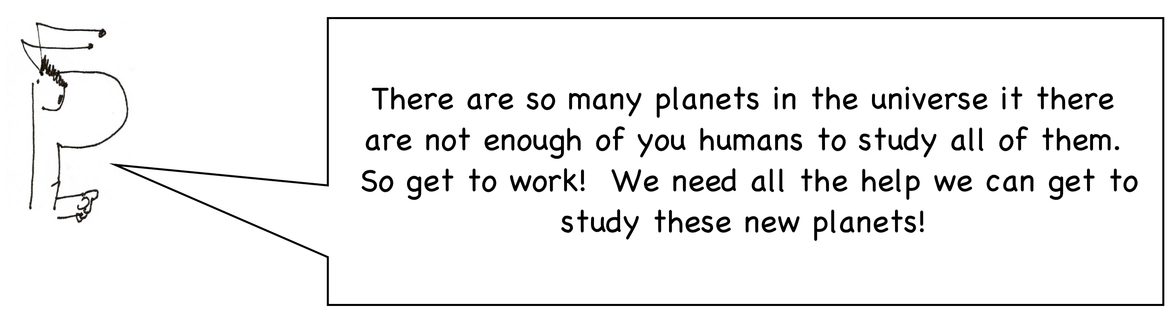

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CA2 4.6: Speed, Distance and Time: Activity

Purpose: To understand how to plot speed, distance, and time on a graph to determine relationships between them.

Equipment needed: none

Procedure: Let's consider a car going on a road trip. As the car travels at a relatively steady speed, say 50 mph, its movement can be described using the relationship

Distance traveled = 50 mph x time spent traveling

Or more generically

Distance = speed x time.

Anyone who drives a car has some innate sense of how this works. If you drive faster, it takes less time to get somewhere. To drive farther at the same speed, one must take a longer amount of time. These ideas are common sense and people use this concept every day.

To understand how such a simple concept has cosmological importance, we must first plot a few graphs to show how astronomers deal with such data.

For example, suppose we were given the following data about a series of cars, all of whom started off on a road trip a little while ago.

Average speed	Distance covered
45 mph	90 miles
30 mph	60 miles
75 mph	150 miles
15 mph	30 miles

It doesn't take a math wizard to see that all the numbers in the right column are just twice as large as the ones on the left. And a little thought will reveal that if this is the current situation with the cars, at this moment in time, they must have all spent the same time travelling.

1. How long have the cars been traveling?

____

____

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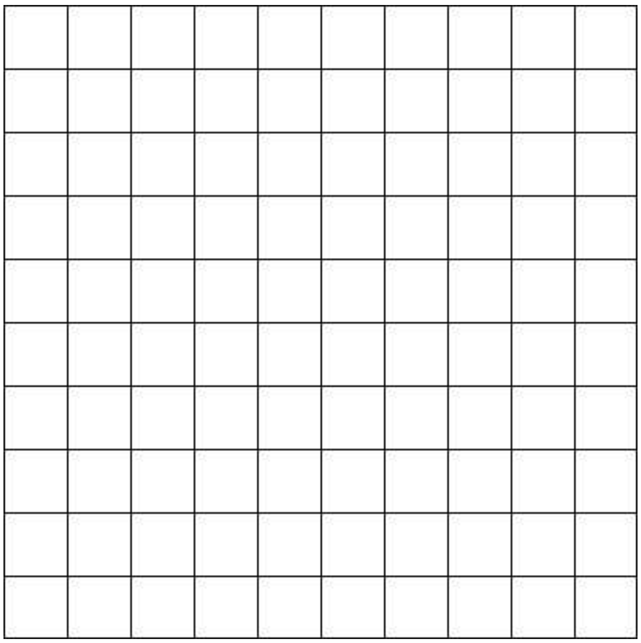
CA2 4.6: Speed, Distance and Time: Activity

2. To discover this number in a more complex situation, astronomers would suggest you plot the data (that's what scientists do when confronted by data—they graph it). So, plot the data provided on the grid below, using speed on the x-axis and distance traveled on the y- axis.



3. Now we would like you to determine the *slope* of this line, as you have done many times in algebra class. Remember, the *slope* of a line is determined by rise/run, or $\frac{\Delta \text{ distance}}{\Delta \text{ speed}}$ in this case. Pick two points, and find the slope just you used to do in algebra class. Show your work and write your result below.

____

____

____

This shows us that ***the slope of a speed vs. distance graph is the travel time***.

4. Assume the data was collected all simultaneously at a specific moment in time. What does this tell us about the time the cars departed?

____

____

5. If this is the location of the cars *now*, then an hour ago they were….

____

____

6. Where were the cars 2 hours ago?

\\ ____

____

This may not seem to have a lot to do with astronomy…but trust me, it will.

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CA2 4.7: The Cosmic Distance Ladder: Activity

Background: The problem with measuring distances in space is that no single method works (if you'll pardon the phrase) *universally*. That means that you have to use a variety of methods to measure distances. The ranges of these various methods overlap somewhat, which is a good thing, because it allows you to verify each method based on an adjacent one. But you have to start somewhere, right?

What follows is a basic description of a few of the methods. Table of Distance Measuring Methods (in no particular order)

Method	Range	Technique
Geometric Parallax	Near Earth Orbit to Interplanetary and Interstellar distances out to ~ 500 light years	We studied this in the parallax lab in this workbook. Basically, we use the earth's orbit as a baseline and triangulate on the positions of nearby stars and planets. The method is limited due to the incredibly tiny angles involved. When it works, it is extremely reliable.
Cepheid Variables	A few hundred light years to millions of light years	Cepheid variables have a strong luminosity/period relationship. Bigger, brighter ones pulse more slowly. If you can see a discrete star, and measure its brightness over time, you can use this data to measure period of oscillation, which yields absolute magnitude, which yields distance. You must be able to see the individual Cepheid variable, which limits its range of usefulness. The method is named after the star Delta Cephei, the first star to be identified of this type.
Radar	Near Earth Orbit to ~1 AU.	Astronomers use radar such as the one in Arecibo, Puerto Rico to measure the distance to Venus at maximum elongation. Using this information, we can determine the scale of distance between Earth and Venus. From Kepler's Laws, we can determine the ratio of the size of Venus' orbit to Earth's. With a precise measurement of the Earth-Venus distance, we can determine the distance between the sun and the Earth. Radar doesn't work on the Sun itself because it is a blackbody. It would just absorb the radio waves without reflecting. This establishes the precise value of 1 AU.
Type Ia Supernovae	thousands to billions of light years	There are several kinds of supernovae, but Type 1a supernovae, formed in binary systems between consisting of red giants orbiting near a white dwarf, are remarkably consistent in brightness because when the red giant grows large enough, it feeds material to the white dwarf companion, which will explode when it reaches a certain critical density. Since they are always the same intrinsic brightness, then we can determine the distance to them by comparing absolute and apparent magnitudes. These are among the brightest things in the universe, but it is impossible to predict in which galaxies and when we might see one.

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CA2 4.7: The Cosmic Distance Ladder: Activity

Method	Range	Technique
Spectroscopic Parallax	A few light years to distances up to about 10,000 parsecs.	By classifying stars by spectra, we find that stars of identical spectral class are the same temperature and intrinsic brightness. Thus specific spectral classes have a known absolute magnitude, and comparison to the apparent magnitude can tell us distance. You must be able to see the specific individual star well enough to take a spectrum of it, which limits the distances you can measure.

There are other steps on the ladder, some more obscure than others, some more useful than others. These are the most important methods, and were used to establish such things as the scale of the universe, determine the expansion of the universe, and many other things.

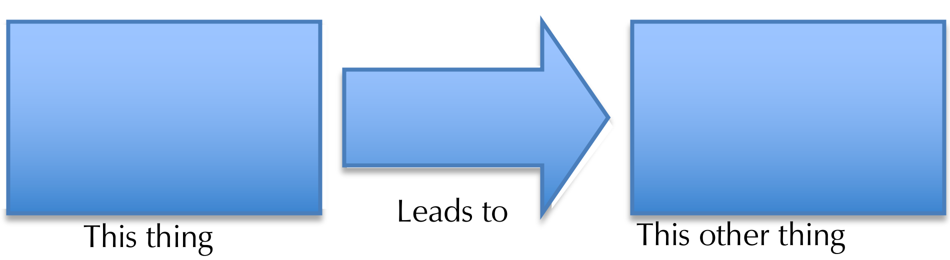
Several of the methods described rely upon a step involving magnitudes. If both the apparent magnitude and absolute magnitude are known, then the distance to an object may be measured by way of the so-called **distance modulus**, or the difference between a star's absolute and apparent magnitudes.

This relationship, previously mentioned in this book, would generate the distance to an object in parsecs given its distance modulus:

Part 1. Create a graphic organizer

Your first task is to create a graphic organizer that shows the relationship between these various methods used to measure distance in space. A ladder is a basic metaphor for this idea. The bottom rung is the most trustworthy, most reliable, and shortest range method in our arsenal. Each rung above it depends on the ones below it for support. Reorder them into *near* vs. *far* order, then create a graphic organizer that preserves the order, gives some indication of the overlap between them, and displays each one's range.

Graphic organizers include flowcharts, graphs, Venn diagrams, and many other methods. Your teacher will give you guidance about what they want to see, but if you choose a flowchart, draw boxes with arrows that lead to the next step, as shown here:



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CA2 4.7: The Cosmic Distance Ladder: Activity

Draw your graphic organizer here.

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CA2 4.7: The Cosmic Distance Ladder: Activity

Part 2. Questions.

1. What would it do to our long-distance measurements if two of the adjacent methods in the cosmic distance ladder did not overlap? Why is the overlap important?

2. Which method, in your opinion, is most trustworthy and reliable? Which is least?

3. A student of the author once measured the distance to the Andromeda Galaxy by the method of Cepheid variables. What exactly did the student measure? What was required to generate the final answer?

4. Which method would likely be used to measure the distance to a….

a. globular cluster inside our own galaxy? ____________________
b. galaxy in the Leo cluster, several million ly away? _____________
c. supernova on the other side of our galaxy? _______________

5. Why is it important to have more than one example of each method? That is, more than one Cepheid variable star, or more than one Type 1a supernova?

6. Which methods require knowing the star's distance modulus

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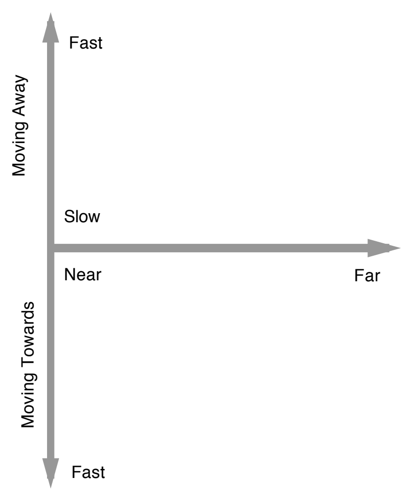
CA2 4.8: The Hubble Expansion Law: Lab

Edwin Hubble assembled a graph of galaxy velocities and distances determined through the Doppler Effect, and the cosmic distance ladder. The chart below shows the possible combinations of distance and speed.



1. Mark on the chart where nearby galaxies, moving away slowly would be.

2. Mark on the chart where distant galaxies, moving rapidly towards us would be.

In his first set of data, Hubble did not see all of these possibilities. You are going to simulate his discovery using data from the Hubble Space Telescope Science Institute.

3. In this activity, we are going to measure the diameter of galaxies and use a simplifying assumption that all galaxies are the same size. This isn't true, but it is close enough to make a good guess about how galaxies are actually distributed in speed and distance. For each of the following galaxies, follow these steps.

INSTRUCTIONS FOR EACH PICTURE

a. Measure the width of the **entire image** (not the galaxy, or the table, but the image in the table) in mm. Don't round.

b. Divide the first scale number in arc minutes (see the area to the right of each picture for this value) by the width of the image you found in a. This is the **plate scale** in arc minutes per mm.

c. Measure the **widest dimension** of the galaxy (see illustration below.) Measure in mm, and don't round. If it's tilted, then tilt your ruler.

d. Use the plate scale to find the size of the galaxy in arc minutes. Multiplying the answer to b (plate scale) by the answer to c (size of galaxy in mm) does this.

Write the answers in the boxes next to each image or on separate paper.

Then collect all this information in the table in the page that follows the images.

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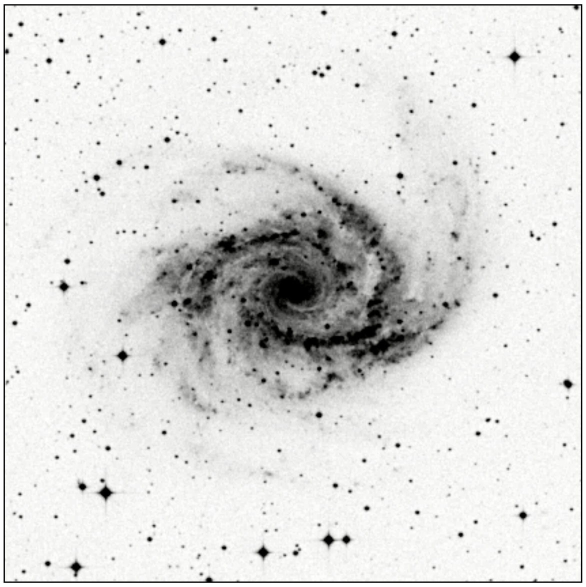
CA2 4.8: The Hubble Expansion Law: Lab



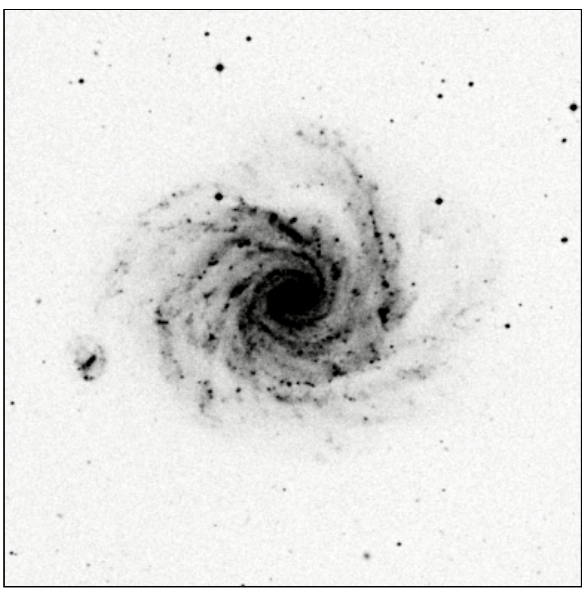
Name: NGC 2997
Velocity: 799
Scale: 27′x 27′
Source:http://ned.ipac.caltech.edu/cgi-bin/ex_refcode?ref-code=1994DSS...1...0000%3A

a. Width of image (mm):

b.Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:



Name: NGC 3521
Velocity: 627
Scale: 9.3′x9.3′
Ref:http://ned.ipac.caltech.edu/cgi-bin/ex_refcode?ref-code=2007SINGS.5......0%3A

a. Width of image (mm):

b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:

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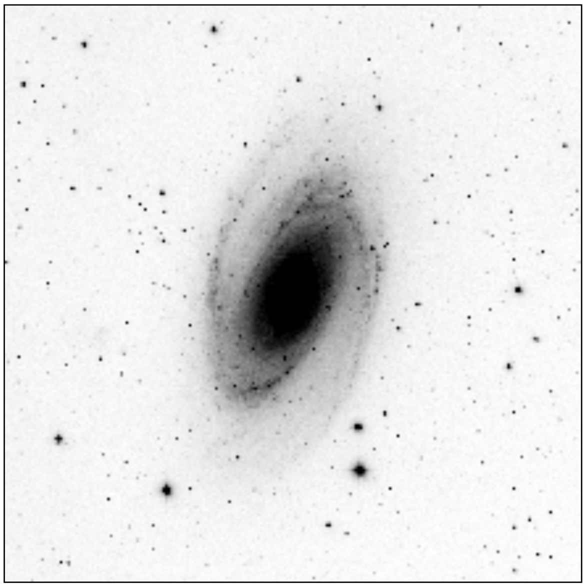
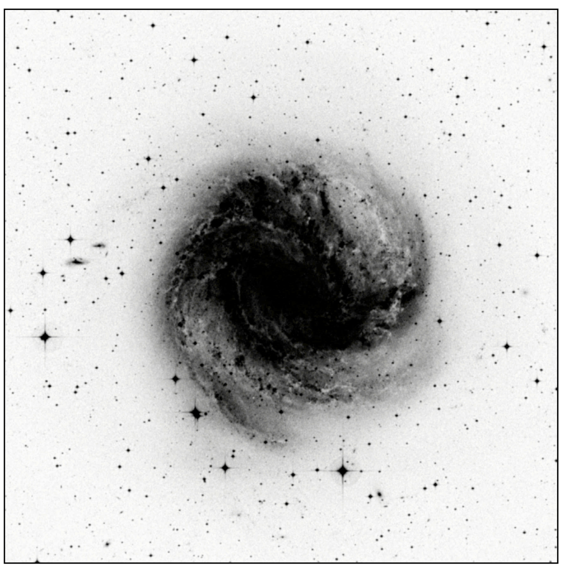
CA2 4.8: The Hubble Expansion Law: Lab



Object: M33
Velocity: 69
Scale: 60′x60′
Ref:http://ned.ipac.caltech.edu/cgi-bin/ex_refcode?refcode=1994DSS...1...0000%3A
a. Width of image (mm):
b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:



Name: NGC 5236
Velocity: 275
Scale: 19′x19′
Source:http://ned.ipac.caltech.edu/cgi-bin/ex_refcode?refcode=1994DSS...1...0000%3A
a. Width of image (mm):
b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:

