

AN OVERVIEW OF LIGO

Brock Wells

Robert L. Olds Junior High School, Connell, WA

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The purpose of this guide is to provide background about the LIGO project at the Hanford site. Hopefully this information will give you material for lessons in the classroom that will encourage your students in their study of related physical science and earth science topics such as gravity, light, and waves. There are two main objectives of this guide:

- ◆ To describe the LIGO Observatory. Hopefully you will come to understand the relationship between the design of the facility and the science that occurs there.
- ◆ To relate the science of LIGO to the basic principles of waves, laser light and gravity

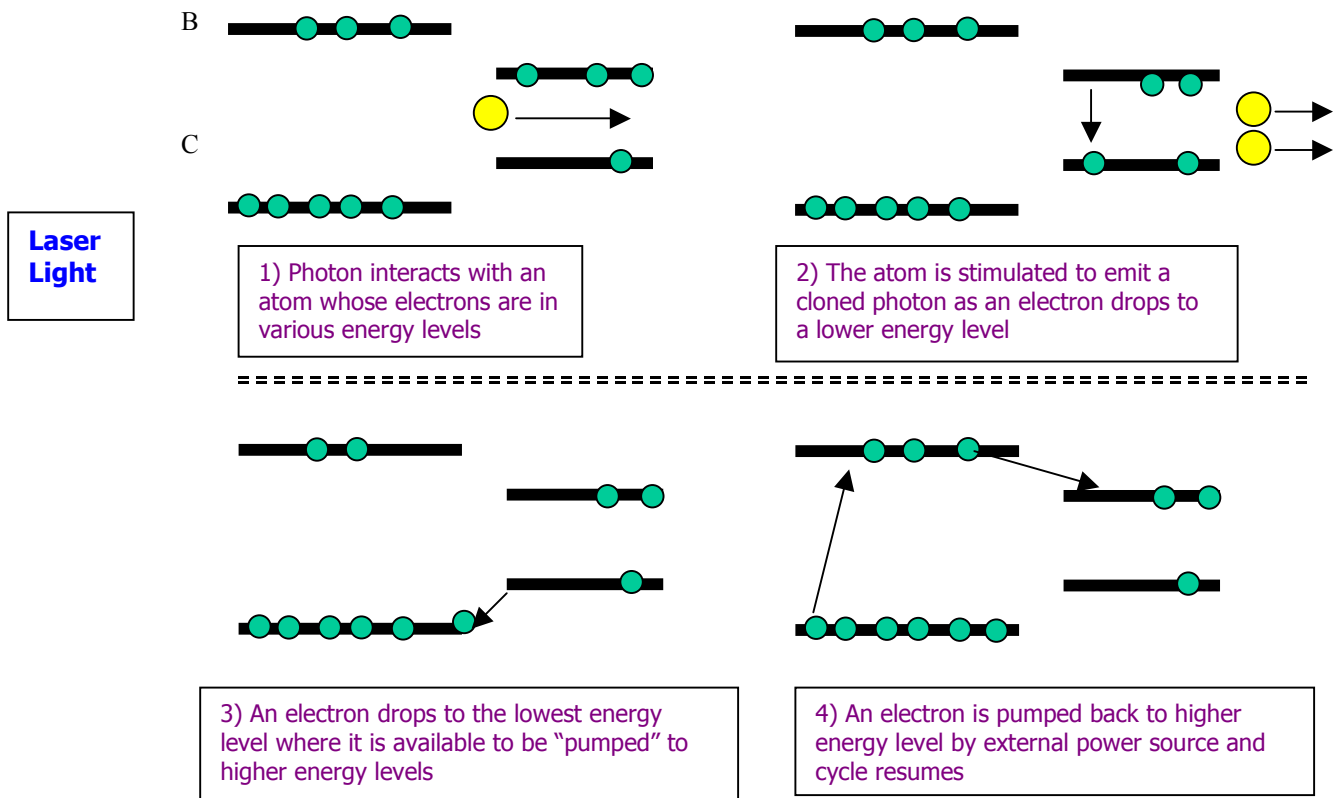
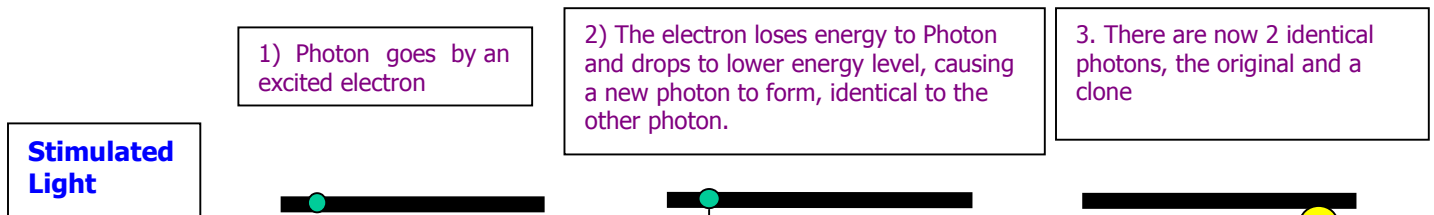
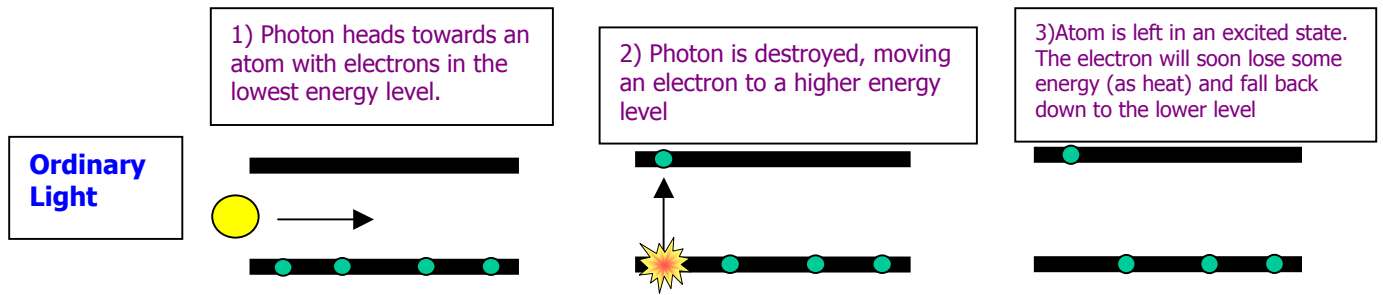
The Massachusetts Institute of Technology (MIT) and the California Institute of Technology (Caltech) joined forces in 1983 and began the initial phases of planning two observatories. The National Science Foundation became the funding agency for the venture in 1992 and the groundbreaking occurred in 1996. Two sites were selected for the observatories, one in Livingston, Louisiana and the other at the Hanford Nuclear Reservation near Richland, Washington.

