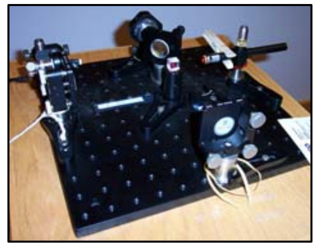
LIGO

# LIGO Explorer Name TEACHER'S GUIDE

*Have fun exploring the science of LIGO!*

## 1. The Little Michelson Interferometer

Location: In the auditorium



Procedure: Try to figure out the path of the laser light through the interferometer. Observe the interference pattern that the device makes. Gently pull the string to move the mirror by a tiny amount.

Questions: Answer the following

1. What do you see when the interferometer's mirrors move by tiny amounts?

   **Tiny mirror movements such as those caused by pulling the string (a mirror movement far too small to see) cause obvious changes in the interference pattern in the interferometer.**

2. Why is this model an important exhibit to have here at LIGO?

   **The small interferometer is a good model for showing how LIGO tries to measure gravitational waves. The LIGO interferometers are much more complicated in many respects, but the basic concept is the same.**

*EALR 2.1.4 Analyze how models are used to investigate objects, events, systems, and processes.

## 2. Interferometer Simulator

Location: Auditorium

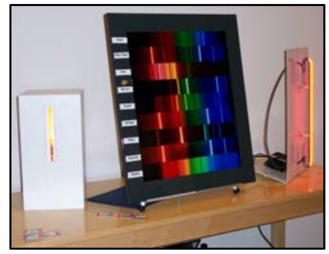
Procedure: The wood blocks in the simulator represent the mirrors in a real interferometer. Slide the wood blocks back and forth while you keep tension on the strings. The strings represent the laser light. Watch the pattern change at the location of the photodetector.

1. In what way does the pattern at the 'photodetector' change when the 'mirrors' (the wood blocks) move?

   **The two sets of stripes (light waves) in pattern overlap each other in different ways as the mirrors move, creating different amounts of bright and dark in the pattern.**

* EALR: 2..1.4 Analyze how models are used to investigate objects, events, systems and processes

## 3. Scoping the Stars



Location: Auditorium

Procedure: Use either a grating or a spectroscope (box) to look at the light sources. Observe the pattern that each light produces. Try to match the pattern that you see with the patterns that are shown on the framed poster. There may or may not be a match.

The name of the red-orange light is **Neon**

The name of the yellow light is **It's not on the poster! (sodium)**

Extra: Use the spectroscope to look at one of the white lights in the auditorium or the lobby.

* EALR: 1.1.3 Understanding the properties of sound, water, and light waves.

## 4. A Shadow- More Than Meets the Eye

Location: Auditorium

Procedure: Stand next to the front wall of the auditorium so that you can cast a shadow on the wall. Use your hands to cast shadows on the wall. Try overlapping shadows. Note: Thank you for not touching the wall. It is a projection screen and works best when it is clean.

Questions:

1. All the colors on the wall are created by what three (3) colors?
   **Red, green, and blue (RGB)**
   **Note: Black is the absence of light and our eyes perceive white as the result of the combination of the three colors red, blue, and green.**

2. Explain how to produce a green shadow on the white section of the wall.

   **Use on hand to block the red light and the other hand to block the blue light. The resulting overlap leaves a green shadow.**

   **Note: It may seem strange that a red and green light mix to make yellow light on the screen. A mixture of red and green light stimulates the red and green receptors on the retina of your eye. These are the same receptors that are stimulated by yellow light.**

* EALR: 1.1.3 Understanding the properties of sound, water, and light waves.

## Websites for Colored Shadows:

http://www.learner.org/teacherslab/science/light/color/shadows/
Use a simulation to further demonstrate how colored lights can cast colored shadows. See "background page" for a link to instructions on how to do the simulation as a class activity.

http://www.exploratorium.edu/xref/exhibits/coloredshadows.html
Information on setting up your own colored shadows demonstration.

http:// www.exploratorium.edu/xref/exhibits/colored shadows.html
Reference information regarding colored shadows.