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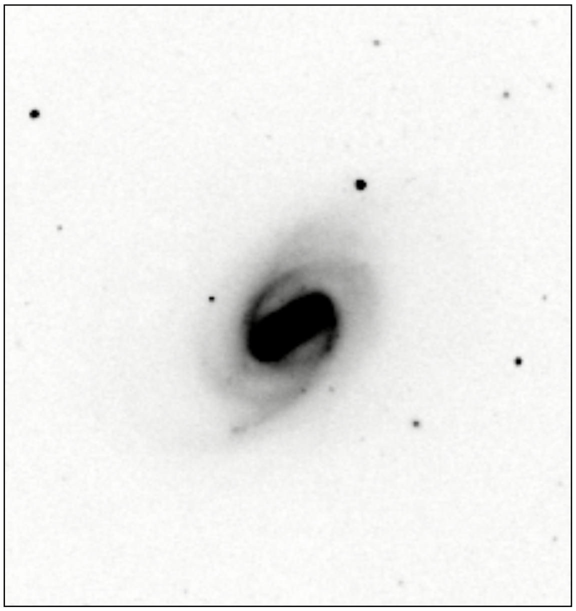
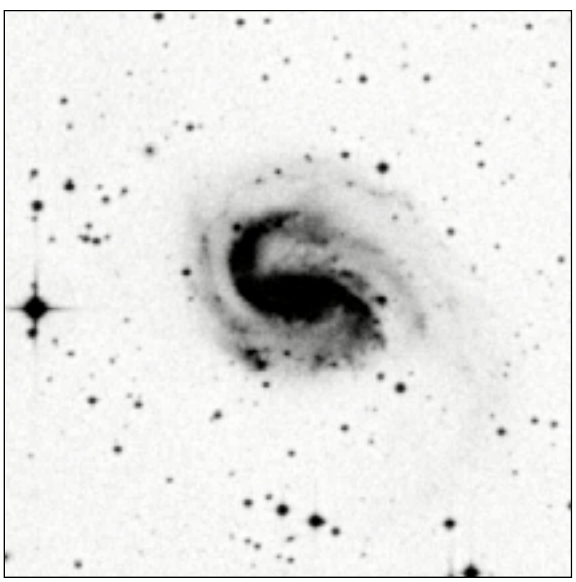
CA2 4.8: The Hubble Expansion Law: Lab



Name: NGC 289
Velocity: 1834
Scale: 4.4′ x4.7′
Ref:http://ned.ipac.caltech.edu/cgi-bin/ex_refcode?ref-code=2002ApJS..143...73E
a. Width of image (mm):
b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:



Name: NGC 2907
Velocity: 3192
Scale: 6.0x6.0′
Ref:http://ned.ipac.caltech.edu/cgi-bin/ex_refcode?ref-code=1994DSS...1...0000%3A
a. Width of image (mm):
b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:

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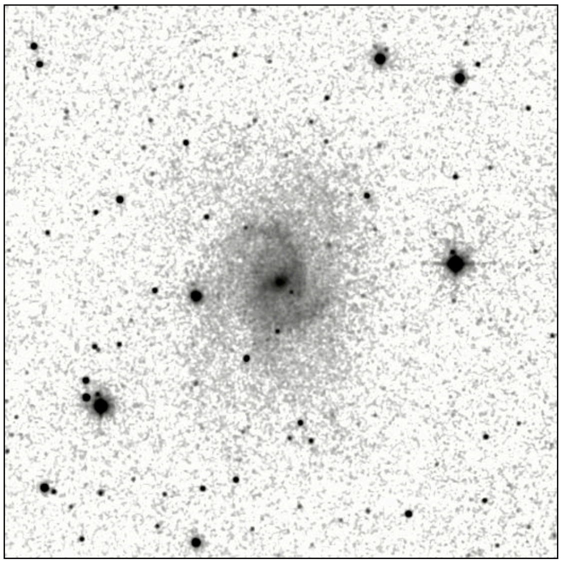
CA2 4.8: The Hubble Expansion Law: Lab



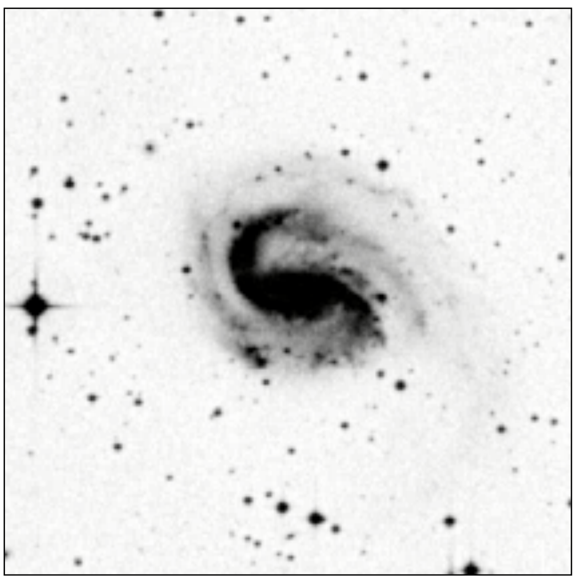
Name: NGC 2835
Velocity: 624
Scale: 8.7x8.7′
Ref:http://ned.ipac.caltech.edu/cgi-bin/ex_refcode?refcode=2003AJ....125..525J

a. Width of image (mm):

b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:



Name: NGC 6907
Velocity: 3192
Scale: 6x6′
Ref:http://ned.ipac.caltech.edu/cgi-bin/ex_refcode?ref-code=1994DSS...1...0000%3A

a. Width of image (mm):

b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:

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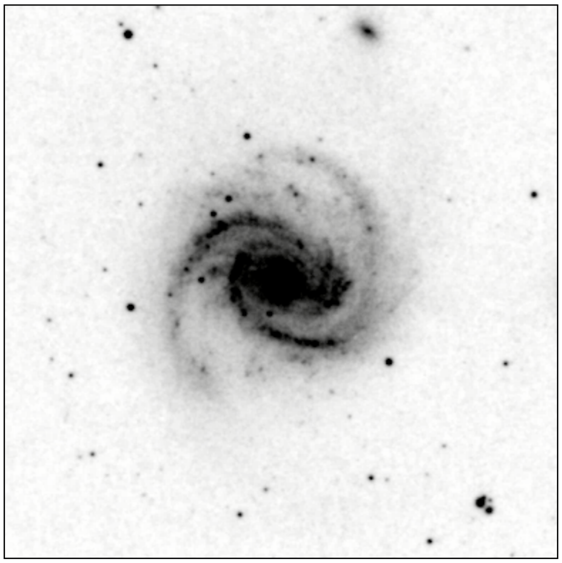
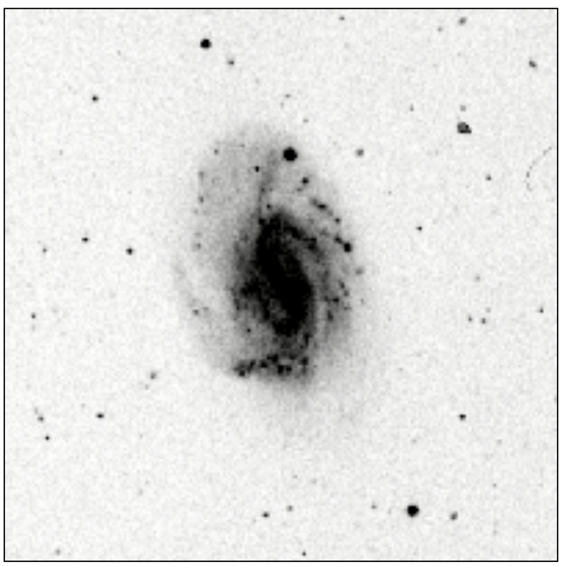
CA2 4.8: The Hubble Expansion Law: Lab



Name: NGC 4321
Velocity: 1464
Scale: 11′x11′
Ref:http://ned.ipac.caltech.edu/cgi-bin/ex_ref-code?refcode=1994DSS...1...0000%3A
a. Width of image (mm):
b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:



Name: NGC 3726
Velocity: 909
Scale: 10′x10′
Ref:http://ned.ipac.caltech.edu/cgi-bin/ex_ref-code?refcode=1994DSS...1...0000%3A
a. Width of image (mm):
b. Plate scale in arcmin/mm=scale/width:

c. Measure the widest dimension of the galaxy (mm):

d. Size of the galaxy in arcmin:

References: Images are from NASA's NASA/IPAC Extragalactic Database as indicated by each image. Velocities are as published in The Atlas of Galaxies, NASA publication SP-496 by Allan Sandage and John Bedke, 1988.

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CA2 4.8: The Hubble Expansion Law: Lab

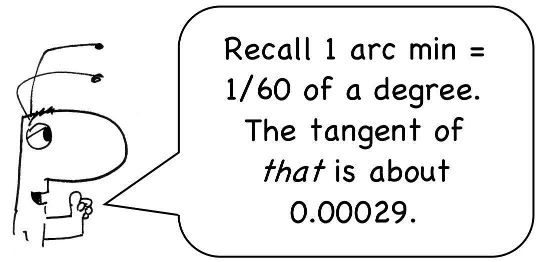
4. Copy the data from your measurements into the first two columns of the data table at the end of this activity. Also copy the recessional velocity into the last column.

5. Now convert these diameters to distances, using the following relationships. We assume (incorrectly, as it turns out, but it's not a bad first guess) that all galaxies are the same size, and they are all the same size as ours. Assume our galaxy is approximately 100,000 ly in diameter. If a galaxy the size of our own would appear to be 1 arc minute wide, it would be located at a distance of:

$$\tan(\text{angular size}) = \frac{100{,}000\ \text{ly}}{\text{distance}}$$

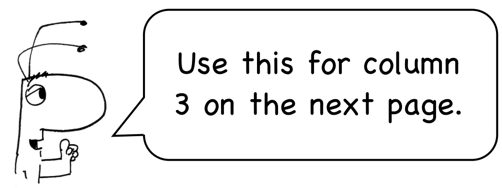
$$\text{distance} = \frac{100{,}000\ \text{ly}}{\tan(1\ \text{arcmin of angle})}$$

$$\text{distance} = \frac{100{,}000\ \text{ly}}{0.00029} = 344\ \text{million ly}$$



In this calculation we have converted 1 arc minute of angle into 1/60 of a degree before using the tangent function. If the galaxy were half the distance, it would appear twice as large, and if it were twice the distance, it would appear half as large. Thus the following ratio can be used to estimate distances of these galaxies:

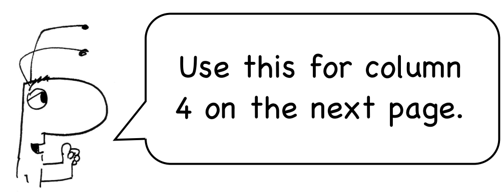
$$\text{distance to galaxy} = \frac{344\ \text{million ly}}{(\text{width of galaxy in arc minutes})}$$



Use this formula to estimate the distance to each galaxy. Enter these in the table.

6. Convert these distances in millions of light-years to mega-parsecs using this conversion.

$$\text{Distance in Mpc} = \text{Distance in Mly}\ \frac{1\ \text{pc}}{3.26\ \text{ly}}$$



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CA2 4.8: The Hubble Expansion Law: Lab

Data Table

1. Image name	2. Size of galaxy in arcmin	3. Estimated distance to galaxy (ly)	4. Estimated distance to galaxy (Mpc)	5.Recessional velocity

7. Now plot the redshift-determined speeds of these galaxies against the distance on the grid below. Put velocity on the y-axis, and distance in Mpc on the x-axis. Select a scale that allows the largest values to be plotted.

8. The points will not line up in a perfect line. Draw a line with a straightedge that passes through the origin (after all, we are in the Milky Way and we don't recede from ourselves) and then passes through as many of the plotted points as possible. Find the slope of this line. Remember slope is just rise over run. The units of this slope will be km/s per megaparsecs.

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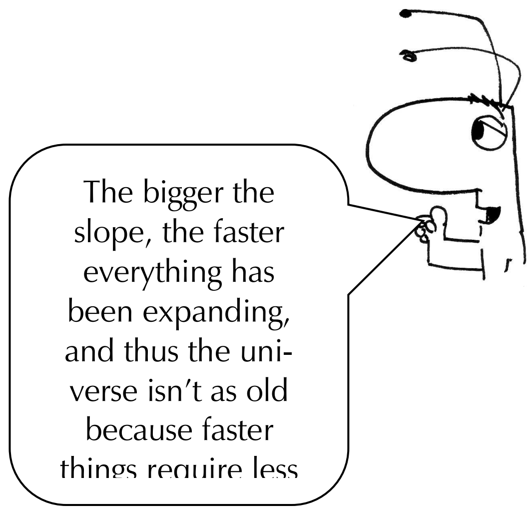
CA2 4.8: The Hubble Expansion Law: Lab

9. Use the chart below to estimate the age of the universe. How the slopes convert into the age of the universe will be explained at the end of this activity.

Slope of v vs. d graph ((km/s)/Mpc)	Age of Universe (years)
10	97,800,000,000
15	65,200,000,000
20	48,900,000,000
30	32,600,000,000
40	24,450,000,000
50	19,560,000,000
60	16,300,000,000
70	13,971,000,000
80	12,225,000,000
90	10,867,000,000
100	9,780,000,000
110	8,891,000,000
120	8,150,000,000
130	7,523,000,000



The answer you got probably differs quite a bit from typically accepted values. This is due to the imperfect method we used to measure distances, and the velocities were based on values published in 1988 by the Space Telescope Science Institute. Using more modern methods of measuring these values (such as Cepheid variables and Supernovas) the following data is currently available (2013) from NASA's Extragalactic Database:

Object	Distance in Mpc	Velocity in km/s
NGC 2997	10.77	1088
NGC 3521	12.078	801
M33	0.833	-179
NGC 5236	6.96	513
NGC 2903	9.058	550
NGC 4321	15.95	1571
NGC 3726	16.892	866
NGC 2835	10.824	886
NGC 289	22.767	1629
NGC 6907	37	3182

10. Plot these values on the same graph as before using a different symbol such as "x" instead of "•". Find the slope of this line as well, and write it here. What age does it imply?

___

___

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CA2 4.8: The Hubble Expansion Law: Lab

Recall from our speed, distance, and time analysis that a graph of this type will only be caused by everything traveling starting at the same time and from the same place.

The slope he got was a bit different than yours or the modern accepted value. Since then, we have refined the value. The modern accepted value is typically referred to as the **Hubble Constant** and its value is approximately 68 km/s/Mpc.

How the Hubble Constant generates the age of the universe, step by step
(This section is for advanced students. Ask your teacher if you need to read it.)

This discussion uses conclusions from the speed, distance, and time activity earlier in this workbook. We concluded earlier that the slope of a distance vs. speed graph (for constant speeds) is the travel time. We have plotted the speed vs. distance instead, which is reversed. (This is traditional with the Hubble diagram.) We will therefore not get the age of the universe unless we invert the slope first. We could simply state that 1/(68 km/s/Mpc) = 1 Mpc/(68 km/s) is the age of the universe and be done with it. Unfortunately the unit of measurement is unfamiliar. We would more typically say the age of something in *years*. Therefore our goal in the process below is to convert your slope into the age of the universe, and then do it again using the accepted value of the Hubble Constant.

11. First, *separate* the problem into numerator and denominator after you invert H.

____

____

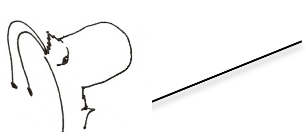
____

12. Next we have to make the distance unit match so they will cancel out. This means we have to convert the km/s to m/s, and the Mpc to meters.

Recall that 1 km = 1000 m, and convert as follows:

Your slope (H) x $\left(\frac{1000m}{1km}\right) =$ ____

This takes care of the denominator in the fraction. Now for the numerator.



Recall that the *numerator* is the top part of the fraction, and the *denominator* is the bottom.

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CA2 4.8: The Hubble Expansion Law: Lab

13. Next we must convert the Mega-parsecs (Mpc) into meters. Here are the conversion factors needed:
1 Mega pc = 1,000,000 pc
1 pc = 3.26 light years
1 light year = the distance light travels in a year = speed of light x time = 300,000,000 m/s x the number of seconds in a year

The distance light travels in a year is:

$$1 \text{ light year} = 300{,}000{,}000\left(\frac{m}{s}\right)\left(\frac{365.24 days}{1 year}\right)\left(\frac{24 hours}{1 day}\right)\left(\frac{60\,\text{min}}{1 hour}\right)\left(\frac{60\,\text{sec}}{1\,\text{min}}\right)= \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$\text{Therefore 1 Mpc = (the answer above) x } \left(\frac{3.26 ly}{pc}\right)\left(\frac{1{,}000{,}00 pc}{Mpc}\right)= \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

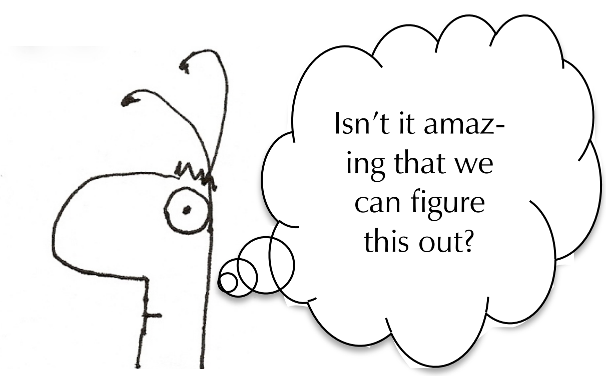
Now we have the numerator. Putting it all together we get…

14. The Age of the Universe

$$\text{The Age of the Universe is } = \left(\frac{\text{the answer to \#13}}{\text{the answer to \#12}}\right)=$$

15. This is of course inconvenient. So we will convert this to years to finish the problem. Use the conversion factors above in #3 to convert seconds back into years.

What is the age of the universe in years?



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CA2 4.8: The Hubble Expansion Law: Lab

Implications and Questions

This relatively simple calculation has led us to some conclusions that are intimidating to say the least. Yet the logic we have used is no more complex than figuring out the trip time when driving a car.

16. Like the driving cars example, the Hubble law graph implies that yesterday, the galaxies were a bit closer together; the day before that, still closer. If we traveled backward in time to the beginning that you calculated, where would all the galaxies be?

