Gravitational Waves

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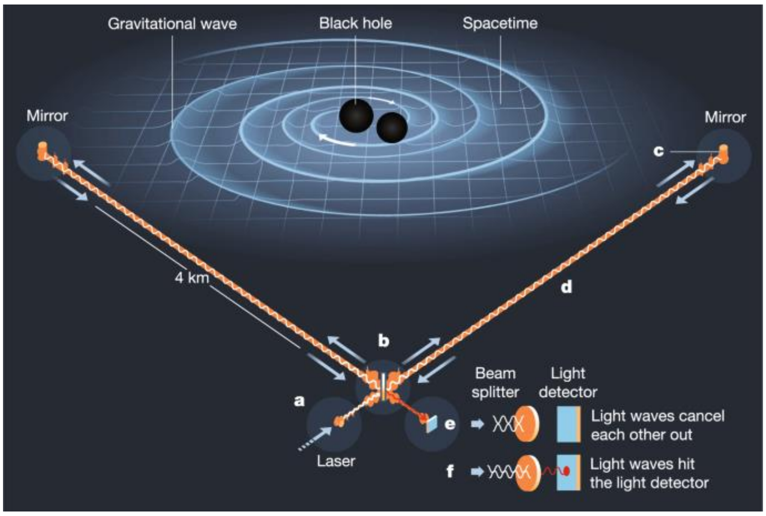
Gravitational waves are ripples in the curvature of space-time caused by accelerating masses that travel at the speed of light away from their source. Henri Poincaré postulated them in 1905, and Albert Einstein predicted them in 1916 based on his general theory of relativity.



Gravitational waves

Gravity waves transmit energy in the form of gravitational radiation, which is similar to electromagnetic radiation in that it is a kind of radiant energy. Because Newton's rule of universal gravitation, which is part of classical mechanics, is predicated on the premise that physical interactions propagate instantly, it does not allow for their existence (at infinite speed). This demonstrates that traditional physics approaches are incapable of explaining relativity phenomena.

The orbital decay of the Hulse-Taylor binary pulsar, which was compatible with the decay predicted by general relativity as energy is lost to gravitational radiation, provided the first indirect proof for the presence of gravitational waves. This discovery earned Russell A. Hulse and Joseph Hooton Taylor Jr. the Nobel Prize in Physics in 1993.

Gravitational waves were directly observed only in 2015. Such a gravitational wave is a ripple in the fabric of space. There are 2 heavy masses orbiting each other and accelerating in such a way that the shape of space changes. In 2015, we received a signal that there was a collision between two black holes that had been orbiting each other for a long time. They started moving faster and faster and eventually collided. Then they merged into a single, even bigger black hole. During the collision, they sent a vibration through the universe at the speed of light. We were able to pick up this vibration millions of years later on Earth. The signal was picked up by a detector called LIGO (Laser Interferometer Gravitational Wave Observatory). However, this signal lasted only one-fifth of a second. This vibration was later called a gravitational wave.

In gravitational wave astronomy, observations of gravitational waves are used to derive data about the sources of gravitational waves. Sources that can be studied in this way include binary star systems consisting of white dwarfs, neutron stars and black holes, as well as events such as supernovae and the formation of the early universe shortly after the Big Bang.

This phenomenon also explains the reason why the Earth revolves around the Sun. The sun is so massive that it causes a great deformation of the space around it. You could compare space to an elastic floor. The heaviest object sinks the deepest, creating an inverted hemisphere where the sun is at its deepest. If you keep walking straight along the edge of the circle, you are walking in circles all the time. That is why the Earth keeps on revolving in the same orbit around the Sun. So not only the Earth but all the other planets also revolve in the same orbit around a massive object. When an object located in such an orbit accelerates, the regularity is broken. These waves are propagated: gravitational waves.