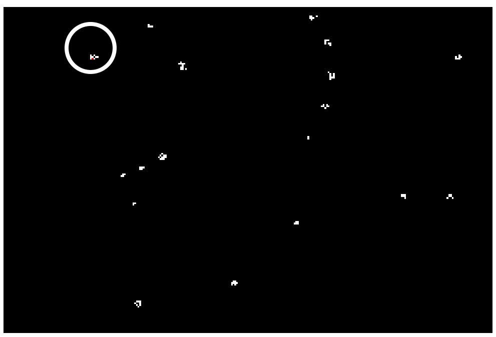
http://www.thegalleriesatmoore.org/activities/colordemo2.shtml
Interactive simulation allowing you to combine the 3 primary colors to create millions of colors.

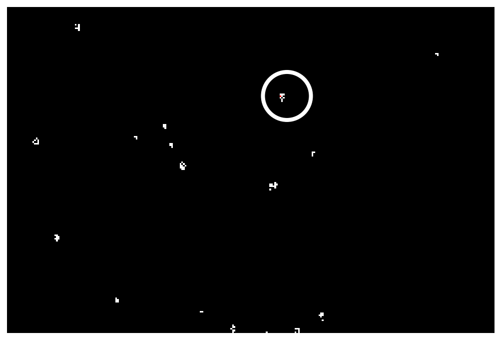
## 5. Search for the Stars

Location: The computer tutorial is on a computer at the rear of the auditorium.

Procedure:

A. Log on to [http://www.stikky.com/0001-nightskies/0001-fulldetails.html](http://www.stikky.com/0001-nightskies/0001-fulldetails.html) on the computer. Click the 'sample pages' link.
B. Spend a few minutes learning how to locate the star **Betelgeuse** in the constellation **Orion**.
C. Locate and circle the star **Betelgeuse** in each of the diagrams below.





## 6. Gravity Well

Location: Lobby, opposite the main entry

Procedure: Pull out the drawer at the bottom of the well. Find a round object and roll it around in the well.

Questions:

1. The ball's orbit becomes smaller as it travels around the funnel. Why?

   **The ball experiences continuous friction against its forward motion as it rolls. This lessens the forward velocity as the funnel continues to push the ball sideways. The orbit shrinks as a result.**

2. Is this exhibit a good model for the earth's orbit of the sun? Why or why not?

   **If the earth's orbit of the sun was shrinking like the orbits in the exhibit, we'd be in deep trouble. There's no friction on the earth as it orbits, unlike the balls in the gravity well.**

*EALR 1.1.2 Understand the positions, relative speeds, and changes in speed of objects.
1.2.5 Understand the structure of the Solar System.
1.3.2 Understand how balanced and unbalanced forces can change the motion of objects.

# 7. Simple Pendulum

Location: The back of the auditorium.

Investigate this question: "Does a heavier object swing at a different rate than a lighter object?"

1. What is your prediction?

    **Answers will vary**.

Procedure: Perform a test using the objects at this exhibit by determining the number of swings the pendulum will make in 15 seconds.

| Color of Bag | Weight of Bag | Number of swings in 15 seconds |
|---|---|---|
| | | |
| | | |
| | | |

2. What did you learn as a result of this experiment? Use your data to support to support your answer.

    **Students should conclude that the weight made no difference in the average swing rate. Remind students to support their conclusion with data from the experiment.**

*EALR 2.1.2 Understand how to plan and conduct scientific investigations.

# 8. Journey to the Stars

Location: The galaxy model is outside

Procedure: Go outside for the "space walk"

Your mission will be to determine the distances from the earth to 6 prominent stars in the **Milky Way Galaxy**. Go to the earth's **Solar System Indictor** located outside at the front corner of the building. We have carefully plotted points on the LIGO grounds to represent 6 stars and their relative distances from the earth. But how will you measure these distances?

Starting at the earth's **Solar System Indicator**, carefully count the number of steps it takes you to walk to the star **Merek** located in the **Big Dipper**. You are now using the length of your step as a unit of measure. Make sure each step is the same length.