17. What does the fact that the Hubble graph is straight and not curved imply?

18. How will the universe be different in a billion years compared to now?

19. How does having a *larger* Hubble constant affect the estimated age of the universe?

20ß. Your teacher will have the age of the universe based on the accepted value of 68 km/s/Mpc. Compare this to your value.

There are some related questions like "*Where* did the universe begin?" and *"What was there before* the universe began?" Such questions are beyond the scope of this activity, but if you would like to know more you might consider the following books:

A Brief History of Time, by Stephen Hawking
The First Three Minutes, by Stephen Weinberg

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CA2 4.9 Active Galactic Nuclei

Purpose: To model an active galactic nucleus, and understand the Unified Theory of AGN

Equipment needed: 2 sugar-type ice cream cones, a bagel, a chocolate doughnut hole, and some cake frosting (something dark, with a bit of chips in it, like chocolate chips); paper plate, plastic knife, and possibly toothpicks.

Background: This activity is derived from the *Tasty AGN* activity developed by the Sonoma State University NASA Education and Public Outreach office, and is used with permission.

Black holes come in a variety of sizes. **Stellar class black holes** are formed from individual super massive star core collapses. Multiple black holes may merge, and when they do, what you get is simply a larger black hole with more mass and a larger event horizon. Thus, multiple black holes may form **Intermediate size black holes** anywhere from a few solar masses to several thousand in size. **Super massive black holes** combine millions to billions of suns, and are typically located in the centers of galaxies. It is not clear if these super massive black holes form from multiple mergers of black holes or form in place from tremendous nebulae that collapse before radiation pressure of newly formed stars can disperse the gas. Of the super massive black holes, there are two kinds: **Quiet** and **Active galactic nucleus**. The giant black hole in the center of the Milky Way is quiet. Other galaxies have active super massive black holes, such as NGC 7502.

When these AGN form, as much as 10% of the galaxy's mass consists of the black hole in the center. Contrary to popular belief, a black hole is not some sort of ultimate cosmic vacuum cleaner. We are not all ultimately doomed to fall into one. However, an explorer finding themselves in the vicinity of such a black hole will not find the trip a comfortable one.

Any material orbiting near the black hole will have a tremendous orbital velocity due to the intense gravity. Things even slightly closer to the hole will move significantly faster; this is caused by the tidal effect of gravity, which can even stretch individual objects as their near-side parts attempt to orbit faster than their far-side parts.

Near the singularity the tide force can even rip things apart. This effect is described by astronomers as **spaghettification**. (No, I did not just make that up.)

These traumatic events, combined with the possibility that orbiting debris can collide, generates a lot of energy. Much of this energy is turned into heat, where the kinetic energy of collisions turns into heat the same way a meteor can cause a tremendous crater simply by colliding with a planet at a high rate of speed.

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CA2 4.9 Active Galactic Nuclei

The energy lights up the surrounding nebula, and makes it glow; material actively falling into the black hole as a result of collisions, giving off radiation at every wavelength, is called the **accretion disk**. Material farther out, in a calmer, more stable orbit, is cooler and can block the radiation from certain angles, is called the **torus.**

Some of the material does not quite make it to the event horizon, however. In a process apparently driven by powerful magnetic fields caused by the rapidly spinning ionized gas near the black hole, powerful magnetic fields redirect some of the accretion disk material as it falls in to the hole. This material is separated into two **jets** of material that spray out above and below the accretion disk. Oftentimes, these jets are the only visible structure near the AGN, as the accretion disk and torus are so small they cannot be seen. (The black hole itself, which cannot radiate energy, can never be seen directly.)

Many years ago (well, if you consider 20-30 years many years) astronomers had an intriguing collection of odd objects they did not completely understand. These objects are described in a table below. Now we know that each of them is an AGN, and the primary difference between them is simply the viewing angle we have from the earth.

Procedure:

To understand this idea, called the **angular unification of AGN models**, we are going to build a model of an AGN using the materials described on the first page. The task at hand is for you to build a model AGN using the materials provided, and then draw a labeled picture of it here. Remember the following points.

- The black hole cannot be seen because it is dark. The event horizon of the black hole surrounds it and forms a border between the rest of the universe and the area closest to the singularity. Once this border is crossed, objects are no longer able to be retrieved or observed.
- The torus resembles a doughnut and surrounds the black hole. The accretion disk, if it is present, tends to be very small and near the event horizon. They also tend to be flat.
- The torus surrounds the accretion disk and is dark. It may contain stars or other debris that has not been destroyed by tidal forces or collisions.
- The jets are narrow at the base and widen slightly as they move away from the black hole in both directions, and they are usually perpendicular to the accretion disk.

Leave the model assembled while your teacher inspects it. Afterwards, if you find it appetizing, you can exert your revenge on the black hole's insatiable appetite by eating it.

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CA2 4.9 Active Galactic Nuclei

Draw a picture of your assembled model here; don't forget to label the parts.

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CA2 4.9 Active Galactic Nuclei

The model of the AGN can be used to explain a variety of odd phenomena observed from earth. Each of the objects described below used to exist independently of the others; that is, astronomers thought they were unrelated. The unification model proposes that all of them are AGN, seen from different angles. Call the angle with respect to the jet theta (θ). What angle of viewing would produce the effects described below? Sketch the AGN's angle with respect to the earth as well.

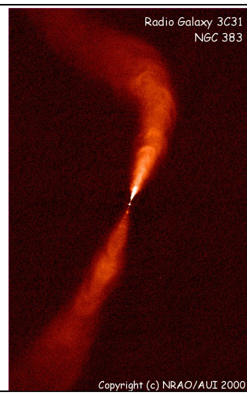
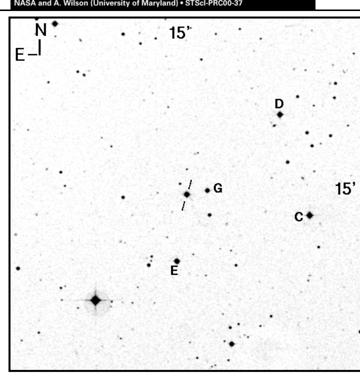
<table>
<tr><th>Description</th><th>Photo</th><th>Sketch of AGN angle</th><th>θ</th></tr>
<tr><td>Radio Galaxy
Only the jets are seen in radio telescope images of distant galaxies. The torus is tiny, and the side view blocks any light from the accretion disk area.</td><td>

Image source: National Radio Astronomy Observatory. NGC 383.</td><td></td><td></td></tr>
<tr><td>Seyfert Galaxy
These are galaxies seen at angles, where the cores of the galaxies are unusually bright, allowing some of the radiation from the accretion disk to illuminate the center of the galaxy.</td><td>

Hubble image of a Seyfert galaxy, by A. Wilson.</td><td></td><td></td></tr>
<tr><td>Quasar
These are some of the most distant objects in the universe, visible only because the jet is aimed directly at earth. It is too far away to harm us, and appears only as a star; hence the name, a combination of quasi-stellar. Using the Hubble Law, the distances to quasars help us define the limits of the observable universe.</td><td>

Quasar 3C 273 is marked with two small lines. The other labeled stars are comparison stars. Credit: Landessternwarte Heidelberg-Königstuhl.</td><td></td><td></td></tr>
</table>

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CA2 4.10 Galaxies and Cosmology Puzzle

Note: Some of the puzzle clues have spaces in them. In the puzzle solution they have been marked with a [shaded box].

1	2	3	4	5 [shaded]	6	7	8	9	10	11	12	13	14	15	16 [shaded]	17	18	19	
20	21	22	23		24	25	26	27	28	29	30	31		32	33		34	35	36
37	38	39	40	41	42	,		W	43	44	45	46		S	47	48	M		49
50		51	52	53	54		55	56		57	58		59	M	B	60	61	62	63
S	S	64	65	66		67	68	69	70	71	S		72	73		O	74	75	
76	H	77	O	78	79	80	S		O	81		82	H	E		83	84	85	86
E	87	S	E	.			88		B	89	90	91	K		H	O	92	E	.
.	.	H	93	S		94	N		95	N	F	96	N	97	98	Y		99	T
	100	T	S		V	E	R	Y		101	E	N	T	E	R	.		–	–
F	R	E	102		W	O	103	F											

1. _ (7) _ (4) _ (54) _ (27) _ (9) _ (8) _ (31) A VARIABLE STAR USED TO MEASURE DISTANCE
2. _ (43) _ (55) _ (24) _ (32) _ (21) _ (19) ASTRONOMER WHO FIRST MEASURED EXPANSION OF UNIVERSE
3. Q _ (74) _ (17) _ (1) _ (20) _ (18) QUASI-STELLAR AGN
4. _ (57) _ (45) _ (11) _ (12) _ (86) _ (28) _ (5) _ (66) _ (60) _ (68) _ (63) _ (51) _ (14) _ (34) _ (70) _ (16) _ (10) _ (83) _ (91) _ (89) _ (30) U _ (6) WHAT AGN STANDS FOR
5. _ (13) _ (41) _ (33) _ (36) _ (47) _ (29) _ (26) AGN GALAXY SEEN AT AN ACUTE ANGLE
6. _ (15) _ (56) _ (69) G _ (46) _ (48) _ (40) _ (49) _ (37) _ (81) _ (39) _ (101) _ (88) _ (58) _ (44) _ (2) _ (35) WHAT HAPPENS WHEN YOU FALL INTO A BLACK HOLE
7. _ (52) _ (90) _ (102) _ (64) _ (23) AGN SEEN FROM SIDE EMITTING RADIO WAVES
8. _ (22) _ (67) _ (72) _ (61) _ (93) _ (92) GALAXY WITH ARMS THAT LOOKS LIKE A SWIRL
9. _ (79) _ (62) _ (75) _ (59) G U _ (103) _ (94) _ (78) GALAXY WITH NO SYMMETRY
10. _ (99) C C _ (71) L _ (77) _ (87) A _ (76) _ (85) _ (25) _ (38) RATE OF CHANGE OF VELOCITY
11. _ (42) _ (95) _ (3) U L A _ (82) _ (96) _ (50) _ (65) USING MATH TO MIMIC THE REAL WORLD
12. D _ (80) C L _ (97) _ (73) A _ (98) _ (100) _ (53) _ (84) SKY LATITUDE

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CA2 4.10 Galaxies and Cosmology Puzzle

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CA2 4.11 Galaxies and Cosmology Questions

1. Are galaxies in the universe or is the universe in a galaxy?

2. Explain briefly how we estimate the number of galaxies in the universe.

3. What is the significance of the positions of globular clusters to astronomy?

4. What kind of galaxy is the Milky Way?

5. Why is it difficult to simulate the evolution of a galaxy?

6. What do we normally call the solution to the "2-body problem?"

7. What is located in the center of the Milky Way?

9. Why did the Hubble Deep Field only use one small section of the sky instead of the entire sky in every direction?

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CA2 4.11 Galaxies and Cosmology Questions

10. How many degrees is 1800 arc seconds?

11. If a car travels at 50 mph for 300 miles how long was the trip?

12. Convert 3 days to seconds.

13. If the Hubble constant was twice as large (say, 130 km/s/Mpc), how old would the universe be?

14. If the Hubble constant was twice as large, how would the universe look compared to how it looks now?

15. Summarize the Unified Model of Active Galactic Nuclei. Explain why astronomers find it so useful.

16. Why is it called the Big Bang Theory?

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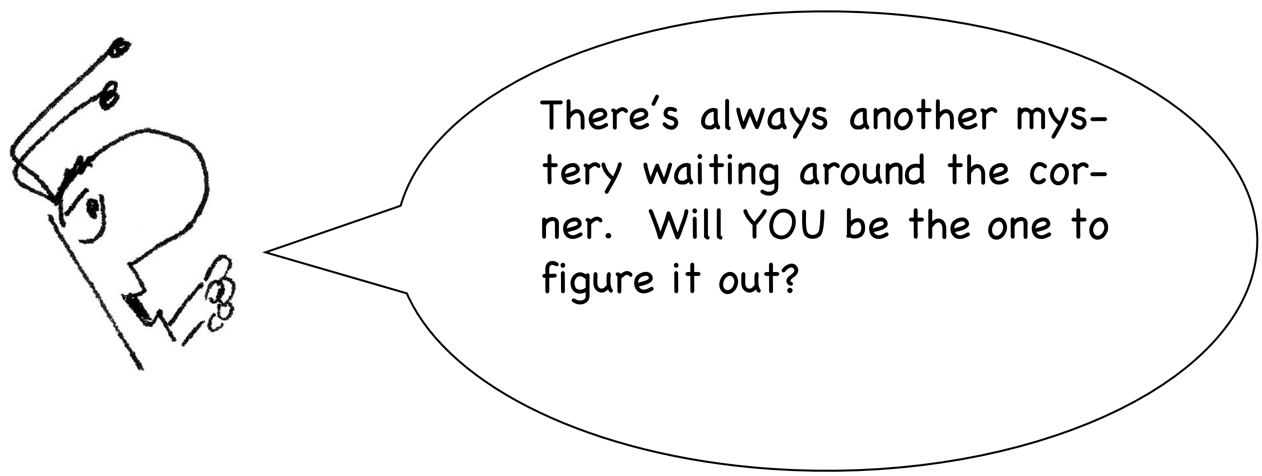
Conceptual Astronomy 2 Unit 5: The Edge of What We Know ?

One of the most important lessons we have learned throughout this course is that science never stops learning new things. Indeed, the history of astronomy is a perfect example of scientists replacing old views of the universe with new ones. Kepler improved upon the work of Ptolemy; Newton improved Kepler.

The remaining mysteries of the universe become more subtle and harder to figure out as time goes on, but they still exist. This section is concerned with defining some of the unknown mysteries that are still with us in the modern era, questions as diverse as the fate of the universe, the nature of mysterious invisible matter known as “dark matter,” and more mundane questions like the arrangement of clouds on Saturn.



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CA2 5.0: *The Edge of What We Know Study Guide*

At the end of unit 5, students will be able to:

- State the Drake Equation.
- Note which variables in the Drake Equation are well established and which are not.
- State the results of the Drake Equation and estimate the number of intelligence-bearing planets in the universe.
- Solve back-of-the-envelope problems where estimation is part of the procedure.
- Discuss some of the difficulties involved in capturing and interpreting a signal from an alien civilization.
- Define prime number.
- Define Dark Matter and explain how we know it exists when we cannot see it directly.
- Find the velocity of an object in an orbit around a massive object like the sun given the radius of the orbit.
- Define Dark Energy and state the observation that led us to conclude it exists.
- Define Big Crunch model and Heat Death model and relate these to the eventual fate of the universe.
- Discuss the difference between our solar system and the typical hot-Jupiter exoplanet systems recently discovered.
- State why it used to be assumed no giant planets would be found close to the sun in other solar systems.
- Define escape velocity and relate it to the presence of gases in a giant planet's atmosphere.
- List several space probes with data accessible to the general public.
- Access NASA databases and obtain images from WISE, Spitzer, Hubble, etc.

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CA2 5.0: The Edge of What We Know Study Guide

Vocabulary list

Absorption line
Astronomical Unit
Big Crunch
Brown dwarf
Centripetal force
Channel
Dark energy
Dark matter
Deteurium
DNA
Drake Equation
Electromagnetic force
Escape velocity
Exoplanets
Expansion
Fermi problem
Flux
Gravitational force
Gravitational lensing
Hot Jupiters
Infrared
Kepler's Laws
Keplerian orbits
Light year
Micron
Nebular hypothesis
Peak wavelength
Prime number
Rotation curves
Solar wind
Spectrum
Strong nuclear force
Weak nuclear force
WISE

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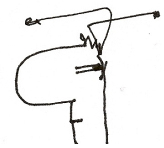
CA2 5.1: The Drake Equation: Activity



Purpose: To estimate the number of intelligent, alien civilizations in the Galaxy and our odds of encountering one of them.

Materials needed: Calculator; internet access.

A famous scientist named Enrico Fermi once challenged his students to estimate, without any references, the number of piano tuners that reside in the city of Chicago. "How are we supposed to know that?" asked his students. Fermi challenged them not to simply guess the answer, but to decide what they would need to know in order to estimate the answer.

The students brainstormed a list of facts they would need to know to make the estimate. Such numbers included

- The population of Chicago
- The number of people who live in a typical home
- The fraction of homes that might own a piano
- How many pianos could a piano tuner tune in a day?
- How many days are there in a year?

And so on. After estimating these values, the students decided upon the estimate. At the time, the only way to answer the question definitively would be to consult a phone book. Even then, some piano tuners who did not advertise in the yellow pages might be missed. Today, students might be tempted to "Google" the answer, but the point of the exercise is to learn how to think in such a way as to define what needs to be known to compute the answer, practicing for more difficult questions that are not in the dictionary or on the internet.

Take, for example, this question: *How many intelligent civilizations exist in the Milky Way galaxy?*

This question was first seriously addressed by Dr. Frank Drake in 1961.

First, Drake made a list of all the factors that would need to be known in order to estimate the answer. On the following page is a list of what Drake estimated, including his estimate.

Since Drake's time, our knowledge of stellar evolution, rate of planet formation, and even evolution have increased dramatically. We are now able to make better estimates of the values in the Drake equation. Still, for some of these factors, our best guess is nothing more than a range of possible values.

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CA2 5.1: The Drake Equation: Activity

1. Calculate the number of intelligent civilizations as estimated by Drake. Use the lower estimates in your calculations for the "Pessimists" column and the higher estimates for the "Optimists" column, and record this number at the bottom of the column labeled "Drake's Estimate."

$$N = R^* \bullet f_p \bullet n_e \bullet f_l \bullet f_i \bullet f_c \bullet L$$

Variable	Interpretation	Drake's Estimate	Pessimists	Optimists
R*	Rate of star formation	1		
f_p	Fraction of stars with planets	0.2-0.5		
n_e	Number of planets per solar system that are approximately earthlike	1-5		
f_l	Fraction of earthlike planets that develop life	1		
f_i	Fraction of life that becomes intelligent	1		
f_c	Fraction of life that wishes and is able to communicate over interstellar distances	0.1-0.2		
L	Expected lifetime of a technological civilization	1000-100,000,000 years		
N	Number of civilizations in the Milky Way that are intelligent, send signals, and can be detected (calculate this)	**Don't fill out this box. Use the columns at right.**		

2. Modern values vary somewhat from Drake's original estimate in 1961. For example, see this article: http://www.skyandtelescope.com/resources/seti/3304541.html in which several modern values are listed. According to authors Grovert Schillng and Alan MacRobert, some values in the equation have not changed with additional research, while others have become more certain and varied slightly. For example, they state that the majority of astronomers think that the values run as shown on the next page.