LIGO

LIGO is an acronym for Laser Interferometer Gravitational-wave Observatory. Other similar observatories are currently being constructed in other countries and will form a network for observation and data analysis.

LASERS

The word “laser” is an acronym for “light amplification by stimulated emission and radiation”. The production of any type of light relies on the fact that electrons in atoms and molecules can exist in different energy levels. The process to produce laser light requires two steps. First, atoms of a material are energized and some of their electrons jump to higher energy levels. Then, the energized atoms are “stimulated” by packets of light energy called photons. The atom releases a “cloned” photon of energy and returns to a lower energy level to be re-energized. Since the resulting photons are clones, they are identical to the original photons in color (frequency), phase, wavelength, direction, etc. These photons are collected and emitted to produce laser light beams. Typical light consists of many different wavelengths that oscillate out of phase with each other. Laser light is essentially a single wavelength that oscillates uniformly, or in phase. The diagrams on the following page illustrate the difference between ordinary light and laser light.



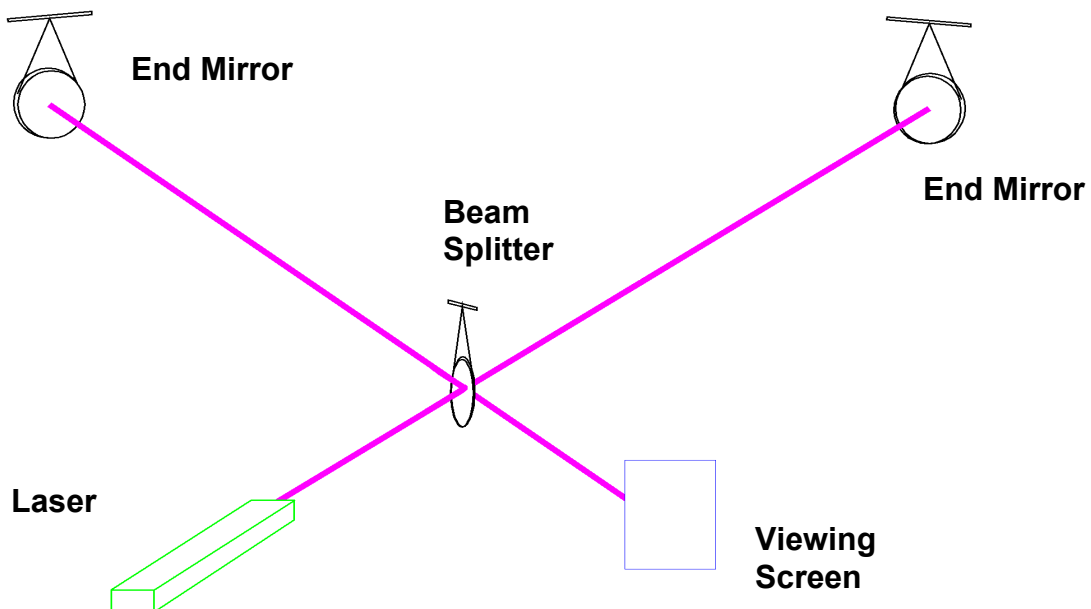
A more detailed explanation of laser light can be found on the web at:
www.laserfantasy.com/Cool_Stuff/how.html#work

INTERFEROMETERS

An interferometer is any instrument that measures interference of waves. In 1881, A.A. Michelson, an American physicist, divided a beam of light into two perpendicular paths and then reunited the beams into one. The resulting beam was made up of waves from both paths that canceled out parts of each other, resulting in a pattern of fringes. When either of the split beams was “disturbed”, the fringe pattern changed.

The laser interferometers at LIGO will use the fringe pattern of a divided laser beam to measure any lengthening or shortening of space due to gravitational waves. The divided laser beam will travel through two steel vacuum tubes oriented at a right angle. When a gravitational wave distortion causes one beam to lengthen and the other to shrink, the interference pattern of the two beams will change. A simple schematic of a Michelson interferometer is shown below.

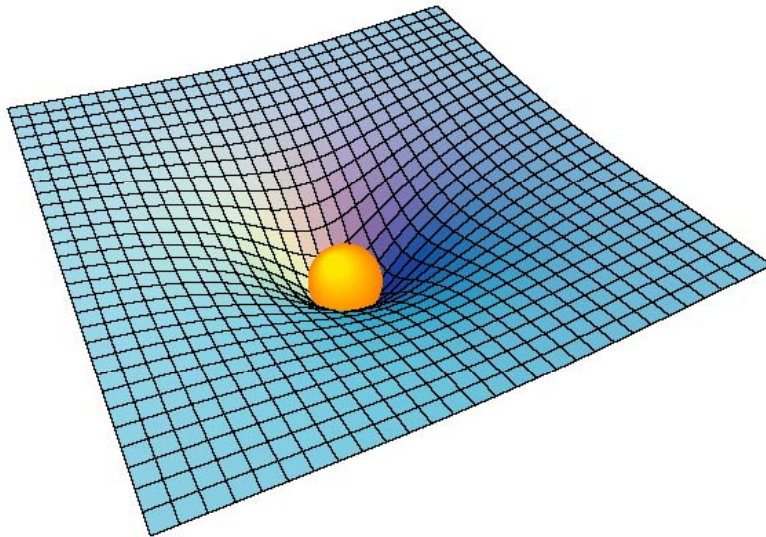
Sketch of a Michelson Interferometer



GRAVITATIONAL WAVES

Imagine a fishing bob in a still pond. The bob distorts the plane of the pond surface in one location as it floats on the water. When a fish disturbs the bob, waves ripple out in all directions over the surface of the water, distorting the plane across its width. Now, imagine a huge mass in space such as a dying star “bobbing” on the plane of space-time as the star explodes. The resulting waves, which ripple from this disturbance, travel at light-speed in all directions of space. These waves, which will change the space in which they move, can be measured with a laser interferometer.