Total number of steps to **Merek** **Often about 35**

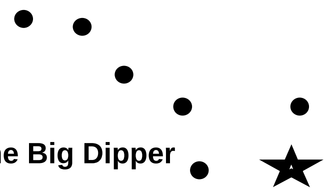
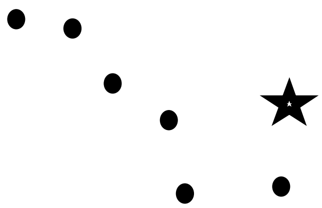
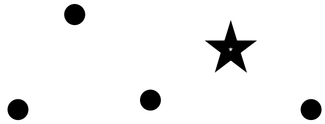
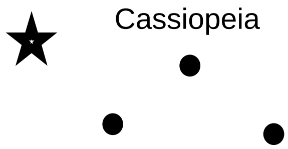
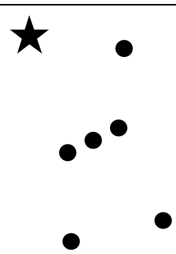
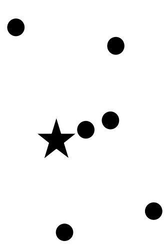
The distances to the stars are enormous. Listing these distances in miles or kilometers give us huge numbers. For example, Merek is 475,000,000,000,000 miles from earth! It is much easier to measure such distances in **light years**. A light year is the distance light travels in one year at a speed of 186,000 miles per second.!

If **Merek** is 80 light years away, and it took **35** steps to get there from earth, then how many light years equals one of your steps?

80 light years divided by **(35)** number of steps equals **2.3** light years per step.

Now determine the estimated distance to each of the 5 remaining stars by counting the number of steps it takes you to walk from the earth's Solar System Indicator to the stars in each constellation.

Complete the table on the following page.

| Constellation or "group of stars" | Star | Facts about the star | Number of your steps | Number of light years |
|---|---|---|---|---|
|  **The Big Dipper** | Merek | Hot white star. The light you see from this star took 80 years to reach the Earth. | | **80** |
|  **The Big Dipper** | Dubhe | Is orbited by another less massive star. Along with Merak has been used for centuries to help people find the north star. | | **124** |
|  Cassiopeia | Ruchbah | About 4 times as big as our sun | | **100** |
| Cassiopeia  | Schedar | A very young star, about 200,000,000 years old. Helps point the way to the Andromeda Galaxy. | | **230** |
| Orion  | Betelgeuse | Red super giant. If Betelgeuse replaced our sun, the surface of the star would extend almost to the orbit of Jupiter! | | **425** |
| Orion  | Alnitak | Left-most of 3 stars that make up Orion's belt. | | **817** |

*EALR 1.1.2 Understand positions, relative speeds, and changes in speed of objects.

**One purpose of the activity is familiarization with some of the interesting stars that can be observed in the night sky. Another is to understand the tremendous size astronomical distances. We included two stars from each of the three most recognizable constellations. Students will hopefully come to understand that stars in one constellation may be vastly different distances from the earth and from each other. Many students will recognize the approximations in the activity i.e. curving paths to stars, inconsistencies in stride length, etc. However, the distances as estimated by astronomers are approximate as well.**

**One direct way to measure distances to the stars is by using "parallax". Hold a finger in front of your face, open one eye, close it, and then open the other eye. Notice that your finger appears to move relative to the objects in the background. Astronomers utilize this phenomenon by observing a star from one side of the Earth's orbit and then the other. The angle that the star seems to shift, when combined with the diameter of the Earth's orbit and some simple trigonometry, yields the distance to the star. If the stars are too far away, the parallax can be too small to measure accurately. The greater the distance to the star, the smaller will be the parallax and the greater will be the uncertainty of the distance.**

**<u>Possible discussion topics:</u>**

1. **Why do astronomers measure distances to the stars in light years instead of miles?**
2. **What factors could give us the variety of distances that our class came up with when measuring the distances to the stars on the LIGO galaxy model?**
3. **If you look up information regarding the distance to a star like Betelgeuse, different resourced will give different distances. Why might that be?**
4. **What do you think the true distance of one light year is on the LIGO galaxy model? ( 1 foot = 1 light year)**
5. **How far do you think the nearest star (other that the Sun) is from the Earth? (Approx. 4.2 ly: Proxima Centauri)**
6. **Would it be possible for an astronaut to reach that distance in a space ship that travels as fast as the space shuttle in low orbit (17,500 mph)? Why or why not?**