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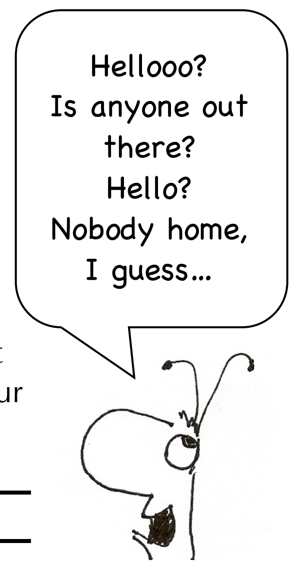
CA2 5.1: The Drake Equation: Activity

3. Compute the number of civilizations estimated using Schilling and MacRobert's numbers. Use the smallest values to find the pessimistic value and optimistic values estimated by astronomers. Write these in the response for #3 below. Then answer the question: Which values are more trustworthy today than they were in Drake's day?

Variable	Schilling and MacRobert
R*	1
f_p	1
n_e	1-3
f_l	~0-1
f_i	~0-1
f_c	~0-1
L	1000-100,000,000

4. Look at the most optimistic total value. Let's consider the idea that these civilizations exist, and that they are evenly distributed throughout the area of the Milky Way (ignoring depth because it's pretty flat.) If the Milky Way is 100,000 ly in diameter, what is the surface area of the Milky Way in square light years?

5. If each civilization is allocated the same area, how much area does each civilization get?



6. Take the square root of your answer to #5 to determine the average distance between such civilizations.

7. Radio was invented in the early 1900's. If alien civilizations can detect and respond to radio waves, what can we conclude about them given your answer to #6? What are the flaws in the reasoning above?

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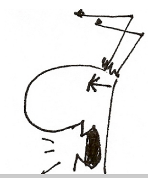
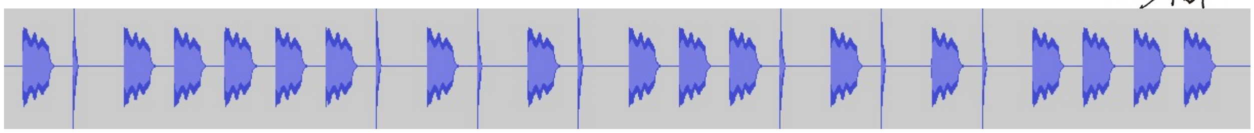
CA2 5.2: Decoding an Alien Signal: Activity





Purpose: To decode a simulated alien signal from space.

Equipment needed: Computer to play audio file, speakers

Used with permission from the Astronomical Society of the Pacific (www.astrosociety.org). Adapted from the original activity, "Decoding Radio Messages from Space" by Dennis Schatz in "Cosmic Decoders: A Guide for Family ASTRO Leaders" (http://astrosociety.org/astro-shop/index.php?p=product&id=18&parent=0)

Background: Suppose one day we intercepted a message from an alien civilization. Could we even understand it? If we decided to be the sender instead of the receiver, what would we say to maximize the odds that the message we sent would be understood?

To illustrate the difficulties involved, suppose you are doing radio astronomy one day and an odd signal was received. The signal is on your teacher's resource disk. If that is not available, the signal is transcribed as a graph, shown at the top of the page. The wide sections sound like a "beep" and the narrow spikes sound like a drum beat "chunk."

After these signals are received from deep space, they begin to repeat. Thus the message is just what is shown above. But what does it say?

Without some clues, it would be difficult to say. But fortunately for you, clues are available. Answer the questions below to find out the secret message. Scientists who try to decode an alien message may not be so lucky.

1. Count the total number of signals in the message (beeps and chunks): _______________

2. Think of numerical factors that multiply together to give this value. List some possibilities here.

____

____

____

3. Pick two of the factors and draw a box with those sides on the grid on the next page.

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CA2 5.2: Decoding an Alien Signal: Activity

hat

as

see

4. Now start marking "beeps" and "chunks" in the grid you've selected, in the order they appear in the graphic on the first page. For "beeps", color in the square with a pencil. For "chunks" leave the square blank.

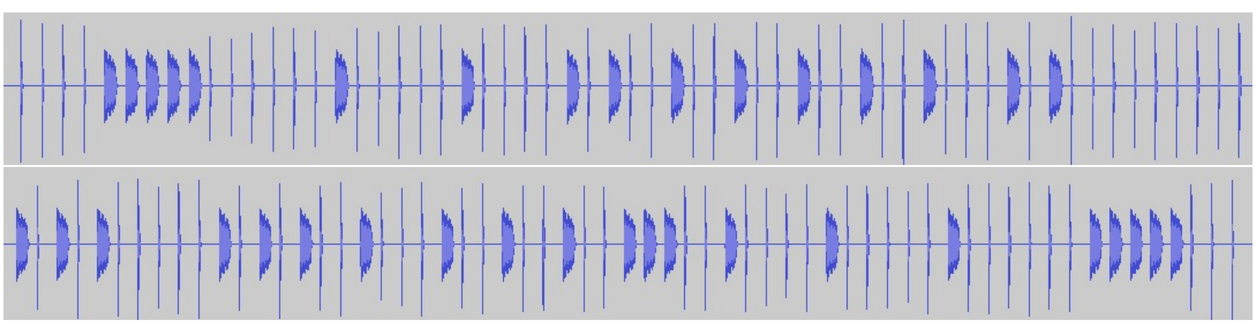
5. What does the picture show?

____

____

6. Some scientists think that alien signals may be encoded with pictures. We don't have any alien signals to analyze yet, but who knows? Someday we may need to decode them. One idea involves the use of **prime** numbers, or numbers that can only be evenly divided by itself and one. An image consisting of 91 bits of information is probably 13 x 7 pixels wide or 7 x13.

Want a bigger challenge? Decode the image in the signal below. You'll need your own graph paper.



7. For an *additional* challenge, try creating a message. Use a piece of graph paper and draw an image, then encode it into 0s and 1s (representing chunks and beeps).

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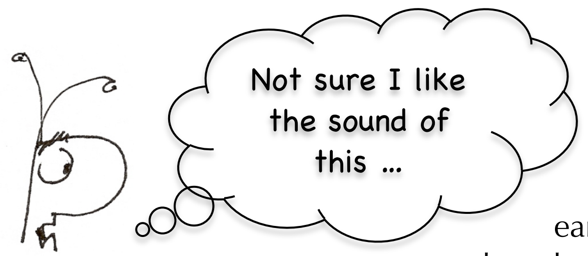
CA2 5.3: Designing an Alien: Activity



Purpose: To think about characteristics of LAWKI (Life As We Know It) and how some of these characteristics might be universal, or not.

There are some things that living creatures on earth share in common. Of course, life on earth is based on **DNA**, or deoxyribonucleic acid. Combinations of DNA create genes and chromosomes and are replicated in our offspring and enable life to continue on even when individuals die.

Within the earth alone, the variation in species is amazing. Creatures swim in the ocean and walk on the land; certain kinds of bacteria are poisoned by oxygen and live on the ocean floor in areas near volcanic vents that are so hot they would kill humans; life clings to rocks on mountain peaks and hides under rocks in desert floors and everywhere in between.

Procedure: Let us consider some things we know about humans and animals here on the earth. As much variation as there is, there are some things we have in common with our animal cousins. For example, compare a fish, a horse, and a person in the following table. Place a check mark for the things we share in common with these creatures. Add a couple of other animals.

Humans	fish	horses	person		
A clearly defined head					
Bilateral symmetry (a left and right side that are pretty much identical)					
Legs					
Arms					
Spherical eyes					
Require oxygen					
A well defined brain					
A heart that pumps blood					
A surface coating to protect us from the environment					
An ability to move independently					

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CA2 5.3: Designing an Alien: Activity

As you can see, we have quite a bit in common, even with fish. We are bilaterally symmetric because we form from embryos that split in half as they reproduce. Our sense organs (eyes, nose, ears, etc.) are near our brains to reduce the time it takes a signal to get from our organs to our brains, which gives us an evolutionary advantage.

Now we want you to consider what an alien might be like on another world. For each place listed below, describe the surface conditions and then "design" an alien adapted to live in that environment. For each alien, respond to the questions listed below. It is hard to imagine a creature from another planet that doesn't just simply look like what we are used to here, but try. In each case consider what evolutionary adaptations make the creature best suited for that environment. For example, on a world with no solid surface, land-based creatures have nowhere to live.

Planet	**Surface Conditions**	**Where Does the Alien Live?**	**How Does it Move?**	**Special Adaptations to This Environment**
Europa				
Jupiter				
Venus				
Titan				

If the teacher requests, draw pictures of the aliens in these environments on your own paper.

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CA2 5.4.1: Dark Matter

Purpose: To define the problem of Dark Matter.

Materials needed: calculator

Background: Recall from Volume 1 of this course that Kepler's Laws of Planetary motion made specific predictions about how things move in orbits around the earth. In our earlier work, we derived the relationship between Period and orbital radius. This was based on the idea that gravity is the **centripetal force** that makes planets orbit the sun.

The algebra we did was based on certain assumptions, unstated at the time we did the work. These assumptions included

- Everything moves in perfect circles.
- All of the mass in the solar system is concentrated in the sun.

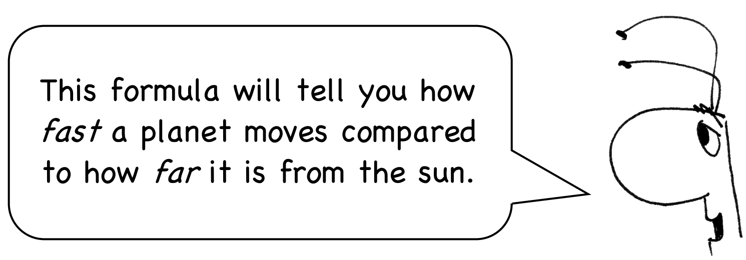
Neither of these assumptions is true. They are good approximations, but the difference is important because careful analysis of galaxy rotation curves reveal a problem: They don't spin according to Kepler's Laws.

Here is the problem. If we make predictions about the *velocity* of the planets in their orbits (as opposed to the *period* we did before) as a function of distance, we find out a different result. According to Kepler's Third Law, planets move faster when they are closer to the sun, causing their orbital periods to be shorter. The exact relationship is

$$v^2 = \frac{Gm_{sun}}{r}$$

or

$$v = \sqrt{\frac{Gm_{sun}}{r}}$$



1. For each planet listed in the table on the next page, compute its orbital velocity using this formula. You will need to use the following constants:

$G = 6.67 \times 10^{-11}$ (units, Nm^2/kg^2)

$m_{sun} = 2 \times 10^{30}$ kg

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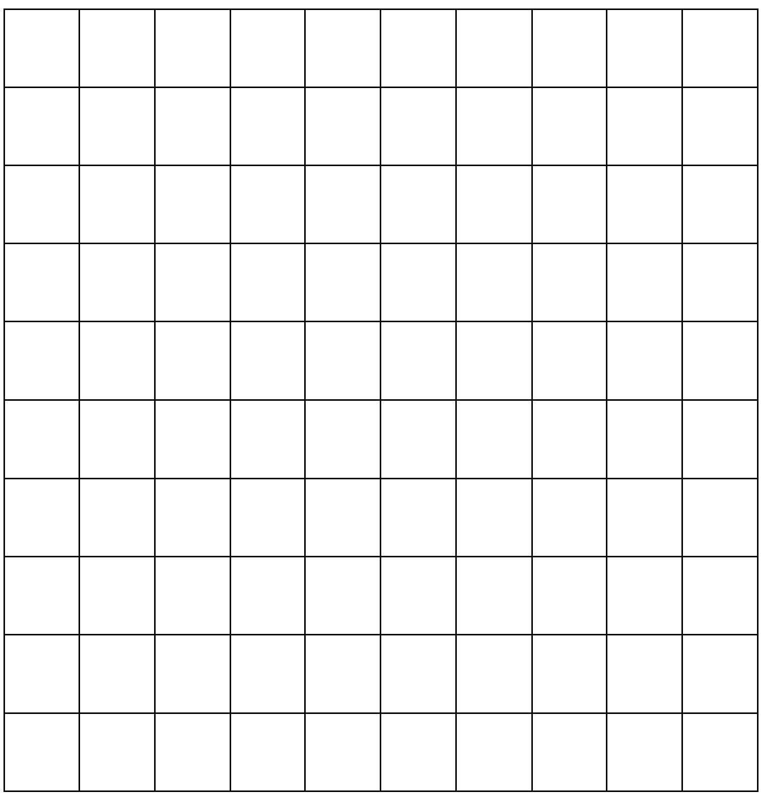
CA2 5.4.1: Dark Matter

Object	r=distance from sun (meters)	v=orbital velocity (calculated)
Mercury	5.7×10^7	
Venus	10.8×10^7	
Earth	14.9×10^7	
Mars	22.80×10^7	
Jupiter	77.8×10^7	
Saturn	142.6×10^7	
Uranus	287.3×10^7	
Neptune	450.1×10^7	

2. Now plot a velocity vs. distance graph on the grid below.



The shape of this graph can be described as **Keplerian**, meaning it closely follows Kepler's laws. The Keplerian orbits of the planets in the solar system obey this relationship because of the simplifying assumptions we mentioned earlier.

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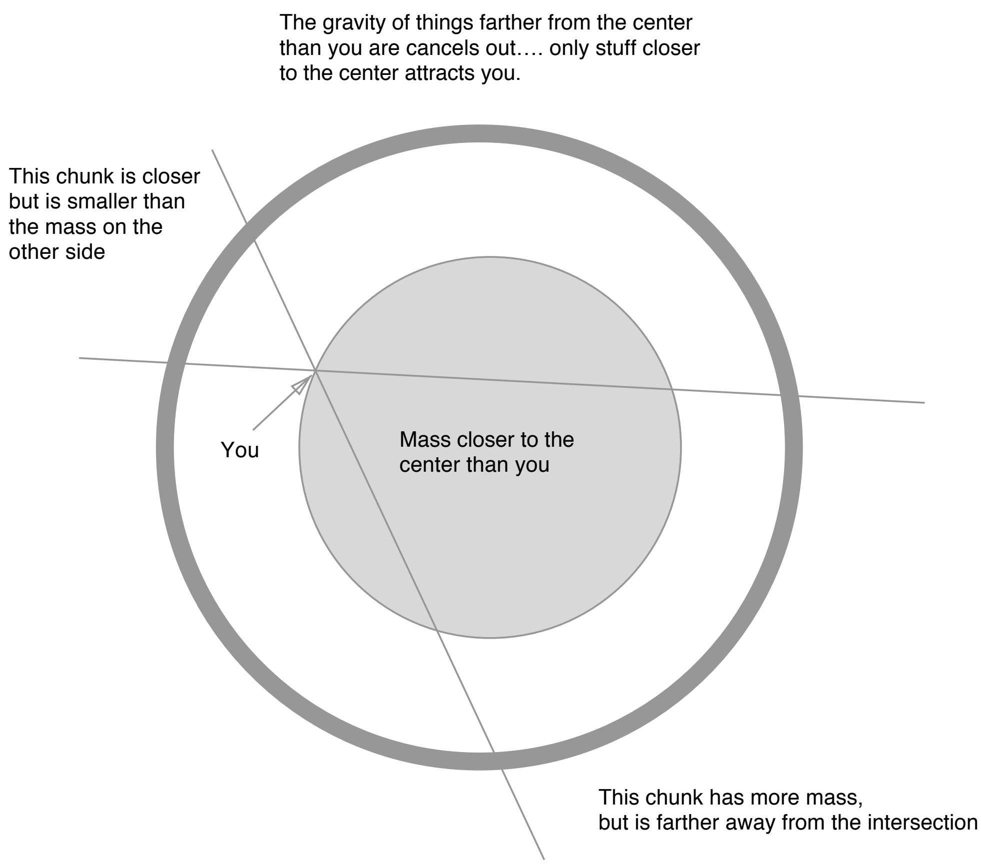
CA2 5.4.1: Dark Matter

The Problem with Galaxies

The problem with galaxies is that while they should be governed by Keplerian rules, they don't seem to be. In a simple Keplerian system, the closer you get to the center of the system (where the gravity originates) the faster you would go.

One problem that must be accounted for is that the mass is not all in the center of the galaxy, although most of it is. Even so, as you approach the center, some of the gravity that pulled on you is now behind you, farther away from the center than you are.

It turns out we can show mathematically that if you are *inside* a circular symmetrical mass, the mass that is farther out than we are does not contribute to the force on us any longer, as shown in the illustration below.



Thus, the closer to the center you get, the less mass is available to pull you into orbit. So instead of getting faster and faster as you get toward the center, the gravity weakens to the point where some of the mass moves slower in the center than it does at some intermediate distance. This is shown in the diagram on the next page.