By the time the waves from events such as the death of a star have reached earth, they have traveled thousands, or even millions of light-years. They reach us as diffuse, weak waves that distort space-time and everything in it, but only a little. This miniscule warping effect is measurable; and to do so, we must rely on the fact that gravitational waves can go through any material and warp what they are passing through. When they arrive at earth, they will distort the space along the interferometer beam paths.



Large masses (yellow) can distort the shape of space-time (blue fabric)

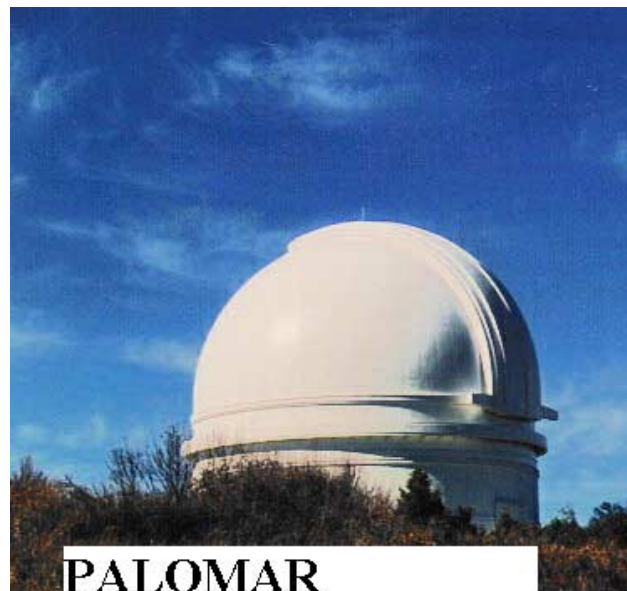
OBSERVATORIES

An observatory is any location where equipment is used to “observe” or measure astronomical activities or occurrences. Some well-known astronomical observatories of different kinds include the Arecibo Observatory in Puerto Rico, which observes radio waves, and the Palomar Observatory in California, which observes visible and infrared light waves. LIGO will be included in this group since it observes gravitational waves.



Arecibo, in Puerto Rico, is one of the world's largest radio telescopes

The Palomar Observatory rests on Mt. Palomar in California



LIGO'S OBJECTIVE

The LIGO mission is to observe gravitational waves of cosmic origin. Here are some of the possible sources of gravitational radiation:

- ◆ The supernova collapse of stellar cores to form neutron stars or black holes
- ◆ The collisions and coalescences of neutron stars or black holes
- ◆ The wobbly rotation of neutron stars with deformed crusts
- ◆ The remnants of gravitational radiation created in the early universe

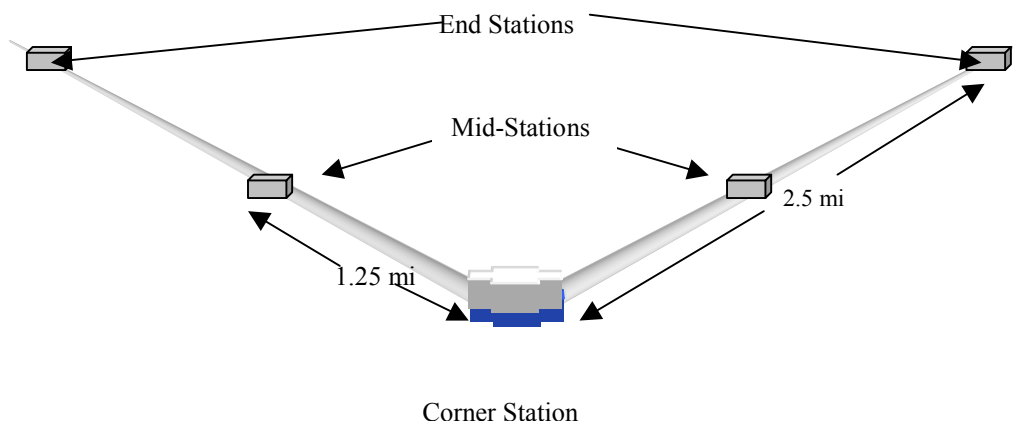
LIGO Hanford is located in the Columbia Basin of Southeastern Washington



