Gravitational waves
NAUTILUS

WHAT ARE GRAVITATIONAL WAVES?

Gravitational waves are disturbances in the gravitational field that propagate at the speed of light. Their existence is predicted by the **Theory of General Relativity** formulated by **Albert Einstein.**

Einstein revolutionized the concepts of **space** and **time,** postulating that the same phenomenon, when observed from different reference frames, can appear to unfold differently, to the point at which time itself seems to run differently.
As a consequence, the reference system describing a given phenomenon consists of the three spatial coordinates plus a time coordinate- four dimensions, rather than three **(space-time).**

The theory of general relativity, which describes phenomena related to gravity, states that the shape of space-time depends on the distribution of the matter contained within it. For example, the mass of a star curves the weave of space-time, as if space-time were an invisible canvas. When the distribution of matter changes, for example, because a massive object moves rapidly, the shape of space-time changes as a consequence. This change does not occur instantly throughout the Universe; instead, the change propagates from its point of origin at the speed of light. The propagation of this disturbance in the shape of space-time is known as a gravitational wave-it can be compared to the ripples on the surface of a lake after a stone is thrown in.

WHAT ARE THE SOURCES OF GRAVITATIONAL WAVES?

Any mass in motion generates gravitational waves, but the signal emitted is so weak that in order to have any hope of observing it, the source must be the motion of a very large mass, such as a black hole, or a catastrophic event, such as the explosion of a supernova.

CAN GRAVITATIONAL WAVES BE DETECTED?

Gravitational waves interact weakly with matter.
For example, a gravitational wave crossing the sun would lose only one part in 10^{16} of its energy.
The detection of such waves therefore poses exceptionally difficult physical and technical problems.

WHY IS IT USEFUL TO DETECT GRAVITATIONAL WAVES?

The detection of gravitational waves would be a scientific discovery of fundamental importance for the study of our Universe.
Because they interact so weakly with matter, gravitational waves travel undisturbed through space, crossing whatever celestial bodies happen to be in their path. This means that they can be used as probes to observe areas of our Universe otherwise hidden from view by stars or interstellar matter. For example, gravitational waves could be used to obtain radiography images of the interiors of galaxies. This type of information would shed light on the distribution of matter throughout the Universe, contributing to studies on its origin and evolution. In particular, it is thought that in the moments immediately after the Big Bang there was significant emission of gravitational waves.
The detection of these gravitational waves of cosmological origin would furnish a photograph of the Universe in the first few instants of its life.

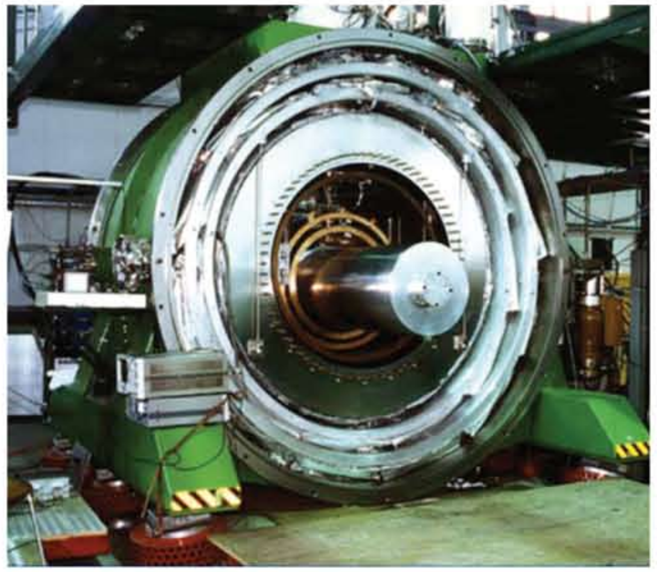
Because gravitational waves interact so weakly with matter, up to now it has not been possible to directly detect them.

HOW CAN GRAVITATIONAL WAVES BE DETECTED?

Gravitational waves can be detected using **resonant detectors** or interferometers. A resonant detector works like an antenna: the passage of a gravitational wave gives rise to a variation in the dimensions of the detector in the plane perpendicular to the direction of propagation of the wave. An interferometer measures the variation of the distance between two free masses induced by the passage of a gravitational wave through the space between them. In both types of detector, the dimensional variations induced by the gravitational wave are smaller than the size of an atom.

WHAT IS NAUTILUS?

NAUTILUS is an ultracryogenic resonant gravitational-wave detector installed at Frascati in 1992. **NAUTILUS** is part of an international network of gravitational-wave detectors that includes ALLEGRO (Louisiana, USA), AURIGA (INFN, Legnaro), and EXPLORER (CERN, Geneva).



HOW IS NAUTILUS MADE?

NAUTILUS is a cylindrical aluminum bar 3 m in length and 0.6 m in diameter, weighing 2770 kg.

The signal to detect is so weak that, in order to be able to observe it, all sources of noise must be eliminated, including both internal noise from thermal agitation in the material of the antenna, and external noise from traffic, seismic background, and even footsteps. To eliminate internal noise, the antenna must be maintained at an extremely low temperature. **NAUTILUS** can be cooled down to a temperature of 0.1 degrees above absolute zero, making it one of the coldest macroscopic objects in the Universe. The isolation of the antenna from external disturbances requires the use of highly effective suspension and shock-absorbing devices.

Under the influence of a gravitational wave, the antenna begins to vibrate. These vibrations are first converted into an electrical signal and then into a magnetic signal that is measurable by a device called a SQUID (superconducting quantum interface device). **NAUTILUS** can measure mechanical distortions of lengths down to 10^{-18} m, making it one of the most sensitive devices ever built.

DO GRAVITATIONAL WAVES REALLY EXIST?

In many laboratories spread across the world, experiments are being conducted to detect gravitational waves with both resonant antennas and interferometers. No experiment has so far succeeded in detecting a signal unequivocally interpretable as arising from the passage of a gravitational wave.

The indirect effects of gravitational waves have been observed. For example, in binary star systems, the stars rotate rapidly about each other and lose energy by radiating gravitational waves into space.

Because of the successes of general relativity in other areas, it seems likely that gravitational waves do in fact exist.