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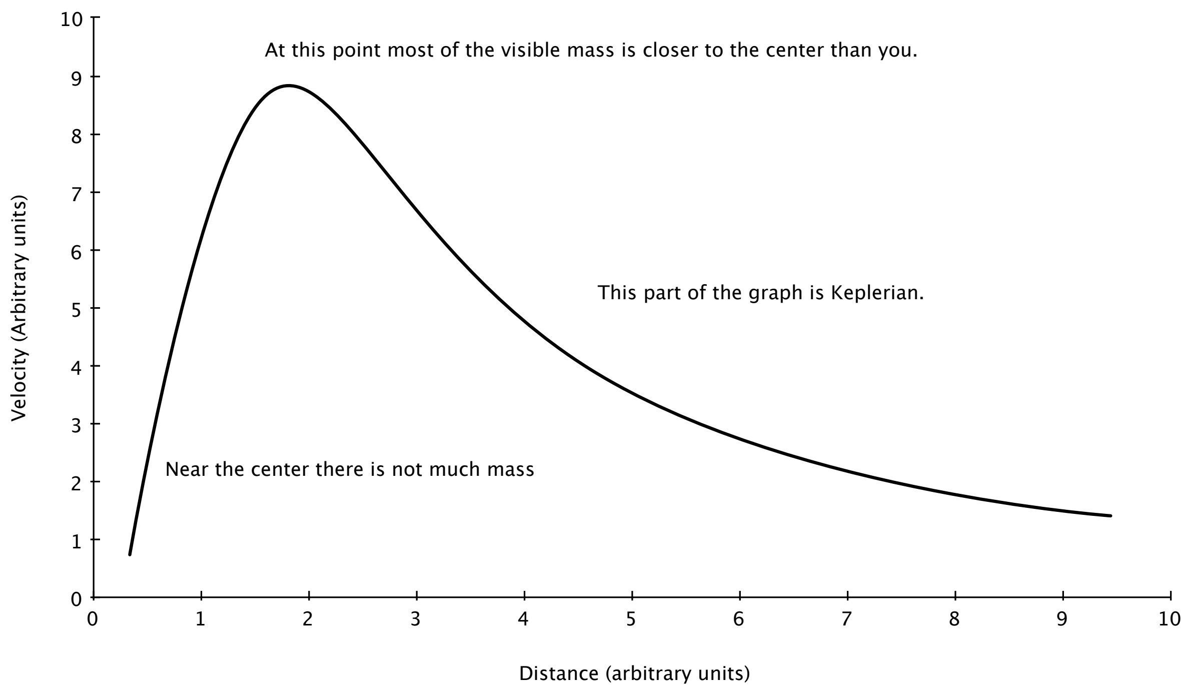
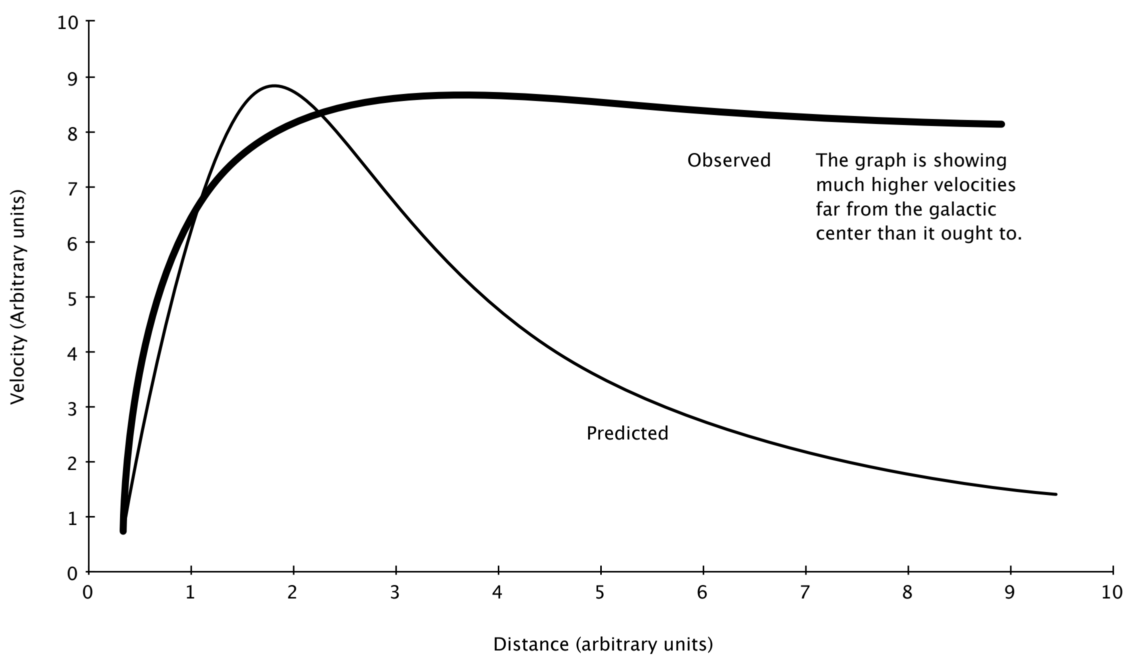
CA2 5.4.1: Dark Matter

This graph shows the predicted rotation curve for a galaxy, from the center towards the edge.



So what's the problem?

When astronomers measure the **rotation curves** of galaxies, they don't see this pattern at all. Instead, they see this:



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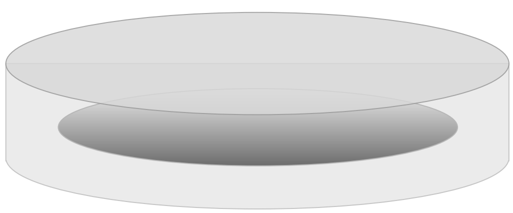
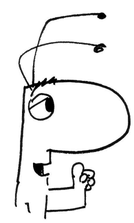
CA2 5.4.1: Dark Matter

Clearly these graphs do not match. The problem, as shown above, is that the velocity of objects far from the center of the galaxy (like us, for example) are not moving as slowly as they ought to. And it's not a measurement error or uncertainty, either; the error is *way* off, indicating a fundamental problem with how we model the behavior of spinning galaxies.

We have already seen that if most of the mass in a gravitationally bound system is farther from the center than you are, the rotation curve can change its shape. Using these idea astronomers Jan Van Oort and Fred Zwicky postulated that the galaxy may be embedded in a material that has mass and causes gravitational attraction, but has few other observable properties. Among other properties, this so called **dark matter** must have the following:

- It doesn't reflect light (because we can't see it)
- It doesn't retain or radiate heat
- It doesn't cause significant friction





Van Oort and Zwicky proposed that if the galaxy was embedded in a volume of invisible dark matter larger than the visible parts we see, the rotation curve would be as we observe it. Galaxy rotation curves are the principal piece of evidence for dark matter.

No one knows what dark matter is yet, but it is a subject of intense research. While galaxy rotation curves were the first place where it was noted, it has also been observed affecting the rotation of large clusters of stars and causing **gravitational lensing** or the bending of light by gravity.

3. How do you think the rotation curve would be different if dark matter added just a little more mass to the galaxy instead of the amount it does?

Current estimates are that dark matter is more than 90% of the mass of the universe! That means the parts we see (stars, galaxies, supernovas, AGN, etc.) account for less than 10% of the mass of the universe. That means this entire course has been about only 10% of the universe, and this one activity you are now reading is all the instruction you get about 90% of the universe. Just when we think we're figuring everything out in astronomy, we discover we're just getting started.

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CA2 5.4.2: Dark Energy: Activity

Purpose: To explain the need for a theory of Dark Energy.

Background: Dark Energy is sometimes confused with Dark Matter, but the two theories are unrelated. Where Dark Matter was invoked to explain "local" anomalies in galaxy rotation curves and effects caused by Einstein's theory of gravitational lensing, Dark Energy is more "universal." It is a theory born of a surprising discovery.

Measurements of red shifts in 1998 led to the discovery that the universe is expanding in an unexpected way. Prior to this discovery, most astronomers assumed the universe was expanding in one of three logical modes:

- Expanding at a steady rate, never slowing down, for all time.
- Expanding at a decreasing rate, slowing, but never stopping, for all time.
- Expanding at a decreasing rate, eventually slowing to a stop and contracting again (The "Big Crunch.")

The observations took everyone by surprised because they revealed a fourth option. According to current observations, the universe is behaving with a fourth, unexpected mode.

- Expanding at an accelerating rate.

The significance and unexpected nature of this observation is … well, astronomical. The reason no one expected it is because there is no known force of nature that could drive it. For example, from what we know about nature from studies of physics, there are only 4 candidate forces of nature to cause the effect. None of them fit the bill.

Force	**Disqualifying effect preventing it from causing dark energy**
Strong nuclear force	extremely short-ranged
Weak nuclear force	extremely short-ranged
Electromagnetic force	The universe is, overall, mostly neutral. Everything cancels out.
Gravitational force	Only repels; doesn't attract

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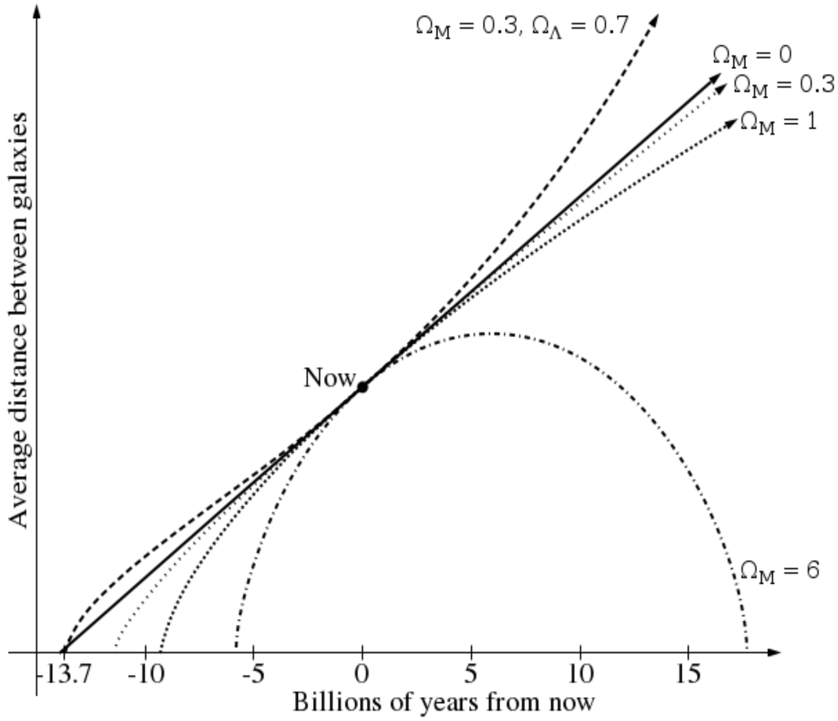
CA2 5.4.2: Dark Energy: Activity

How was this "force" called Dark Energy discovered and later characterized?



As this standard cosmology diagram shows, there are several scenarios for the universe which yield relatively flat measurements for the Hubble Constant marked "Now" but diverge into separate eventual outcomes. The guided questions below will help you interpret the graph.

1. What is on the y-axis?

____

____

2. Where would galaxies that are relatively close together be plotted?

____

3. What is on the y-axis?

____

4. Where would galaxies be that existed near the Big Bang?

____

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CA2 5.4.2: Dark Energy: Activity

5. According to the chart, was there ever a time in the distant past when the average distance between galaxies was very large?

___

6. Where on the x-axis is the present time?

___

___

7. The **parameter** (factor) omega (Ω) in this chart refers to the relative influence of mass (M) and dark energy (Λ) in the expansion model. If Ω_Λ isn't listed, then it would be zero in the model. This means that the existence of dark energy isn't required to explain the observations.

The curve at the top of the diagram is the one that is closest to our current understanding of how the universe is put together. Which curve represents a universe with no dark energy and a constant mass?

___

8. Which curve do you think represents the Big Crunch model, where galaxies eventually stop and collapse in on themselves?

___

___

So what *is* Dark Energy? There are several competing theories. One says that it is a heretofore undiscovered property of gravity—that we do not understand the way gravity behaves at tremendous distances as well as we thought we did. Another idea is that Dark Energy represents a sort of fifth force of nature that has the property of repelling matter, and repelling it more strongly with increasing distance, a property we have never observed in other forms of force-at-a-distance interactions. It is sometimes referred to as "Anti-gravity" by these researchers, although they do not mean the kind of anti-gravity that is sometimes seen in movies.

Whatever Dark Energy is, in a few years the theory will either be better defined and we will note this period in time as when we first discovered it, or it will become another discarded theory of science, superseded by something that explains our observations even better. We have not done all the science that can be done, even now. Discoveries continue to be made and research continues in labs and observatories all over the world.

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CA2 5.5: Hot Jupiters: Activity

Purpose: To point out the apparent contradiction of Jupiter-sized planets existing close to their home stars.

Background: For most of human history, the visible planets and the ones discovered by telescopes were all that we knew. While many people wrote stories about other planets, there was no definitive proof that such planets actually existed. In the 1990's the technology of large telescopes, adaptive optics, and digital photography allowed us to discover **Exoplanets** for the first time. Planets beyond the solar system went from a single discovery, to a collection of planets in other solar systems, and now we have evidence of thousands of planets in nearby solar systems.

When all we knew was one solar system, certain theories were developed about the formation of the solar system. The discovery of Exoplanets allowed us, for the first time, to test these theories and see if they were correct.

According to the **nebular hypothesis**, which was formulated as early as the mid-1800's, the sun was created from a collapsing nebula. Absent any other external force, a gas nebular will naturally contract due to the law of gravity. If it contracts fast enough, the mass will compress in the center, grow hotter, and eventually initiate nuclear fusion, becoming a star. Any small rotation present in the gas would be concentrated in the star, and it, as well as any other planet orbiting it, would all rotate the same way.

All that fits well with observations of our solar system and others. One additional observation was the idea that in our solar system, the smaller rocky terrestrial planets formed near the sun, and the larger gas giants formed far from the sun, and such formation was not accidental. During the early formation of the system, the sun's **solar wind** of radiation pushed lighter gases away from the center of the system, leaving small rocky planets near the center, and large gas giants much farther away, where the sun's radiation is not intense enough to push the gas away. The same effect makes comet tails point away from the sun.

Even if a planet like Jupiter formed near the sun, the theory said, it would not be able to retain a lightweight atmosphere for long, because the sun's heat would cause the occasional molecule to reach **escape velocity** and essentially "leak" into space. The lighter elements hydrogen and helium would be lost first, because they are less massive particles and more likely to reach escape velocity. Escape velocity is determined by imagining a particle falling from an enormous distance and having it strike a planet due to gravitational attraction. If you project a particle upward at this velocity or higher, gravity will not be able to slow it down and make it return. Thus it escapes the influence of the planet's gravity.

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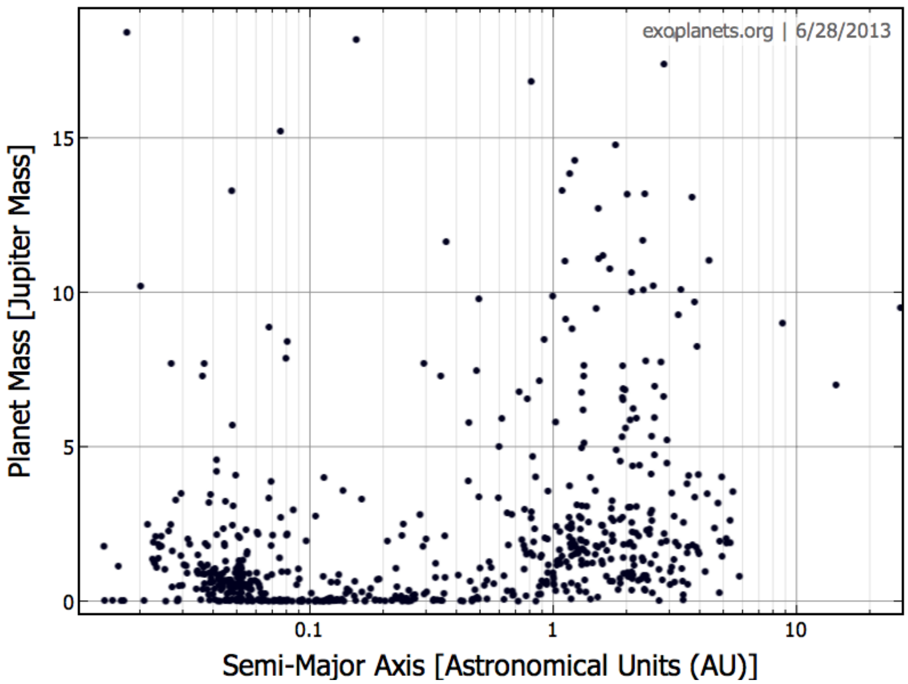
CA2 5.5: Hot Jupiters: Activity

The problem arose when astronomers began measuring the properties of planets in other solar systems. We expected to find variations on a theme: rocky inner solar system, gas giant outer solar system. The graph below, from www.exoplanets.org, shows what we actually found.



Answer the following questions about this graph.

1. Each dot represents one planet discovered outside of our solar system. The x-axis is how far the planet is from its sun in **Astronomical Units.** Recall 1 AU is the distance between the earth and sun. The y-axis is the mass of the planet, where 1 = Jupiter's mass. Why do you think they used Jupiter's mass instead of Earth's?

____

____

____

2. Find the one planet on the chart that is more than 15 Jupiter masses and farther from the sun than the earth. Circle it.

3. Which kind of planets are more common? Smaller or larger planets?

____

____

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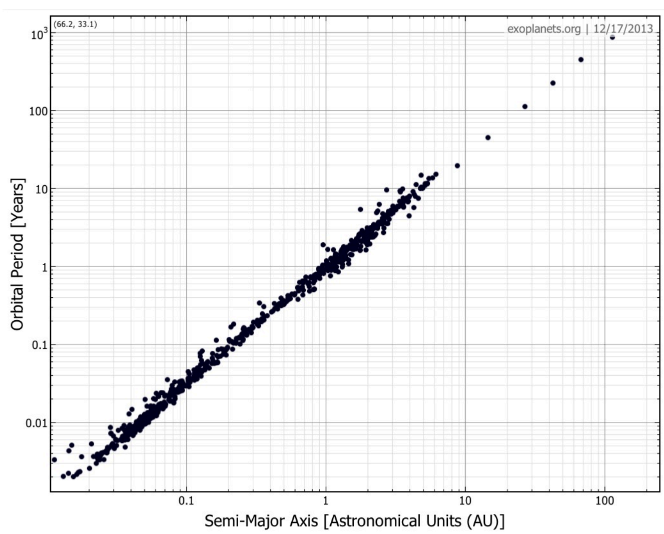
CA2 5.5: Hot Jupiters: Activity

4. Draw a line showing all the planets closer to the sun than Mercury (approximately 0.4 AU). Draw another line showing all the planets more massive than Jupiter (M = 1). Circle the region that shows *planets more massive than Jupiter that are closer to the sun than Mercury.*

There isn't a precise definition, but certainly these planets represent what we refer to as **hot Jupiters**, planets that are much hotter than Jupiter because they are so close to the sun. The mystery is how did such planets come to be in these locations, when well-understood theories predict they should not have formed there in the first place?