An aerial view of LIGO Hanford



LHO Head Fred Raab in front of the Corner Station



HOW LIGO'S INTERFEROMETERS WILL WORK.

LIGO Hanford houses two interferometers that will run simultaneously and will use the same beam tube for their paths. The smaller '2K' interferometer has perpendicular beam paths that terminate at the mirrors in the mid stations (see diagram above). These paths are 2 kilometers in length. The '4K' interferometer's beam paths bypass the mid station mirrors and travel to the mirrors at the end of each arm, 4 kilometers from the corner station. The LIGO project thus consists of three interferometers – the 2K and 4K at Hanford and another 4K at Livingston, LA. Multiple instruments will help the LIGO scientists sort out genuine gravitational wave signals from 'noise', since a genuine signal should be detected in all three instruments. The LIGO interferometers, along with the European and Japanese instruments that are now coming on line, will hopefully produce an effective system for identify the locations in the sky of events that release gravitational waves.

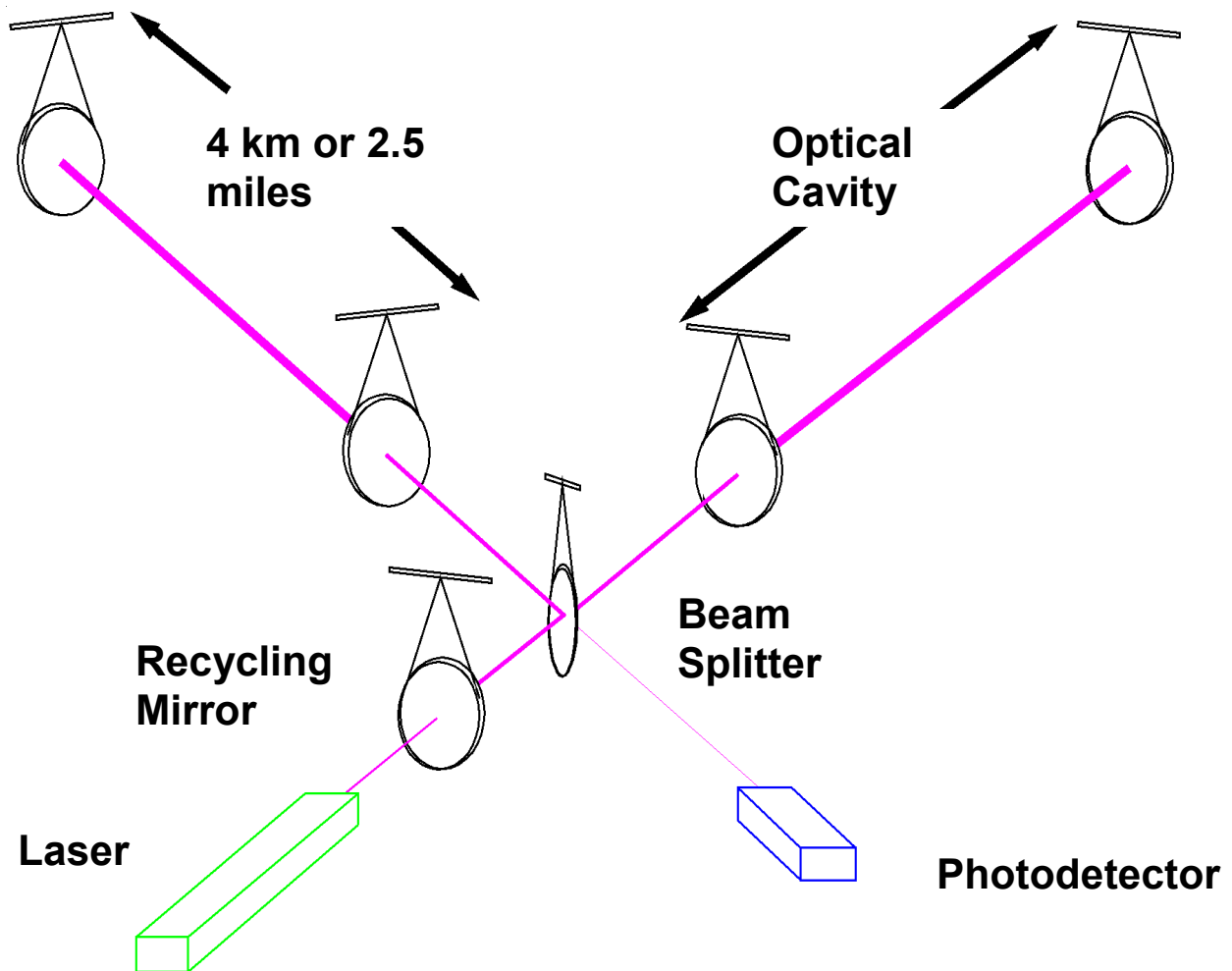
The LIGO interferometers work by splitting a laser beam into two beams that travel through vacuum tubes situated at a right angle. The original beam directly from the laser is modified by various optical elements in the corner station to produce a working beam of exceedingly high uniformity and stability. The vacuum chambers are 4 km. (2.5 mi) in length and are constructed of welded steel tubes that are 1.3m (4 ft.) in diameter and 3mm. (1/8 in.) thick. The 250 mm. (10 in.) mirrors are suspended at the mid and end stations. The mirrors are suspended on wires from tables that are designed to eliminate any movement caused by other forces such as earthquakes, wind, earth tidal motion, etc. The vacuum tubes and optical chambers where the mirrors are housed are designed to create a "clean" pathway through which the laser light can travel.

