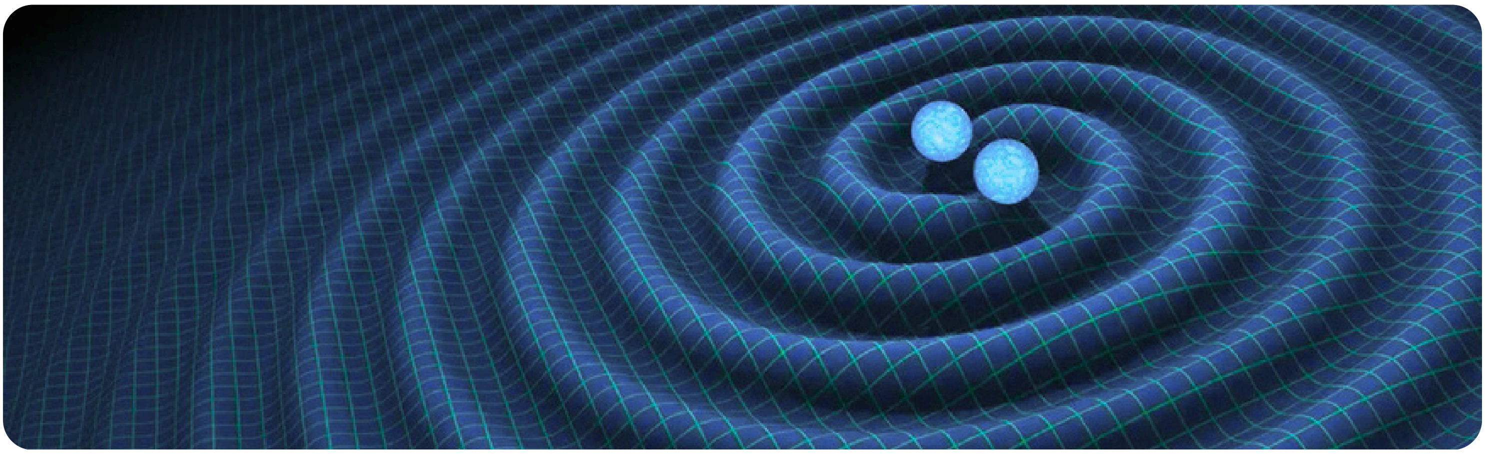
Gravitational Waves - What are they and how we measure them



Invisible gravitational waves constantly cross our Solar System. These waves travel in the fabric of spacetime and thus conventional detectors like our eyes, telescopes and particle detectors cannot observe them. However, recent advances in technology have made measurements possible. Two types of observatories are active on Earth, and ESA is preparing the first mission to study these waves from space.

A gravitational wave is an invisible (yet incredibly fast) ripple in space. Gravitational waves travel at the speed of light (186,000 miles per second). These waves squeeze and stretch anything in their path as they pass by. Einstein predicted that something special happens when two bodies—such as planets or stars—orbit each other. He believed that this kind of movement could cause ripples in space. These ripples would spread out like the ripples in a pond when a stone is tossed in. Scientists call these ripples of space gravitational waves.

The most powerful gravitational waves are created when objects move at very high speeds. Some examples of events that could cause a gravitational wave are:

- when a star explodes asymmetrically (called a supernova)
- when two big stars orbit each other
- when two black holes orbit each other and merge

The discovery of Gravitational wave has provided a key to the theory of relativity to define the universe. It improves on common electromagnetic observations by providing a new way to observe cosmic events. These waves enable the exploration of historically unreachable regions of space-time, such as the cores ofblack holes. They also reveal the nature of gravity and spacetime, providing the opportunities for testing theories other than General Relativity.

Crab Nebula - A supernova remnant

In 2015, scientists detected gravitational waves for the very first time. They used a very sensitive instrument called LIGO (Laser Interferometer Gravitational-Wave Observatory). These first gravitational waves happened when two black holes crashed into one another. The collision happened 1.3 billion years ago. But, the ripples didn't make it to Earth until 2015!

