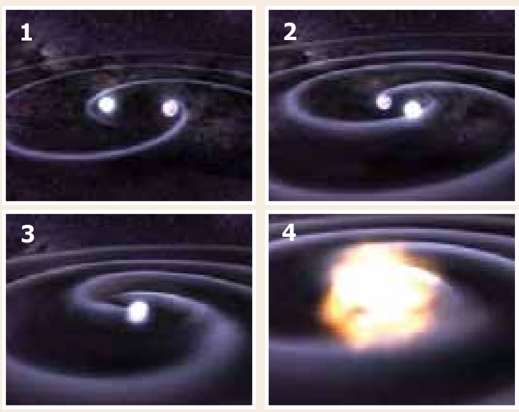
GRAVITATIONAL WAVES

Throughout history, we have relied on different forms of light to observe our universe. Now, we are on the verge of looking at the universe with a new set of eyes—gravitational wave observatories. Gravitational waves, originally predicted by Albert Einstein, carry information on the motion of objects in the universe. But unlike light, gravitational waves are neither absorbed nor reflected by objects in the universe, so we will be able to see them as they were when they were created. What will we learn as we enter the age of gravitational wave astronomy?

What happens when stars collide?



Images provided by NASA

Orbiting pairs of black holes and neutron stars will emit inspiral gravitational waves. As the two masses revolve around each other, the distance between them decreases and their speeds increase, causing the frequency of the resulting gravitational waves to increase until the objects collide. The waves that are emitted will tell us about the dynamics of these spectacular events.

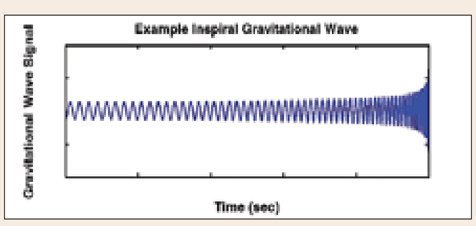


Image provided by A. Stuver

What happens when a star explodes?

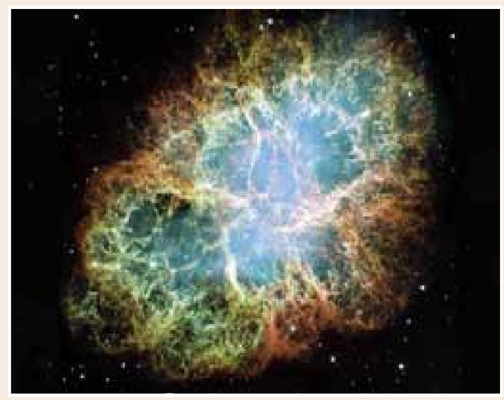


Image provided by NASA

Scientists predict that explosive events such as supernovae and gamma ray bursts may produce burst gravitational waves. The exact form these waves will take, however, is still a mystery. The Crab Nebula (left) is the remains of a supernova observed on Earth in 1054, and in its center is a pulsar, which is another potential source of gravitational waves.

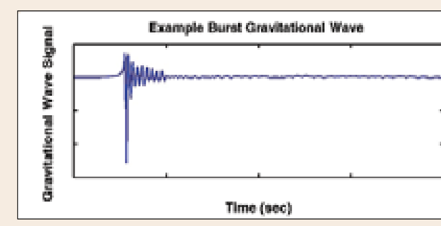


Image provided by A. Stuver; using data from C. Ott, D. Burrows, et. al.

What powered the Big Bang?

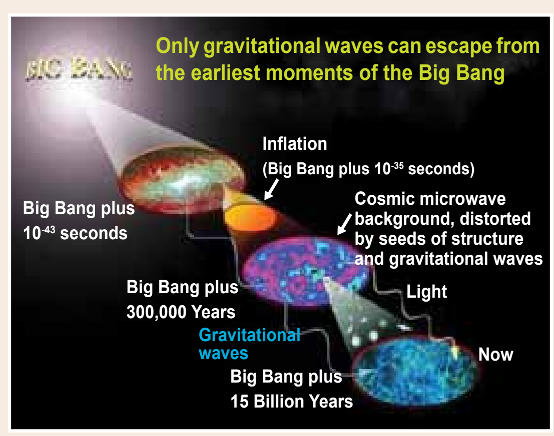


Image provided by NASA

Gravitational waves will give us a window to the beginning of the universe. The first light to travel freely–known as the cosmic microwave background–was produced when the universe was 300,000 to 400,000 years old, but scientists believe that the first gravitational waves were produced less than a second after the Big Bang. The signal from these stochastic gravitational waves is similar to radio static, and is expected to be the same from every part of the sky.