LIGO's interferometers have additional mirrors besides those shown in the Michelson drawing above. Fabry-Perot mirrors, which are located in the corner station, cause the laser light to bounce back and forth within each arm a number of times as more light is added to the arms, building up the light power in each arm before the light is able to escape. A recycling mirror, also in the corner station, sends returned light back to these Fabry-Perot cavities. The additional light power created by these features allows the interferometer to detect weaker signals.

As the laser beam travels back and forth between the mirrors up to 100 times in a millisecond, any shift of the mirrors by a gravitational wave will be detected by changes in the interference pattern that will be seen at the interferometer's detector.

A schematic of the LIGO-style recycling interferometer is shown below.

Fabry-Perot-Michelson with Power Recycling



LIGO'S EXHIBITS

LIGO maintains several on-site exhibits that demonstrate some of the important science and engineering principles of the interferometers. Field trips to view the site and these exhibits are welcomed. Teachers who wish to bring groups of students to LIGO will find a variety of resources in the "Teacher's Corner" link on the LIGO Hanford Web site that will make a field trip more productive.

Arrangements for a trip can be made through http://www.ligo-wa.caltech.edu/teachers_corner/contact.html. Standards-based science classroom activities that relate to the exhibits at LIGO can be downloaded at http://www.ligo-wa.caltech.edu/teachers_corner/teachers.html.

OTHER TEACHING RESOURCES

Websites

- ◆ The LIGO main page: <http://www.ligo.caltech.edu>. Here you will find links to a large number of LIGO-related concerns
- ◆ Laser information: <http://www.laserfantasy.com/LFI/howlaserswork.html>
- ◆ Physics Simulations: <http://home.a-city.de/walter.fendt/phe/phe.htm> (note: this site is one of a huge number on the Web that provide Java applets that demonstrate physics principles)

Magazines

- ◆ Astronomy www.astronomy.com
- ◆ Sky and Telescope www.skypub.com
(These magazines have excellent articles on LIGO and related stories in the October 2000 issues.)