DETECTING THE WAVES

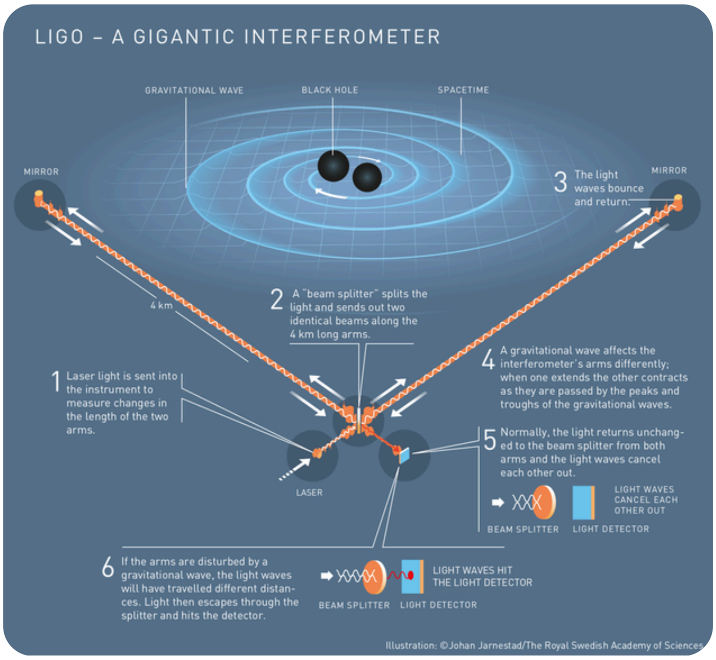
When a gravitational wave passes by Earth, it squeezes and stretches space. LIGO can detect this squeezing and stretching. Each LIGO detector consists of two 4km long arms consisting of 1.2m L-shaped steel vacuum tubes surrounded by a 10ft x 12ft concrete sheath to protect the tubes from the environment. LIGO jointly operates two observatories: the LIGO Livingston Observatory in Livingston, Louisiana and the LIGO Observatory in Hanford located on the site of the Hanford Department of Energy near Richland, Washington

A passing gravitational wave causes the length of the arms to change slightly. The best way to measure the distortion or to observe gravitational waves is to use the speed of light. This speed does not stretch. If the space between two points stretches, light would take longer to go from one point to another. If the space stretches back or squeezes in, light would take less time to go back-and-forth from the two points. The observatory uses lasers, mirrors, and extremely sensitive instruments to detect these tiny changes.

The entire observation includes an L-shaped tunnel that uses laser and mirrors placed at the two ends of the tunnel. LIGO fires and splits laser from the center or vertex of the L-shaped tunnel for two laser beams to travel into two paths—one for each arm of the L. Each laser beam sent to the two ends of the tunnel would be reflected back to the center. The laser fundamentally measures the changes in the distance between the ends of the tunnel.

When gravitational waves pass through the entire LIGO, the spacetime fabric stretches in one direction and stretches back or squeeze in another direction. This stretching or strain in the spacetime fabric would create discrepancies in distance between the ends of the tunnel. This is because the strain would change the timing of when the split laser beams travel back and forth to their destination.

These discrepancies reflect the stretching and squeezing from two directions. Furthermore, These discrepancies would mark the existence of gravitational waves. LIGO essentially records these discrepancies after measuring the fluctuating distance caused by the stretching and squeezing of the spacetime fabric.



THE FUTURE

The future of gravitational wave research looks hopeful. Complex space-based observatories, such as the Laser Interferometer Space Antenna (LISA), are designed to identify lower-frequency waves that expand our observing capability. Scientists also plan to utilize gravitational waves to investigate phenomena such as cosmic strings and the early stages of the Big Bang, maybe bringing up some new secrets of the birth of the universe.

Gravitational waves are the result of the merging of black holes or the same sorts of singularities due to their gravity. Researchers can use those wave signals or the ripples to determine black hole masses, spins, and movements. Observations of black hole mergers have resulted in the detection of black holes with intermediate mass. This can help to study the population of black holes in the universe.

The detection of a gravitational wave signal and a gamma-ray burst at the same time appears to back up the long-held notion that BNS mergers are connected to short-gamma-ray bursts. Detailed analyses of gravitational-wave data from BNS systems, combined with anecdotes of solar flares, are yielding novel clues into the astrophysics of compact binary systems and gamma-ray bursts, dark matter, the nature of gravitation, and unbiased cosmological tests. As detection technology becomes more precise, the study of gravitational waves may deepen our understanding of gravity, cosmology, and the fabric of the universe.