On the website of the Belgian University KU Leuven, there are rumours about a Belgian Gravitational Wave centre. The Gravitational Wave Centre is a research initiative aimed at investigating the implications of recent advances in theoretical high-energy physics for gravitational wave observations and astrophysics more generally. The Centre also acts as a platform to strengthen and coordinate nationwide collaboration on gravitational wave science for Belgium’s participation in the LISA mission and the Einstein Telescope ground-based observatory exploring the gravitational universe.

A special detector was assembled to detect these waves: LIGO. Apart from LIGO, there are many others, but this one is the best known.

LIGO

This and LIGO's sensitivity to external vibrations make the choice of location for the instruments difficult.

The Laser Interferometer Gravitational-Wave Observatory, or LIGO for short, is a huge physics experiment that examines direct gravity. LIGO consists of two identical detectors laying 700 km away from each other, one at the Livingston and the other at the Hanford Site in Richland.

Why exactly are there two detectors? Well, these detectors are used to 'feel' the smallest vibrations on earth. These vibrations are caused by sources that can be very far away. Earthquakes, acoustic noise and even internal laser fluctuations can be causes to simulate a gravitational wave signal in each interferometer. The instruments are far apart, so the timing of the detected waves would not be the same. The difference of a few milliseconds is enough.

The enormous distance between the detectors means that they do not sense the same local vibrations, but gravitational wave vibration at approximately the same time. By comparing the data from both locations, scientists can ignore the vibrations that differ between the locations and look only for identical signals that occurred at the same time at both locations.

Ligo’s interferometer

As a result, a minimum of two detectors are required. Only gravitational wave signals remain as outliers after one works as a noise filter for the other. Gravitational waves would never be identified by an interferometer like LIGO if scientists didn't cooperate in this way to corroborate each other's results.

The arms of the interferometers are incredibly long, namely 4 kilometres.

VIRGO

Virgo is a gravitational wave detector located near Pisa, in Italy. The Virgo interferometer takes its name from the Virgo Cluster, which consists of about 1,500 galaxies in the Constellation of Light that is about 50 million light-years away from Earth. It is composed by a large optical laser interferometer called “Michelson's Interferometer” and it is formed by 3km long arms.

There are many international contributions to the Virgo collaboration, such as France with the CNRS (Centre National de la Recherche Scientifique), Holland with the Nikhef, Hungary with the MTA Wigner RCP, Poland with the POLGRAW, Spain with the VALENCIA UNIVERSITY, Italy with the INFN (National Institute of Nuclear Physics). They all want to detect these gravitational waves which come from all parts of the universe. Thanks to this international collaboration there were and there are many improvements.

The Virgo detector, with the help of the two interferometers of the Laser Interferometer Gravitational Observatory (LIGO), in the United States, in Louisiana, observed the sky between 2007 and 2011.

Virgo and LIGO interferometers are currently trying to improve their program. In fact, this program pushed all the technologies used to the limit and it improved a lot Virgo's sensitivity. The interferometer improved, it was called Advanced Virgo, and together with LIGO, in 2016 thanks to this acquired a better sensitivity than the one that the detectors of the previous generation had.

Previously it was mentioned Virgo, who collaborated with Ligo for the first recording of the passage of a gravitational wave in 2015, which two years later led them to the attribution of the Nobel Prize for Physics. But what are Virgo's goals? Originally Virgo's first aim was to observe gravitational waves, they successfully pursued together with Ligo's collaboration. Virgo’s currently aim is to detect more and more gravitational signals and extract as much scientific information as possible.