The best theory at the time of this writing (2013) is probably that the giant Jupiters formed far from the sun, as we expected, but that they eventually *moved* inward once formed. With sufficient size and gravity, they could last millions of years at positions closer to the sun than Mercury. As the chart shows, most of the ones we have found are larger than Jupiter. That isn't because most planets are larger than Jupiter, it's because planets larger than Jupiter are easier to detect.



The chart at left shows another example of the kind of data that can be plotted at the exoplanets.org interactive web site. This section is optional and may or may not be assigned by your teacher. (Ask.)

5. Note that both the x-axis and y-axis of this graph are *logarithmic*. The scale is not equal-valued; each box to the right is 10 x the value of the previous one on the x-axis, for example. Graphs of this type take the form $y=x^{slope}$. Find the slope of the line (hint: it's a fraction) and substitute the quantities on the axis for x and y.

Write down the function that this graph reveals about planets in all solar systems.

____

____

6. Where have you seen this rule displayed before? What is it called?

____

____

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CA2 5.5: Hot Jupiters: Activity

7. Consider investigating other graphs that can be generated at the exoplanets.org web site. This may be assigned by your teacher as an extension or challenge activity. Use the space below to make notes about the choices you made for the x-and y-axes, and to discuss what patterns you think the graphs may reveal.

X-axis:
Y-axis:
Sketch of graph:

Interpretation:

X-axis:
Y-axis:
Sketch of graph:

Interpretation:

X-axis:
Y-axis:
Sketch of graph:

Interpretation:

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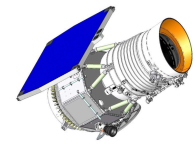
CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab



Purpose: To create a color picture using images obtained from the WISE infrared space telescope, and to gain links and references about where students and teachers might obtain more original images from space missions for projects.

This project is based on "Light Detectives," developed by Jeff Adkins, Stephen Sundin, and Nia Imara of the Berkeley Space Sciences Laboratory at UC Berkeley, California, and is used with permission. The "Light Detectives" project originated as a Brown Dwarf search project developed by teacher Chris Martin and his students in Tucson, Arizona.

Detecting Brown Dwarfs: a WISE Student Activity Using NASA images

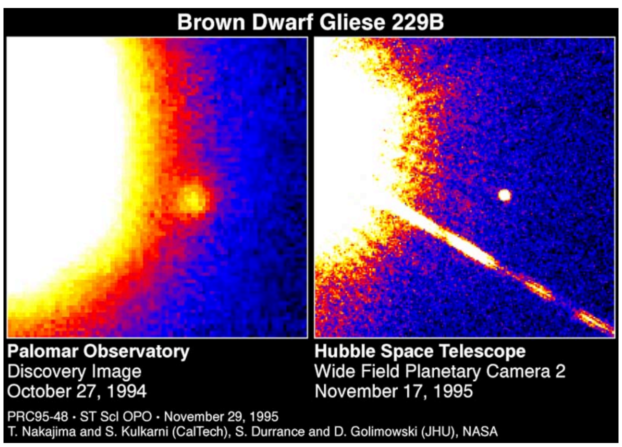
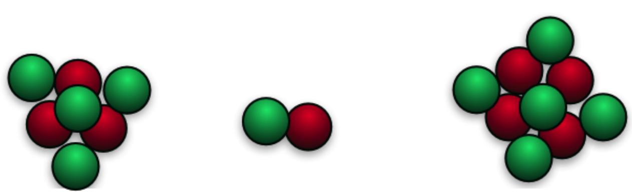


Figure 4. A photo of a brown dwarf.

Student background:

What's bigger than a planet but smaller than a star?

Astronomers call such an object a *brown dwarf*. The image to the left shows a picture of a brown dwarf orbiting a star about 19 *light-years* from Earth. The definition of a brown dwarf has more to do with what is happening inside of it than some arbitrary definition based on size. In a star, nuclear *fusion* fuses hydrogen into helium and other elements while releasing energy. This is what makes the Sun and all the stars shine. In a planet, no fusion occurs.
In a brown dwarf, fusion occurs but it is deuterium and lithium that acts as the fuel. Deuterium is an isotope of hydrogen with a neutron in its nucleus (normal hydrogen does not have a neutron).



$$^{7}_{3}\mathrm{Li} + ^{2}_{1}\mathrm{H} \rightarrow ^{9}_{4}\mathrm{Be}$$

Figure 1. This equation shows how Lithium and Deteurium (Heavy Hydrogen with one extra neutron) can fuse to make Beryllium.

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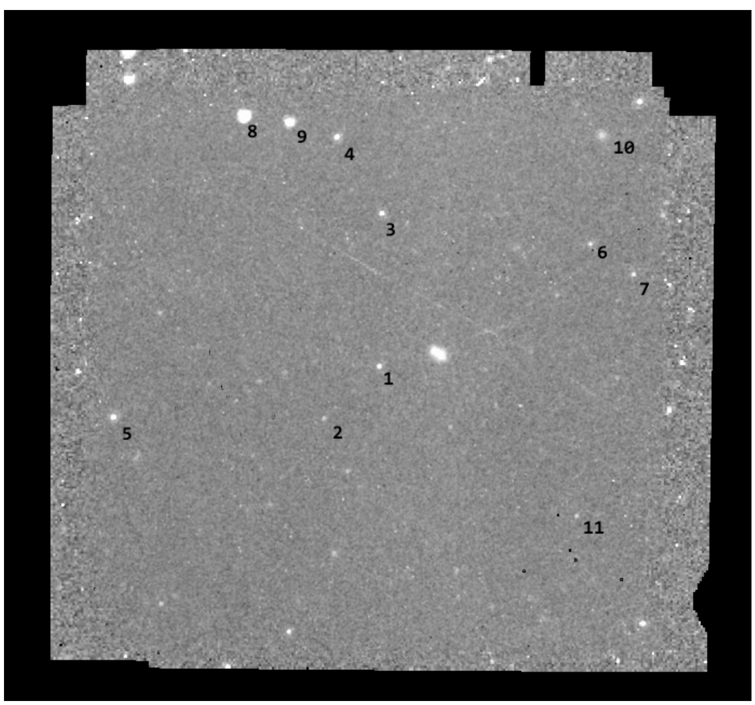
CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

For most brown dwarfs this fusion reaction does not last for long and the object otherwise cools. It generates energy only through gravitational contraction after that. The masses of brown dwarfs range from not smaller than around 13 times the mass of Jupiter to about 80 times the mass of Jupiter. Objects less massive than 13 times the mass of Jupiter would be classified as giant planets; objects more massive than 80 times the mass of Jupiter probably fuse hydrogen and would be called stars. These are the kind of objects that the WISE mission will be searching for.

In this activity you will measure and analyze the light from a number of objects in a photo taken by researcher Giovanni Fazio. The images were taken by the Spitzer Space Telescope. They are very similar to what the WISE mission will generate. By examining the brightness of a star at different wavelengths of light, you will be able to tell whether or not it is a brown dwarf. The range of wavelengths you will use is in the infrared portion of the electromagnetic spectrum.

The procedure that follows will show you how to measure the brightness of an object in 3.6, 4.5, and 8 microns. These are referred to as Channel 1, Channel 2, and Channel 4 respectively. Then you will plot the values you obtain on a graph.

The diagram below is called a Finder Chart. It contains a list of the targets you will measure. The numbers are arbitrary. The targets were selected because they appear in each of the three images you will analyze.



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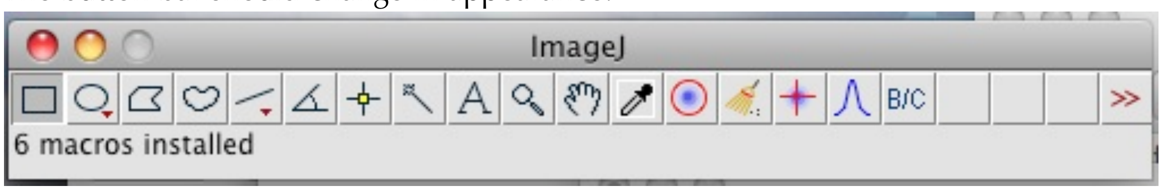
CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

Collecting Data

Image J instructions:

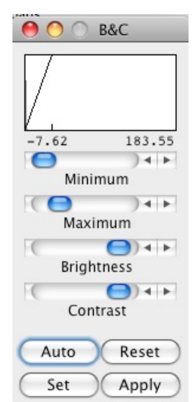
1. Open the Image J 1.42 folder and start Image J.
2. In the button bar that appears pick the double red arrow and choose Astronomy tools.

3. The button bar should change in appearance.



4. Choose Plugins/Astronomy/Set Aperture. On the first window that says "Set Other Aperture Photometry Parameters" click OK. On the second window that appears, "Aperture Photometry Parameters," enter as follows and click OK.
   a. Aperture Radius: 10
   b. Inner-sky radius: 12
   c. Outer-sky radius: 20

5. Choose Open from the File Menu. Maneuver to the Desktop and pick Brown Dwarf Project. Then Pick Brown Dwarf Images. Then pick Channel1.fits. Compare the image you see to the finder chart.



6. The image may initially appear blank. If so, pick Image>Adjust>Brightness and Contrast. Choose Auto once or twice until the image appears. If that doesn't work, try moving the Maximum slider slowly to the left until the stars appear in the image.

7. Locate star number 1 on the finder chart and see if you can find it in the image.

8. Choose the bull-eye button with the red circle from the button bar. (You can also pick Plugins>Astronomy>Aperture.) A red circle will appear in your image. A data table will pop up with numbers in it. There are many numbers in the table but you only need a few.

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CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

9. From the table copy the following numbers into your data table:
   x, y, source-sky
   Make sure you list the "Source-sky" number in the flux column corresponding to the wavelength of the picture. If you are measuring the 3.6 micron image, put the "source-sky" number under the 3.6 micron heading in the table.

NOTE: One ROW of the data table corresponds to ONE STAR. One COLUMN of the data table corresponds to data collected from ONE PICTURE.

Finder Chart #	x	y	C1: 3.6 micron flux	C2: 4.5 micron flux	C4: 8 micron flux	Ratio C2/C1 (x)	Ratio C4/C2 (y)	brown dwarf? y/n
1								
2								
3								
4								
5								
6								
7								

One row of numbers corresponds to the fluxes you measure from a single star, appearing in each of the three separate photos.

One column of numbers represents the fluxes you measured from several stars, all appearing in the same photo.

10. Measure all the finder chart stars in this fashion.

11. Open the next image (the Channel 2, 4.5 micron image) and zoom in to the same area. It is important you identify the same stars in the image. The finder chart can help you with this. For each of the stars you measured before, measure the same star again in the new image and add that data to the table. This new data goes in the next COLUMN of the table.

12. Repeat for the other image. There are three images altogether.

13. Stars that are bright with spikes coming out of the side or with black dots in the center are probably too bright to analyze (the pixels are overloaded with light). If the aperture circle is too small, you should either skip that star or adjust the aperture circle's size to accommodate the bright star.

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CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

Plotting the Color/Color Diagram

14. Compute the *ratio* of the fluxes. This means you take the 4.5 micron flux value (C2) and divide by the 3.6 micron flux value (C1). In the table enter your result in the column Ratio C2/C1. Remember, it is the ratio of C2 divided by C1. This may not result in an answer greater than 1.
15. Do the same thing for the 4.5 and 8.0 micron flux values. Enter these values in the column Ratio C4/C2.
16. Create a graph to plot these values, using C4/C2 as the horizontal (X) value, and C2/C1 as the Y value. Plot the values.

Analysis of the Diagram – Where are the brown dwarfs?

Brown dwarfs are noted for having an *absorption line* near the 3.6 micron wavelength. That means that due to the chemical composition of the brown dwarf, wavelengths near 3.6 microns are absorbed by the brown dwarf; the fluxes tend to be unusually low. This means that the ratio of the 4.5 micron flux to the 3.6 micron flux will tend to be high while other objects will have smaller values.

However, brown dwarfs are not the only objects that might have 4.5 to 3.6 flux ratios in that high range. Certain giant stars or dusty galaxies may also have similar ratios (or "color" as astronomers use the term). To separate out those objects we can look at the flux ratio between 8.0 and 4.5 microns. Brown dwarfs and stars will tend to have smaller flux ratios compared to the dusty galaxies and red giant stars.

Thus, brown dwarfs will tend to be higher, and farther to the left, than other stars (or background galaxies). Identify stars that might be brown dwarfs. Mark the location of these stars on the data table by checking the box in the "Brown dwarf?" column.

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CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

Questions (Easy):

1. Define a brown dwarf.

____

____

____

2. If an object is cooler than a brown dwarf, it would be a ….

____

3. If an object is hotter and more massive than a brown dwarf, it would be a….

____

4. What does the software measure, exactly, when you click on a star?

____

____

____

5. What sources of error might there be in this experiment?

____

____

____

Questions (Challenging/Optional):

6. Describe objects that would appear in the lower right corner of the graph. Compare your graph to the appearance of the stars in the image. Where are the brightest stars? The dimmest stars?

____

____

____

7. What is the Inner and Outer Sky radius for in the software?

____

____

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CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

Data Table:

Finder Chart #	x	y	C1: 3.6 micron flux	C2: 4.5 micron flux	C4: 8 micron flux	Ratio C2/C1 (x)	Ratio C4/C2 (y)	brown dwarf?y/n
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								

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CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

Graph for Flux Ratios

You should label the axes as instructed in the directions.

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CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

Going further:

Since this activity uses real data, there are questions which might be asked that are not part of the original instructions.

Is there a relationship between the likelihood a star is brown dwarf and its position in the picture, or it's proximity to other stars?

Dr. Fazio investigated over 2 dozen brown dwarfs in his proposal. Images are available for analysis by using the Spitzer Science Center's Leopard tool. Enter the proposal number in the search field and you can have other images to analyze.

Software you might need for this lab:

Image J 1.42 was downloaded from:
http://rsbweb.nih.gov/ij/download.html
The -64 version was removed as unneeded.

Astronomy Plug-in downloaded from:
http://www.astro.physik.uni-goettingen.de/~hessman/ImageJ/
and installed manually into the Plug-in and Macros folders as instructed.

APT is available for other platforms from this address:
http://spider.ipac.caltech.edu/staff/laher/apt/

JAMA 1.0.1 downloaded from:
http://math.nist.gov/javanumerics/jama/#Package and installed in the Plug-in folder.

References

The four images are of a target selected by researcher Giovanni Fazio. They were obtained from the Spitzer Space Telescope through the Leopard archive tool, using proposal 40198 written by Dr. Fazio.

The Brown Dwarf project was originally designed by Chris Martin and his students at Howenstine High Magnet School. Revisions and instructions were made by Jeff Adkins and Stephen Sundin at Deer Valley High School in Antioch, California.

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CA2 5.6: Accessing and Using Observatory and Space Mission Data: Lab

X Y coordinates of the targets
(in case you cannot decide if a particular star is one of the ones on the finder chart.)

Finder	x	y
1	1151	471
2	1100	422
3	1153	612
4	1112	683
5	905	424
6	1346	584
7	1387	556
8	1024	704
9	1067	697
10	1357	684
11	1334	334

Sources for space probe images for use in other projects

Source	Address
MARS GLOBAL SURVEYOR	http://ida.wr.usgs.gov/graphical.htm
SPIRIT AND OPPORTUNITY	http://marsrover.nasa.gov/gallery/all/opportunity.html
CASSINI	http://www.ciclops.org/search.php
CURIOSITY	http://mars.jpl.nasa.gov/msl/multimedia/raw/
HUBBLE	http://hla.stsci.edu/hlaview.html
HUBBLE IMAGE PROCESSING TUTORIAL	http://hubblesite.org/get_involved/hubble_image_processors/
INFRARED IPAC SCIENCE ARCHIVE	http://irsa.ipac.caltech.edu
HEASARC (HIGH ENERGY ASTROPHYSICS)	http://heasarc.gsfc.nasa.gov
FERMI	http://fermi.gsfc.nasa.gov/ssc/data/access/
WISE IMAGE EXAMPLE INSTRUCTIONS	http://wise.ssl.berkeley.edu/edu_accessing_images2.html
IMAGE J	http://rsbweb.nih.gov/ij/
TUTORIAL ON USING IMAGE J WITH ASTRONOMY PLUGINS	http://www.astro.physik.uni-goettingen.de/~hessman/ImageJ/Book/Making%20Color%20Images/index.html

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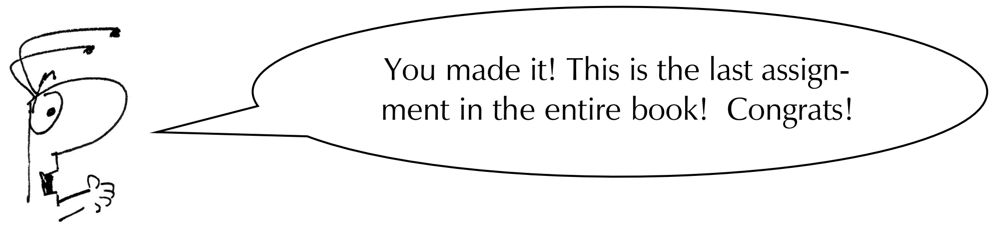
CA2 5.7: The Edge of What We Know Puzzle

Some of the terms in the puzzle have spaces. These are marked with a (shaded box).