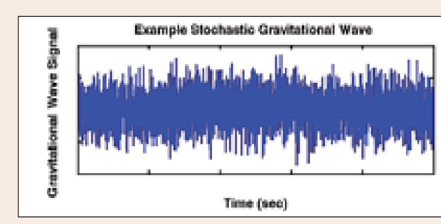


Image provided by A. Stuver

Seeing Gravitational Waves

Physicists think of gravitational waves as "ripples on space-time." Imagine dropping a bowling ball on a trampoline–ripples will travel outward in all directions. Similarly, physicists believe large masses in the universe can create gravitational waves when they rotate around each other, collide with each other, or explode.

Physicists expect gravitational waves to stretch space in one direction and compress it in another. Therefore, most gravitational wave detectors have two arms of equal length at right angles to each other. A single laser beam is split at the intersection of the two arms. Mirrors are suspended at the end of each arm and near the beam splitter. Laser light in each arm bounces back and forth between these mirrors, and finally returns to the intersection, where it interferes with light from the other arm.

If the lengths of both arms have remained unchanged, the two combining light waves should completely cancel each other out. However, if a gravitational wave were to slightly (about 1/1000 the diameter of a proton) stretch one arm and compress the other, the two beams would no longer completely cancel each other, yielding light patterns at the photodetector. Encoded in these light patterns is the information about the gravitational waves, which tells us about objects in the universe.

Diagram of LIGO

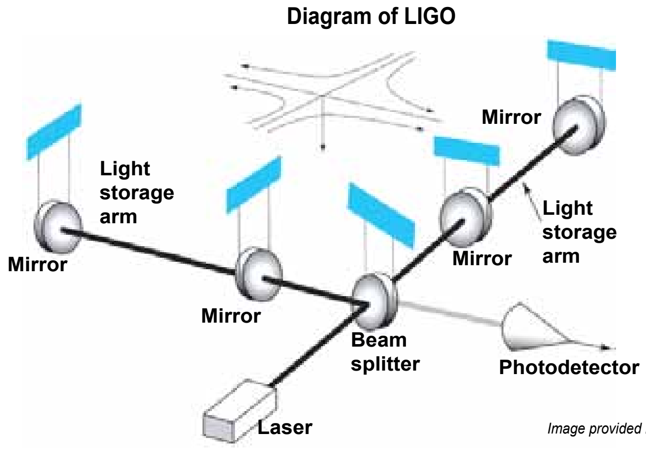


Image provided by LIGO

The Detectors

The Laser Interferometer Gravitational-Wave Observatory, or LIGO, is the world's largest gravitational wave observatory, with two detectors whose arms are 4 kilometers (a little less than 2.5 miles) in length. LIGO's detectors are located in Hanford, Washington (top) and Livingston, Louisiana (bottom). Other gravitational wave detectors include VIRGO in Italy, GEO600 in Germany, and TAMA300 in Japan.

Why multiple detectors?

Multiple detectors are necessary to eliminate disturbances caused by local sources, like trees falling in the woods, that can appear similar to gravitational waves in the data that is collected. Also, because gravitational waves are expected to travel at the speed of light, there will be a delay in the time when they are observed at the different detectors. Using this delay, scientists will be able to pinpoint the location of the source object in the sky.

Images provided by LIGO

SOURCES: Laser Interferometer Gravitational-Wave Observatory (LIGO), California Institute of Technology (Caltech), Massachusetts Institute of Technology (MIT), National Aeronautics and Space Administration (NASA)
LIGO is supported by the National Science Foundation. Poster funded by APS and NSF grant PHY 07-57058.
CREDITS: Text and images by Amber Stuver, LIGO; text edited by Gabriel Popkin, APS; designed by Nancy Bennett-Karasik, APS.

LIGO Laser Interferometer Gravitational-Wave Observatory
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