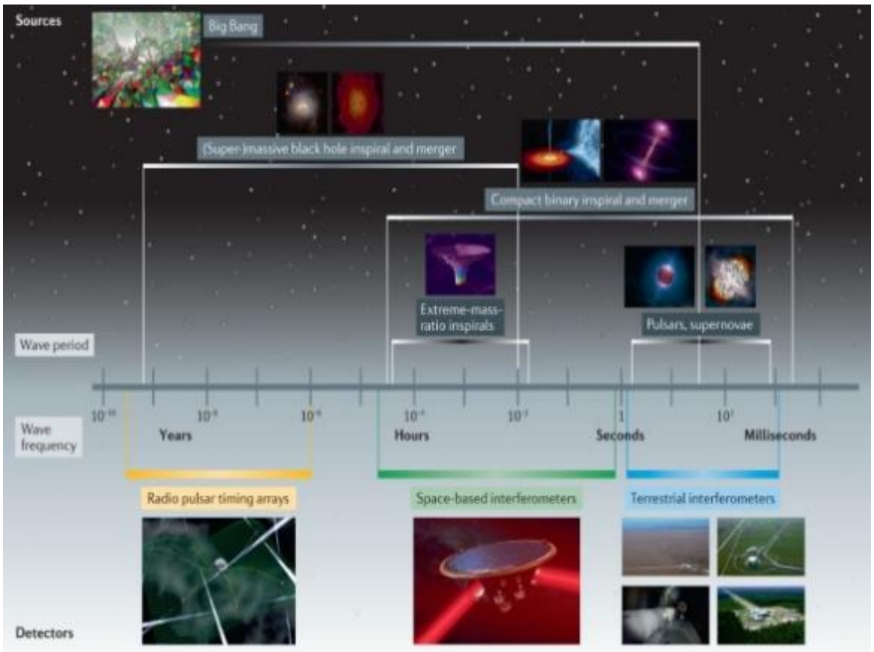
In fact, for this reason Ligo and Virgo collaborate: they want to increase the sensitivity of the interferometer over time in order to detect even the smallest gravitational waves.

Virgo’s interferometer

New detectors such as KAGRA in Japan and the third Ligo interferometer in India are also being built to achieve this purpose.

It currently manages to detect waves with frequencies between 10,000 and 5,000 Herz.

Functions and possibilities of gravitational waves

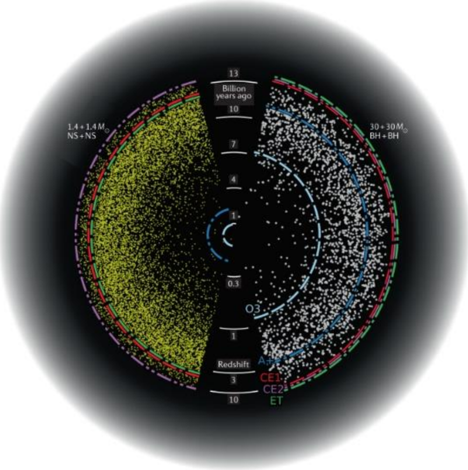


Functions and possibilities of gravitational waves

Gravitational waves astronomy has already revolutionised several areas of physics and astrophysics, but this is only the tip of the iceberg. There is still a lot of potential in this new aspect of astronomy.

An organisation that deals with gravitational waves science is the Gravitational Waves International Committee also known as the GWIC. It was founded in 1997 with the aim of promoting international cooperation in the construction, operation and use of the most important waves detection facilities. Thanks to this organisation, it is suddenly much easier to work with it and explore the potentials in future. What these detectors will mean in the future is that they will change the landscape of physics and address the most pressing problems in astrophysics and cosmology. In the future, new detectors will be built that are even more sensitive, and the detectors that already exist will be modified to be more sensitive. with all these techniques, one can expect more SNR (which means signal-to-noise ratio) events that may reveal signs of new physics. What gravitational waves science and its detectors also makes possible is that we can look much further into the universe at the redshift (this is what we can see in universe when something is moving away from us. It’s caused by a lower frequency of emitted light/elektro magnetic radiation.) This way, we can look back to the Big Bang time and discover new aspects of it.

In the picture on the right side we can see the current range of detectors now and the future detectors. With this it will be possible to see binary black holes (left) and neutron stars (right) in function of being able to look back to the Big Bang time. The intention is that the future detectors will eventually be able to map all stellar mass. In other words, thanks to these new techniques we can start looking at the universe in a completely new way.



Current range of detectors now
and the future detectors

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