1	2	3	4 (shaded)	5	6	7	8	9	10 (shaded)	11	12	13 (shaded)	14	15 (shaded)	16	H	17	18	19
20 (shaded)	21	22		23	24	25	26	27		28	29	30	31	32	33	34	35	36	37
	C	38	39	40	L	41	X	42	43	44		45	46	47		48	49	C	H
50	51	S	S		52	53	54		S	T	55	56	N	G	57	N	58	S	S
	T	H	59	T		I	S		60	61	S	62	L	63	T	64	L	Y	
65	66	67	S	O	68	69	.			D	O	U	G	L	A	S		A	D
A	70	S																	

1. _(9) _(7) _(14) K _(3) _(4) _(26) Q _(23) _(35) _(1) _(11) _(6) _(18) FORMULA FOR ESTIMATING THE NUMBER OF ALIENS
2. _(22) _(37) _(27) _(39) _(17) PROBLEM BASED ON ESTIMATING VALUES
3. _(32) _(45) _(31) K _(10) _(68) _(52) _(16) _(24) _(41) _(48) MYSTERIOUS SUBSTANCE WITH GRAVITY AND NOT MUCH ELSE
4. _(47) _(56) _(55) K _(13) _(51) _(29) _(57) R _(19) _(44) SORT OF LIKE ANTIGRAVITY
5. _(40) R _(28) _(70) _(58) _(15) _(34) _(63) M _(61) _(64) R A NUMBER DIVISIBLE EVENLY BY ITSELF AND ONE ONLY
6. _(2) _(21) _(25) JUPITER-SIZED PLANETS CLOSE TO THE SUN
7. B R _(30) _(5) _(46) _(20) _(54) _(66) _(59) R F BIGGER THAN A PLANET SMALLER THAN A STAR
8. K _(67) P _(8) _(69) R _(33) _(60) _(50) AN ORBIT THAT FOLLOWS KEPLER'S LAWS
9. W _(42) _(12) E WIDE-AREA INFRARED SPACE EXPLORER
10. R _(38) _(36) _(65) _(43) _(49) _(62) _(53) PROPERTY OF GALAXIES THAT REVEALS DARK MATTER

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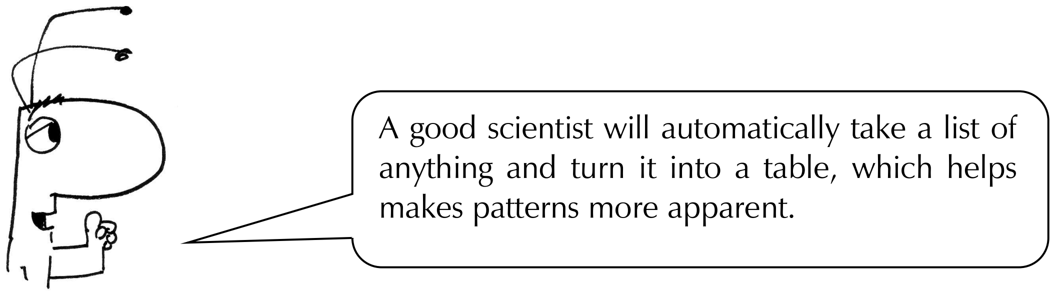
Appendices and Tables

This section contains tables of information used in labs and activities. You might find the information useful for projects involving modeling as well.



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Conceptual Astronomy 2: Glossary

Absolute magnitude – the magnitude of a star as it would appear if it were 10 parsecs, or 32.6 light years, from the Earth.

Absorption line – in a spectra of a star or brown dwarf's light, certain colors or wavelengths are absorbed by the object's atmosphere. This causes a particular color may be dimmer, or even missing, from an object's spectrum. Absorption lines are used to identify the composition of a star, and its radial velocity through the Doppler effect.

Acceleration – the rate of change of velocity.

Accretion disk – material orbiting a black hole or other object in space that is slowly accumulating material falling inward.

Active galactic nucleus – a multi-billion solar mass equivalent black hole, found in the centers of some galaxies. They are characterized by enormous jets of material thrown from the area of the accretion disk before it falls into the black hole, and are the origin of quasars and other exotic objects in space.

Aperture – an opening in a telescope, camera, or virtual camera that allows light to enter.

Apparent magnitude – the magnitude of a star as observed from the surface of the Earth.

Arc minute – one sixtieth of a degree, usually denoted as ‘. 40 arc minutes = 40 ‘.

Arc second – one sixtieth of an arc minute, usually denoted as ′′. 30 arc seconds = 30 “.

Arms (of a galaxy) – strands or swirls of stars within a spiral galaxy.

Astronomical Unit (AU) – the distance from the earth to the sun.

Barred spiral galaxy – a galaxy with arms that begin in the central core of the galaxy at the end of an apparent straight segment, called a bar, that crosses the center of the galaxy. The Milky Way is a barred spiral.

Baseline (Base) – A side of a triangle used to determine unknown sides or angles.

Big Crunch – A theory of the fate of the universe that says the expansion of the universe will eventually end, causing the universe to contract.

Binary system – A star system with two suns.

Black dwarf – The eventual, theoretical state of a white dwarf that has cooled after many billions of years such that it no longer glows.

Black Hole – A dead core of a giant star (or several of them merged together) formed when a super massive star collapses during a supernova event. Black holes have so much mass light itself cannot escape.

Brightness – A slightly less technical way of describing flux, the amount of light that is detected in a camera observing a star or other object.

Brown dwarf - an object which is more than 13 times the mass of Jupiter and less than 80 times the mass of Jupiter, characterized by temporary fusion of deuterium and lithium.

CCD – A charged coupled device, a digital camera that uses photo sensors that detect individual photons. CCD cameras are used to measure brightness and flux.

Center of curvature – The center of the three-dimensional sphere matching the curvature of a lens or mirror. The distance from the center of curvature from the lens is twice the focal length.

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CA2 A.1. Glossary

Centripetal force – any force that makes an object move in a circular path.

Cepheid variable – a particular kind of variable star that has the property that the slower a particular star pulsates, the more massive and brighter it is.

Channel – usually refers to a particular color or wavelength measured by a filter and CCD combination.

Collision (of galaxies) – when two galaxies merge, and change shape due to mutual gravitational distortion.

Concave – a negative radius of curvature, concave surfaces "cave in."

Convex – a positive radius of curvature, convex surfaces "bulge out."

Continuous – a spectrum with all wavelengths represented. Incandescent bulbs emit continuous spectra.

Dark energy – a theory that the expansion of the universe is being driven by a mysterious additional force or property of gravity causing the expansion to accelerate.

Dark matter – a hypothesized substance that has a gravitational field but does not exhibit many other properties of normal matter. Dark matter affects the distribution of gravity in a galaxy or cluster of stars.

Dark nebula – a nebula of gas and dust that does not glow from internal or external sources of energy. It can obscure the view of things beyond it. Internal gravity can make a dark nebula collapse and become protostars or emission nebulas.

Declination – sky coordinate measured from the celestial equator towards the north and south celestial poles. It is similar to longitude on the Earth.

Deep field – a long term exposure of an image allowing the capture of extremely faint objects.

Degrees – a standard angular measurement. There are 360 degrees in a circle.

Deuterium – an isotope of hydrogen; has one proton and one neutron in the nucleus, whereas normal hydrogen has no neutron. Also known as heavy hydrogen.

Distance modulus – the difference between absolute and apparent magnitudes.

DNA – Deoxyribonucleic acid, the building block of life as we know it.

Doppler effect – an effect that causes waves from a moving source to become shorter, or blueshifted, as the object approaches, and longer or redshifted, as an object recedes.

Drake Equation – a formula devised by Dr. Frank Drake to estimate the number of intelligent species in the Milky Way.

Eclipsing variable – a variable star caused by an object covering or blocking a star, especially periodically.

Electromagnetic force – a fundamental force of nature that encompasses both electric and magnetic fields.

Electron degeneracy pressure – the force separating atomic nuclei in a white dwarf.

Elliptical galaxy – a galaxy shaped like a spiral disk, wider than it is thick, with winding spiral arms.

Emission nebula – a nebula, usually consisting of hydrogen, lit from inside, energizing the nebula and making it appear reddish pink. Stars are often formed in emission nebulas.

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CA2 A.1. Glossary

Escape Velocity – the velocity an object must have in order to never return to the surface of the body it is leaving.

Event horizon – the position near a black hole where the escape velocity is equal to the speed of light.

Exoplanets – planets in other solar systems.

Expansion – the observed effect of galaxies moving away from each other as time passes.

Extrapolate – to use a pattern of data and estimate values beyond those measured.

Eyepiece – the lens of a telescope closest to the observer's eye.

Fermi problem – a kind of problem that can be analyzed for the factors involved and estimated in a small amount of space, such as the back of an envelope.

Field star – a star in the vicinity of a cluster, appearing in the image with a cluster, but not a member of the cluster.

Flowchart – a diagram that shows step-by-step processes that are time based or require decisions.

Flux – a measurement of the amount of light reaching a detector per unit area, per unit time. The flux is determined by both the brightness of the source and the amount of time the light is allowed to accumulate on the detector. The brighter a source is, the larger its flux will be.

Focal length – the distance between a lens and its focal point.

Focal point – the point where a double-convex lens or concave mirror converges light to a point from light coming from a distant source.

Force – a push or pull.

Fusion - a nuclear reaction in which the nuclei of two atoms are combined together to create a new element, and in the process energy is released

Galaxy –A large group of millions to billions of stars, of various shapes (spiral to elliptical to irregular). All other stellar phenomena are in a galaxy (nebulas, supernovas, etc.)

Geometric parallax – triangulation on the distance to an object using geometry. Depends on the observer moving and observing from two widely separated positions. Sometimes just called "parallax."

Giant star – a star larger than the sun, both in mass and volume. Resides near the top of the H-R diagram.

Globular cluster – a large spherical cluster of stars from hundreds of thousands to a million stars, found orbiting galaxies in a shell surrounding the galaxy. Most globulars are not in the galaxy or in the plane of the galaxy.

Gravitational force – a fundamental force of nature. All bodies in the universe attract each other with a force proportional to mass and inversely proportional to the square of the distance between them. Gravity is the weakest of the four forces of nature.

Gravitational lensing – a phenomenon that is caused by large objects in space bending light around them, acting as a gigantic lens that can focus the light of objects even farther away but located behind them from our point of view.

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CA2 A.1. Glossary

H-R diagram – a graph of Luminosity vs. Spectral class (or any of several equivalent variants) that shows stars in a stable nuclear fusion of hydrogen state (the main sequence) or stars that are changing into giants or white dwarfs as they die.

Hot Jupiters – planets as large or larger than Jupiters, located relatively close to their suns. The discovery of Hot Jupiters was a surprise to planetary scientists, expecting giant planets to be far from the sun as in our own solar system.

Hour Angle – the number of hours until an object reaches the meridian.

Hubble constant – the slope of a velocity vs. distance diagram for galaxies. The Hubble constant changes as new values are measured but typically hover around 70 km/s/Mpc.

Hubble expansion law (Hubble's Law) – most galaxies are moving away from each other at a velocity proportional to the distance between them. The farther apart they are the faster they separate.

Hubble fork diagram – a diagram created by Edwin Hubble to show a possible evolutionary path for galaxies as they age. While still used for classification, the evolutionary sequence is now thought to be driven primarily by collision effects.

Infrared – electromagnetic waves longer than red, primarily noted for delivering heat.

Intergalactic Medium – the (extremely sparse) material between the galaxies. Over thousands and millions of light years, this material (dust and gas) can interact with material.

Intermediate size black holes – black holes formed from individual mergers of single stellar mass black holes.

Interpolate – to estimate between known or measured values of a quantity. Usually considered more reliable than *extrapolation*.

Intrinsic – a characteristic inherent to the structure of an object and not caused by the observer's position or intervening material. A student might say "how bright is *really,"* when they are asking about a star's intrinsic brightness or size.

irregular galaxy – a galaxy that is disorganized or not symmetrical. These are usually smaller than other types.

Jet – a stream of material ejected from the vicinity of various astronomical phenomena such as active galactic nuclei or newborn stars.

Kepler's Laws – Laws that govern the movement of planets as they orbit the sun. For details on these laws see Volume 1.

Keplerian orbits – Orbits that obey Kepler's laws. Non-Keplerian orbits are due to some intervening force.

Light curve – a graph of brightness vs. time.

Light year – the distance light travels in a year, approximately 6 trillion miles.

Magnetar – a neutron star spinning and generating an unusually large magnetic field.

Magnitude – a system of measuring star brightness based on the human eye. 6^{th} magnitude stars are generally accepted as the dimmest thing the human eye can see.`

Main sequence star – a star that is fusing hydrogen in its core and lies upon the main sequence line on the H-R diagram.

Mass – a resistance to changes in inertia. Measured in kilograms.

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CA2 A.1. Glossary

Meridian – an imaginary line in the sky from North, through zenith, to South.

Micron – a unit of length, used by astronomers to measure wavelengths of light in the infrared section of the electromagnetic spectrum. Larger numbers have longer wavelengths and are less energetic than waves with smaller values. Equal to one millionth of a meter.

Nebular hypothesis – the theory that the solar system formed from a nebula, which condensed due to internal gravity to form the sun and the planets.

Neutron star – a dead core of a star consisting of essentially neutrons in contact with each other. Neutron stars are extremely dense. They spin rapidly and occasionally some emit radio waves that can be detected by astronomers, in which case they are called *pulsars*.

Nova – an exploding star. A *classic nova* is a system consisting of a red giant star dumping material on a white dwarf companion due to gravitational tides.

Nucleus (of a galaxy) – the central bulge of a galaxy, especially spiral galaxies.

Open (Galactic) Cluster – a cluster consisting of dozens to thousands of stars. These clusters are typically located within the plane of the galaxy. Astronomers study clusters because they offer some control over interfering variables of distance and age of the cluster.

Parallax – a shift in position of an object due to movement of the observer. The amount of shift expressed as an angle is called the *parallax shift* or the *parallax angle*.

Parsec – a *parallax-arc second*, a unit of length derived from a star having a parallax angle of one arc second with a baseline of 1 AU. 1 parsec (pc) = 3.26 light years.

Peak wavelength - The brightest color in a star's or brown dwarf's spectrum. The peak wavelength of light of a star acting like a blackbody can be used to determine the star's temperature. Brown dwarfs, however, do not exhibit classic blackbody radiation characteristics because the strong absorption of light in certain wavelengths.

Period luminosity relationship – a relationship between the period of variation and the average luminosity of a star. Generally the larger the star the slower it pulsates. This variation is noted most in stars called Cepheids which show a direct relationship between the variables.

Planetary nebula – the leftover husk of a dead sun like star. Planetary nebulas usually appears as circles or pairs of cones, with a white dwarf that was originally the core of the star that died.

Plate scale – for CCD photography, the number of pixels per arc second in an image.

Prime number – a number divisible evenly only by itself and 1. Prime numbers starting from zero are 1, 2,3,5,7,11,13,17, and so on.

Protostar – a star in the process of forming.

Pulsar – a rotating neutron star that emits radio waves that can be detected from Earth.

Quasar – a *quasi-stellar* object. Quasars are the jets of active galactic nuclei, aimed directly at the earth. From a great distance quasars look like stars in images.

Quiet galaxy – a galaxy without a super massive black hole or with a black hole that has no material falling into it.

Radians – unit of angular measure. 180 degrees = π radians.

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CA2 A.1. Glossary

Radio galaxy – a galaxy that emits large amounts of energy in the radio part of the electromagnetic spectrum. Many radio galaxies are made from jets of material leaving the vicinity of an AGN and interacting with the intergalactic medium.

Red Giant – a star that is near the end of its life. Stars that leave the main sequence as hydrogen burning ends in the core become giants as they start to fuse helium and larger elements.

Redshift – a change in frequency of a source of waves due to motion of the source (or the observer) because the source is getting farther away from the observer. Most galaxies are "redshifted."

Right ascension – a sky coordinate based on 24 hours RA = 360 degrees. 0 h RA is located at the vernal equinox in the sky and increases to the east (left) of that point until it returns to the same location in 24 hours. RA is useful because it can be used directly to estimate hours of visibility base on the hour angle (HA) of a star and its RA.

Rotation curves – a graph of velocity vs. distance from the center of galaxies to the edge.

Seyfert galaxy – a kind of AGN that is a spiral galaxy viewed at an angle that reveals the extra radiation in the core but does not have the central black hole's jet aimed at the earth. In short exposures Seyferts resemble stars.

Simulation – a mathematically calculated model of reality.

Solar wind – particles and radiation emitted by the sun (or stars, called the *stellar wind*) that can exert pressure on gas or dust in a system.

Spaghettification – a tidal stretching effect theorized to occur to as objects fall in to the singularity at the center of a black hole.

Spectra – the colors of a star separated into separate wavelengths; in everyday language, a spectra is a *rainbow*. Plural of spectrum.

Spectral class – stars sorted into categories based on temperature and spectral line patterns; the names of the categories are OBAFGKM. O is hot, M is cold.

Spectrascope – a device that takes starlight and produces a spectra.

Spectroscopic parallax – a method of determining the distance to a star by estimating its absolute magnitude (due to its spectral class) and comparing it to its apparent magnitude.

spectrum graph- A graph of a star's brightness as a function of the colors of light it emits. On these graphs, the brightness of the light is on the Y-axis, and the wavelength or color of the light is on the x-axis.

Spiral galaxy – a galaxy that has a swirling structure with winding arms. Spiral galaxies are characterized by arms where stellar nurseries are located. The arms are now considered to be shock waves from supernovas that trigger new areas of star formation.

Standard Candle – an object which is known to have a steady, predictable brightness and can be used to estimate distances. Note, standard candles are not always stars.

Standard star – a star that does not vary in brightness and is used as a standard of comparison for stars that vary.

Stefan-Boltzmann Law – a formula that relates the luminosity or intrinsic brightness of a star to its radius and its temperature. $L = \sigma 4 \pi r^2 T^4$

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stellar class black holes – a black hole formed from a single supergiant star.

Stellar evolution – the pattern of change of a star as it is formed, lives its "life," and dies.