**<u>Optional Extensions</u>**

1. **Our entire Solar System stretches approximately 11 light hours across. How big do you think our Solar System would be on the LIGO galaxy model? 1 foot = 1 light year. ( 1 ly = 12 inches, 1 light month = 1 inch, 1 light day = 0.033 inches, 1 light hour = 0.00138 inches X 11 hours = 0,01527 inches.) Converted to meters is about 100 microns or about the width of a human hair. <u>Note:</u> The Solar System is huge by earthly standards. Pluto takes 248 years to orbit the Sun traveling at an average speed of 10,000 miles per hour.**
2. **The Milky Way is about 100,000 ly across in size. What distance would that be on the LIGO model? (Approx. 19 miles).**
3. **The distance from the Earth to the Sun is about 8 light minutes. What distance would that be on the LIGO model? (Approx. 0.0002 inches or 0.0000006 meters; this is a thousand times smaller than a millimeter!)**
4. **Students could calculate the length of their stride using the LIGO scale factor of 1 foot = 1 light year.**
5. **Students can watch and record the movement of the stars near the north celestial pole (North Star, Polaris) over the course of several hours. (Choose the time of year with an early sunset)**
    a. **Find an unobstructed view of the northern sky.**
    b. **Locate the North Star, Big Dipper, and Cassiopeia early in the evening.**
    c. **Draw the outline of the northern horizon near the bottom of a piece of paper. Use dots to show the position of the stars.**
    d. **Record the time of the drawing.**
    e. **Wait 2 to 3 hours and return to the site. Using the same piece of paper, draw the stars again. Record the time**

f. **Wait 2 to 3 hours and repeat. The Big Dipper and Cassiopeia should have rotated around the North Star.**

**Note: Teachers could ask students to write a report detailing their findings, including a description of the procedure, the final copy of their diagram, and an explanation of what they observed.**

## Websites:

**www.visitingmoon.org/**

**This is the site we used for part one of the Journey to The Stars exhibit. (Click " learn the constellation sequence here." Then click "sample pages".) Suitable for all levels.**

**www.cita.utoronto.ca/-dubinski**

**This site provides information about the merger of the Milky Way and Andromeda galaxies. It describes the possible fates of the sun and the earth. It includes a computer simulation of the colliding galaxies. Suitable for all levels.**

**www.netguides.org.uk/guides/starMap.html**

**This site explains how to make a device that will show you the stars that are visible in the Northern Hemisphere according to the month. Suitable for all levels.**

**www.pbs.org/weta/roughscience/discovery/observatory.html#starclock**

**This site has directions for building a simple clock based on the positions of the stars. Suitable for all levels.**

**http://quest.arc.nasa.gov/itc/special/mlk/gourd1.html**

**This site explains how locating the North Star helped many slaves escape to freedom in the North. Suitable for all levels.**

**http://solar.physics.montana.edu/astro**

**This site provides a variety of ways of becoming more familiar with star patterns while integrating math concepts in the areas of algebra, geometry, measurement, data analysis, probability, problem solving and communication. Suitable for K-6.**

**www.astro.Washington.edu/larson/Astro101/CoursePak/cpo9_parallax_stars.pdf**

**This site has a lesson plan for using parallax to determine distances. Suitable for 9-12.**

**www.skypub.com/**

**This site provides a sky chart for any location on Earth, on any date, at any time. Very cool! Suitable for 6-12**

# 9. Pendulum Snake

Location: In the corner station

Procedure: Grab the red handle and lift the board. Set the board down quickly. Watch the pendulums.

Questions:

1. Why do the pendulums swing at different rates?

   **The length of the string determines the swing rate**.

2. Describe or draw the different patterns that you observe.

   **The pendulums start with a wave motion then the pattern appears disordered. Next every other ball swings exactly out of phase with its neighbor, then the pattern becomes disordered again. Finally they repeat the wave motion then return to synchronization, then the entire pattern repeats (30 seconds for the entire pattern to repeat)**

*EALR 2.1.1 Understand how to generate a question that can be answered through scientific investigation.
2.1.4 Analyze how models are used to investigate objects, events, systems, and processes.

# 10. Vibrating String

Location: In the corner station

Procedure: With the motor on, pull tightly on the string and watch the wave patterns that it forms.