Stellar nursery – an emission nebula in the process of forming many protostars.

Strong nuclear force – one of the fundamental forces of nature, responsible for binding nucleons in the atomic nucleus. The strong force is the strongest of nature's known forces, but has a limitation in that its effectiveness weakens rapidly with distance. Generally the strong force is only effective over the diameter of a proton or neutron.

Subraster – a subsection of a large image.

Supergiant – a star that begins its life as a giant will become supergiant as it dies and leaves the main sequence.

Super massive black holes – black holes containing millions to billions of solar masses.

Supernova – an exploding star. Larger than a nova.

Supernova remnant – the nebula that remains after a supernova explosion. Supernova remnants can re-form into new, second generation stars.

Torus – a cloud of material orbiting an accretion disk but not actively falling into the body it orbits. Toruses can block the radiation from an AGN.

Type Ia Supernova – a type of supernova that occurs when a red giant or other star dumps material on a companion white dwarf until the density of material on the white dwarf reaches a critical mass and causes the white dwarf to explode. In a classic nova only the surface material explodes.

Type II Supernova – a type of supernova caused by the collapse of the core of a giant dead star. Generally once a giant star forms iron in its core (which will not yield energy when it fuses) it will go supernova shortly thereafter.

Unification model of AGN – a theory that says Seyfert galaxies, quasars, and radio galaxies are all manifestations of Active Galactic Nuclei, all seen from different angles.

Variable – a star which is not steady in luminosity but changes its brightness over time.

Velocity – the rate of change of position; speed with a direction.

Wavelength – the distance between any point in a wave and where the next wave repeats in the same pattern.

Weak nuclear force – a fundamental force of nature used in nuclear decay and nuclear fusion of particles. The weak force (a misnomer) is actually the second weakest force after gravity.

White dwarf – the core of a dead sun like star, consisting of disorganized nuclear particles too hot and dense to form normal chemically bonded matter.

Wien's Law – a rule that says the peak or brightest color in a blackbody's spectrum can be used to determine its temperature. $T = \frac{2900}{\lambda_{peak}}$ where the wavelength is measure in Angstroms.

WISE – the Wide-area Infrared Space Explorer, a NASA infrared space telescope.

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Appendix A.2: Physical Constants

1370	Solar Constant (W/m^2)
$1.5x10^{11}$	radius of the earth's orbit (m)
$5.97X10^{24}$	mass of the earth (kg)
$1.99x10^{30}$	mass of the sun (kg)
695,000	radius of the sun (km)
$1.67325x10^{-27}$	mass of one hydrogen atom (kg)
$6.645x10^{-27}$	mass of one helium atom (kg)
300,000,000	speed of light (m/s)
$6.67x10^{-11}$	Universal Gravity Constant ($\frac{Nm^2}{kg^2}$)
9.8	Local acceleration of gravity on earth (m/s^2)
31558464	Number of seconds in a year
149,600,000 km	1 Astronomical Unit (AU)
3.26 light years	1 parsec (pc)
$9.467 x10^{12}$ km	1 light year
1.609 miles	1 km
2.54 cm	1 inch

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Appendix A.3: Logarithms

Logarithms are generally considered very mysterious to students weak in math, but they are actually helpful and not too complicated.

On every calculator, there are functions that undo other functions. For example, - undoes +. If you add 3 to a number, you can subtract it as well and return to the original number. In this sense addition can be seen as the opposite function as subtraction.

Multiplication undoes division.

Square roots undo squares; thus $\sqrt{x^2} = x$.

So what is a logarithm? It is the function that *un-does* the function 10^x.

Recall 10^5 = 100000; thus the logarithm of 100000 = log (100000) = 10. In the parlance of function, log *cancels* 10^x. As shown above, then, log (10^x) =x.

Logarithms have other properties that are useful in astronomy. A few of these are listed below.

Log (A^B) = Blog(A)
Log (AB) = log(A)+Log(B)
Log (10^x)=x
There are other properties, but these are the ones you need for this book.

Sample problems:
Evaluate the following. Rewrite using the rules above and calculate the values with a calculator.

1. log (10^5)=

2. log(45^3)=

3. log(30*130)=

4. log(2.512^6)=

5. log($2.512^{m_2 - m_1}$)

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Appendix A.4: The Nearest Stars

Source: Research Consortium on Nearby Stars, GSU (2007-09-17). "The One Hundred Nearest Star Systems". *RECONS*. Retrieved 2013-12-09.

	RA	DEC	proper motion "/year	trigonometric parallax in arcsec (")	Spectral Class		apparent mag	absolute Mag	Common Name
	----------	-----------	-----	-----	G2.0	V	-26.72	4.85	Sun
1	14 29 43.0	-62 40 46 H	3.853	0.76885	M5.0	V	11.05	15.48	Proxima Centauri
	14 39 36.5	-60 50 02 H	3.71	0.74723	G2.0	V	0.01	4.38	alpha Centauri A
	14 39 35.1	-60 50 14 H	3.724	0.74723	K0	V	1.34	5.71	alpha Centauri B
2	17 57 48.5	+04 41 36 H	10.358	0.54551	M3.5	V	9.58	13.25	Barnard's Star
3	10 56 29.2	+07 00 53 N	4.696	0.4191	M5.5	V	13.53	16.64	Wolf 359
4	11 03 20.2	+35 58 12 H	4.802	0.39325	M2.0	V	7.47	10.44	Lalande 21185
5	06 45 08.9	-16 42 58 H	1.339	0.38002	A1.0	V	-1.43	1.47	Sirius
	06 45 08.9	-16 42 58	1.339	0.38002	DA2		8.44	11.34	Sirius B
6	01 39 01.3	-17 57 01 N	3.368	0.3737	M5.5	V	12.61	15.47	BL Ceti
	01 39 01.3	-17 57 01	3.368	0.3737	M6.0	V	13.06	15.93	UV Ceti
7	18 49 49.4	-23 50 10 H	0.666	0.33722	M3.5	V	10.44	13.08	Ross 154
8	23 41 54.7	+44 10 30 N	1.617	0.31637	M5.5	V	12.29	14.79	Ross 248
9	03 32 55.8	-09 27 30 H	0.977	0.31122	K2.0	V	3.73	6.20	epsilon Eridani
	03 32 55.8	-09 27 30	0.977	0.31122	planet				
10	23 05 52.0	-35 51 11 H	6.896	0.30508	M1.0	V	7.34	9.76	Lacaille 9352
11	11 47 44.4	+00 48 16 H	1.361	0.29814	M4.0	V	11.16	13.53	Ross 128
12	22 38 33.4	-15 18 07 N	3.254	0.2895	M5.0	VJ	13.03	15.33	EZ Aquarii A
	22 38 33.4	-15 18 07	3.254	0.2895	M	V	13.27	15.58	EZ Aquarii B
	22 38 33.4	-15 18 07	3.254	0.2895	M	V	15.07	17.37	EZ Aquarii C
13	21 06 53.9	+38 44 58 H	5.281	0.28608	K5.0	V	5.2	7.48	61 Cygni A
	21 06 55.3	+38 44 31 H	5.172	0.28608	K7.0	V	6.03	8.31	61 Cygni B
14	07 39 18.1	+05 13 30 H	1.259	0.28517	i F5 I	V-V	0.37	2.65	Procyon
	07 39 18.1	+05 13 30	1.259	0.28517	DQZ		10.7	12.98	Procyon B
15	18 42 46.7	+59 37 49 H	2.238	0.28383	M3.0	V	8.9	11.17	
	18 42 46.9	+59 37 37 H	2.313	0.28383	M3.5	V	9.69	11.96	
16	00 18 22.9	+44 01 23 H	2.918	0.27987	M1.5	V	8.08	10.31	GX Andromedae
	00 18 22.9	+44 01 23	2.918	0.27987	M3.5	V	11.06	13.30	GQ Andromedae
17	22 03 21.7	-56 47 10 H	4.704	0.27607	K4.0	V	4.68	6.89	epsilon Indi A
	22 04 10.5	-56 46 58 S	4.823	0.27607	T1.0	V			epsilon Indi B
	22 04 10.5	-56 46 58 S	4.823	0.27607	T6.0	V			epsilon Indi C
18	08 29 49.5	+26 46 37 N	1.29	0.2758	M6.0	V	14.90	17.10	DX Cancri

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Appendix A.4: The Nearest Stars

	RA	DEC	proper motion "/year	trigonometric parallax in arcsec (")	Spectral Class		apparent mag	absolute mag	Common Name
19	01 44 04.1	-15 56 15 H	1.922	0.27397	G8.5	V	3.49	5.68	tau Ceti
20	03 35 59.7	-44 30 45 *	0.826	0.27201	M5.0	V	13.09	15.26	
21	01 12 30.6	-16 59 56 H	1.372	0.26908	M4.0	V	12.10	14.25	YZ Ceti
22	07 27 24.5	+05 13 33 H	3.738	0.26623	M3.5	V	9.85	11.98	Luyten's Star
23	18 45 05.3	-63 57 48 *	2.664	0.2595	M8.5	V	17.40	19.47	
	18 45 02.6	-63 57 52	2.664	0.2595	T6.0	V			

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Appendix A.5: The Brightest Stars

Common Name	Bayer Name	Distance (light years)	Apparent Magnitude	Absolute Magnitude	Spectral Type	
Sun		-	-26.72	4.8	G2	V
Sirius	Alpha CMa	8.6	-1.46	1.4	A1	Vm
Canopus	Alpha Car	74	-0.72	-2.5	A9	II
Rigil Kentaurus	Alpha Cen	4.3	-0.27	4.4	G2 + K1	V
Arcturus	Alpha Boo	34	-0.04	0.2	K1.5	IIIp
Vega	Alpha Lyr	25	0.03	0.6	A0	Va
Capella	Alpha Aur	41	0.08	0.4	G6 + G2	III
Rigel	Beta Ori	~1400	0.12	-8.1	B8	Iae
Procyon	Alpha CMi	11.4	0.38	2.6	F5	IV-V
Achernar	Alpha Eri	69	0.46	-1.3	B3	V
Betelgeuse	Alpha Ori	~1400	0.50 (var.)	-7.2	M2	Iab
Hadar	Beta Cen	320	0.61 (var.)	-4.4	B1	
Acrux	Alpha Cru	510	0.76	-4.6	B0.5+B1	Iv+Vn
Altair	Alpha Aql	16	0.77	2.3	A7	Vn
Aldebaran	Alpha Tau	60	0.85 (var.)	-0.3	K5	III
Antares	Alpha Sco	~520	0.96 (var.)	-5.2	M1.5	Iab
Spica	Alpha Vir	220	0.98 (var.)	-3.2	B1	V
Pollux	Beta Gem	40	1.14	0.7	K0	IIIb
Fomalhaut	Alpha PsA	22	1.16	2.0	A3	Va
Becrux	Beta Cru	460	1.25 (var.)	-4.7	B0.5	III
Deneb	Alpha Cyg	1500	1.25	-7.2	A2	Ia
Regulus	Alpha Leo	69	1.35	-0.3	B7	Vn
Adhara	Epsilon CMa	570	1.50	-4.8	B2	II
Castor	Alpha Gem	49	1.57	0.5	A1 + A2	1V
Gacrux	Gamma Cru	120	1.63 (var.)	-1.2	M3.5	III
Shaula	Lambda Sco	330	1.63 (var.)	-3.5	B1.5	IV

Source: http://www.astro.wisc.edu/~dolan/constellations/extra/brightest.html Adapted from Norton's 2000.0, 18th edition (copyright 1989, Longman Group UK).

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Appendix A.6: Some Conversion Factors

1 mile = 5280 feet
1 mile = 1.609 km
1 yard = 3 feet
12 inches = 1 foot

2.54 cm = 1 inch

1 km = 1000 m
1 m = 100 cm
1 m = 1000 mm

1 nm = 1 $x10^{-9}$m
1 Angstrom = $1x10^{-10}$m

1 cm^3= 1 ml = 1cc
1000 ml = 1 liter

1 parsec = 3.26 light years
1 year = 365.24 days

At the Celestial
equator, 24 hours RA = 360 degrees

1 hour RA = 60 min RA
1 min RA = 60 sec RA

1 degree declination = 60′ = 60 minutes declination
1 minute declination = 60″ = 60 seconds declination

2π radians = 360 degrees

1 AU = 93 million miles = 149.6 million km
light year = 9.46 x 10^{15} m

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Appendix A.7: Spectral Classes

Class	Surface temperature	Conventional color	Apparent color	Mass	Radius	Luminosity	Hydrogen lines
O	≥ 33,000 K	blue	blue	≥ 16 $M_\odot$	≥ 6.6 $R_\odot$	≥ 30,000 $L_\odot$	Weak
B	10,000–33,000 K	white to blue white	blue white	2.1–16 $M_\odot$	1.8–6.6 $R_\odot$	25–30,000 $L_\odot$	Medium
A	7,500–10,000 K	white	white to blue white	1.4–2.1 $M_\odot$	1.4–1.8 $R_\odot$	5–25 $L_\odot$	Strong
F	6,000–7,500 K	yellowish white	white	1.04–1.4 $M_\odot$	1.15–1.4 $R_\odot$	1.5–5 $L_\odot$	Medium
G	5,200–6,000 K	yellow	yellowish white	0.8–1.04 $M_\odot$	0.96–1.15 $R_\odot$	0.6–1.5 $L_\odot$	Weak
K	3,700–5,200 K	orange	yellow orange	0.45–0.8 $M_\odot$	0.7–0.96 $R_\odot$	0.08–0.6 $L_\odot$	Very weak
M	2,000–3,700 K	red	orange red	≤ 0.45 $M_\odot$	≤ 0.7 $R_\odot$	≤ 0.08 $L_\odot$	Very weak

Notes

$M_\odot$ = one solar mass

$R_\odot$ = sun's radius

$L_\odot$ = sun's luminosity

Source: Wikipedia; most data is from Tables VII, VIII, Empirical bolometric corrections for the main-sequence, G. M. H. J. Habets and J. R. W. Heinze, *Astronomy and Astrophysics Supplement Series* **46** (November 1981), pp. 193–237, Bibcode: 1981A&AS...46..193H. Luminosities are derived from M_{bol} figures, using $M_{bol}(\odot)=4.75$.

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Appendix A.8: Observing Notebook Checklist

Lab Measurements:
When you do lab measurements, such as photometry readouts, angular sizes, spectrum wavelength observations, and so on, these kinds of data are appropriate for observing notebooks. Be sure to label the data tables with quantities and units, and to write enough to remember what the data was for, such as a reference to the lab instructions, the instrumentation used, and the date of the observation. Real measurements should be distinguished from simulated data.

Observations:
Observations are records of what you have seen. Items in this list which are easy to see are marked in italics. Items listed after colons are the most famous or easiest to see example in each category. Remember, this is a beginner to intermediate list. There are many books which can show you how to take your observing to the next level.

"Landmarks in the sky"
- *Summer Triangle*
- *Pointer Stars on the Big Dipper*
- *Arc to Arcturus*
- *Spike to Spica*

Atmospheric Phenomena
- *Rainbows*
- *Sunsets*
- *Light Pollution*
- Sun Dogs
- Moonbows

Solar System
- Mercury
- *Venus*
- *Earth's moon*
  - *Cycle of Phases*
  - *Major surface features*
- *Mars*
- Asteroids (challenging)
- *Jupiter + moons*
- *Saturn + rings*
- Comet (if lucky)
- Meteor Shower

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Appendix A.8: Observing Notebook Checklist

Deep Sky
- Messier Objects (any)
- NGC Objects (any)
- Galaxies: Andromeda
- *Globular Clusters: M13*
- Open Clusters: Pleiades
- Emission Nebulas: Orion Nebula, Lagoon Nebula
- Supernova Remnants: Crab Nebula
- *Planetary Nebulas: Ring Nebula*
- *Double Stars: Alberio, Double-double in Lyra*
- *Variable Stars: Algol*
- Stars with known planets (planets will NOT be visible)
- Stars with known black holes (black holes not visible)

Constellations, Stars and Asterisms
- *Circumpolar (visible all year)*
  - *Ursa Major (Big Dipper)*
  - *Ursa Minor (Little Dipper)*
  - *Polaris*
  - *Dubhe, Merak, Mizar, Alcor*
  - *Cassiopeia*
- Fall
  - *Cygnus, Lyra, Aquila*
  - Pegasus, Hercules
  - Sagittarius, Scorpius
  - *Deneb, Vega, Altair*, Antares
- Winter
  - *Orion*, *Gemini*, Taurus, Perseus
  - *Betelguese, Rigel, Capella, Castor, Pollux,* Procyon, *Sirius*, Aldebaran
- Spring
  - *Leo,* Libra, Bootes, Hercules, Corona Borealis, Gemini
  - *Regulus, Arcturus, Spica, Denebola*

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Observing Notebook Observation Forms

These observing forms on the following pages can form the basis for the beginning of your observing notebook. Copy additional pages as needed.

Remember, use a pencil (no one's perfect). It is important that you record the date, time and place, so the observation can be verified. Use the circle to represent the field of view through a telescope.

For naked eye observations, ignore the circle and just draw the environment near the object you are observing.

Print Name ____________________________ Period _________ Date _________________

Object Name:	
Date of Observation:	
Time of Observation:	
Location:	
Instrument:	
Field of View:	
Magnification:	
Camera settings (for photos):	
Seeing:	
Transparency:	
Description:	

Object Name:	
Date of Observation:	
Time of Observation:	
Location:	
Instrument:	
Field of View:	
Magnification:	
Camera settings (for photos):	
Seeing:	
Transparency:	
Description:	

Print Name ______________________________Period _________ Date __________________

Object Name:	
Date of Observation:	
Time of Observation:	
Location:	
Instrument:	
Field of View:	
Magnification:	
Camera settings (for photos):	
Seeing:	
Transparency:	
Description:	

Object Name:	
Date of Observation:	
Time of Observation:	
Location:	
Instrument:	
Field of View:	
Magnification:	
Camera settings (for photos):	
Seeing:	
Transparency:	
Description:	