Questions:

1. This exhibit makes waves called "standing waves". Why do you think that they are called standing waves?

   **Standing waves appear not to move along the string.**

2. How many standing wave patterns can you make?

   **The current LIGO record is 8 half-wavelengths (7 nodes).**

*EALR 1.2.2 Understand how various factors affect energy transfers and that energy can be transformed from one form of energy to another.
1.1.3 Understand sound, water, and light waves; their properties, behaviors, etc.
2.1.4 Analyze how models are used to investigate objects, events, systems, and processes.

# 11. Pencil Waves

Location: In the corner station

Procedure: With your hand, press down on the pencils on one end of the exhibit. Quickly remove your hand. Watch the pencils.

Questions:

1. What happens to a wave when it reaches the end of the string?
   **The wave reflects off the end of the frame and returns .**

2. Make waves on the device. Watch just one pencil. Describe the pencil's motion
   **The pencil bobs up and down**. **A wave is a collection of individual oscillators.**

*EALR 1.2.2 Understand how various factors affect energy transfers and that energy can be transformed from one form of energy to another.
1.1.4 Understand sound, water, and light waves; their properties, behaviors, etc.
2.1.5 Analyze how models are used to investigate objects, events, systems, and processes.

# 12. Giant Slinky

Location: In the corner station

Procedure: Grab the handle that comes from the blue can and push it back and forth or swing it side to side.

Questions:

1. What happens to a wave when it reaches the end at the wall?
   **The wave reflects off the far end of the fixture and returns down the spring.**

2. What happens when waves collide with each other?
   **The wave appear to pass through each other and continue. The point of interaction is where they interfere.**

3. What must you do to make waves on the Slinky that look like the standing waves that you make on the vibrating string?
   **You must keep agitating the rod and you must do this at one of several precise frequencies. Only at these frequencies will standing waves persist.**

*EALR 1.2.2 Understand how various factors affect energy transfers and that energy can be transformed from one form of energy to another.

## 13. Sound Waves

Location: In the corner station

Procedure: Using the tuning forks, your voice and other noisemakers, make waves on the computer monitor by making noise in the microphone.

Question:

1. What differences do you see between the computer wave patterns made by different tuning forks?

   **Shorter, higher-pitched forks create waves that are more crowded together – waves of higher frequency and shorter wavelengths**

*EALR 1.1.3 Understand sound, water, and light waves: their properties, behaviors, etc.

## 14. Waves in Time and Frequency

Location: In the corner station

Procedure: Watch and listen. The function generator (middle unit) makes electrical waves. These waves are graphed in time on the oscilloscope (right-side unit). The frequency of the waves appears on the signal analyzer (left-side unit). You also can hear the frequency (pitch) of the waves coming out of the speakers.

Question:

1. When the pitch (frequency) of the sound changes, how do the graphs change?

   **As the pitch increases, the waves on the oscilloscope get skinnier and more crowded and the peak on the signal analyzer moves from left to right.**

*EALR 1.1.3 Understand sound, water, and light waves: their properties, behaviors, etc.

**Web sites related to waves:**

**www.colorado.edu/physics/2000/index.pl**

**This site has interactive activities and animations regarding many aspects of physics.**

**www.scinecejoywagon.com/explrsci/media/soundwav.htm**

**This site has an interactive animation of sound waves.**

**www.gmi.edu/"drussel/Demos.html**

**This site has interactive activities and animations regarding different types of waves and their properties.**

# 15. Gravity Racer

Location: In the corner station

Procedure: Place three golf balls behind the starting gate at the top of the ramps. MAKE A PREDICTION OF WHICH BALL WILL WIN THE RACE TO THE BOTTOM. Now let the balls go. Was your prediction correct? Release the balls from other positions on the ramps by letting them go by hand.

Question:

1. Was your prediction correct?
   **Students are often surprised to observe that the balls on the curved path win the race. The shortest span in distance is not necessarily the shortest span in time!**

2. What is your guess about the way this device works? Why does the ball that travels farther reach the bottom first?

   **On the curves, the balls undergo substantial acceleration in the first instant of their travel. This increases their velocity enough that they can beat the straight-path ball even though they travel a greater distance.**

*EALR 1.1.3 Understand sound, water, and light waves: their properties, behaviors, etc.