14 september 2015: the discovery of the gravitational waves

Ball on an invisible sheet

In 1952, Albert Einstein was offered the presidency of the state of Israel, but he declined the post, saying that he thought he was too naive for politics. To quote his words: "*For me, equations are more important, because politics is for the present, but an equation is for eternity*".
Almost forty years earlier, precisely in 1916, the physical theory of General Relativity (*Die Grundlage der allgemeinen Relativitatstheorie*) of A. Einstein was published in number 7 of the *Annalen Der Physik*.The theory of General Relativity, created as a theory unifying Special Relativity and the Theory of Universal Gravitation, described gravitational interaction no longer as action at a distance between massive bodies (Newtonian theory, find out more: "*The crisis of classical physics*"), but as the effect of a physical law that links the geometry (more specifically, the curvature) of space-time.
In Physics, by the concept of space-time (direct consequence of the theory of relativity, to find out more: "*The Theory of Relativity*") is meant the four-dimensional structure of the universe which is therefore composed of four dimensions: three for space (length, width and depth) and one for time. The points of space-time are called events and each of them corresponds a phenomenon, identified by four coordinates, which occurs in a certain spatial position and at a certain time.
Space-time combines our classical traditionally separate concepts of space and time in a single construct (space and time are linked in a single entity). According to Einstein, the shape of space-time depends on the distribution of mass present in the same: matter, due to its mass, deforms (bends) the fabric of space-time, as if this were an invisible sheet on which a ball rests, thus generating the force of gravity.

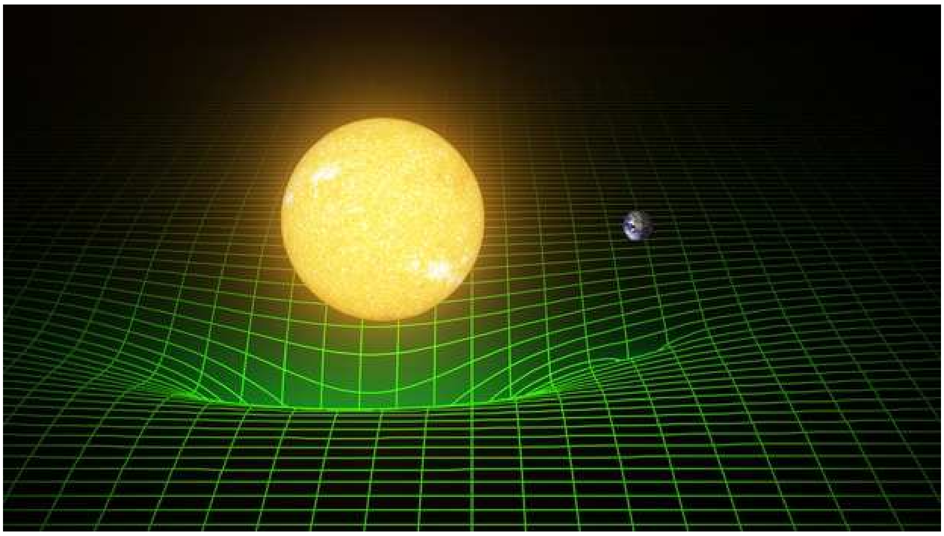

Image taken from: Massive Bodies Warp Space-Time, Credit: T. Pyle/Caltech/MIT/LIGO Lab

Einstein was right

100 years ago, the General Relativity of A. Einstein predicted that heavy moving objects emit gravitational waves, ripples in the curvature of space-time that travel at the speed of light (in the same way as light and electromagnetic waves). Like light, gravitational waves carry energy away from the objects that emit them. It would be expected, therefore, that a system of objects with mass ultimately stabilises in a stationary state, because at any moment energy would be carried away by the emission of gravitational waves. Think of when you drop a cork in water: at first it bobs up and down for a while, but since the waves carry away its energy, it finally stops in a steady state (in Physics with the term finally is meant

the final time, i.e. the exact moment in which the experiments subject of the study terminate).
Also the revolution movement of the Earth in its orbit around the Sun, for example, produces gravitational waves. The continuous loss of energy will have the effect of altering the orbit of the Earth so that it will gradually get closer to the Sun, following a spiral movement, until it collides with it and stabilises in a steady state. The rate of energy loss in the case of the Earth and the Sun is very low: the Earth will take approx. one thousand million million million million years to fall into the Sun.
The change in the orbit of the Earth, as a consequence of this loss of gravitational energy, is too small to be observable because of the relatively small energy and physical dimensions involved. If, on the other hand, the gravitational collapse concerns a star which has started to form a black hole whose mass is much greater than that of the Sun, then we can understand that the movements would be much faster and the energy loss rate would be much higher. The star would therefore not take very long to stabilise in a steady state (from "*A brief history of time*", *1988 by Stephen W. Hawking*).

36+29=62?

In 1974, this effect was observed in the binary pulsar called PSR 1913+16 by astrophysicists Russell Hulse and Joseph Taylor (Nobel Prize for Physics in 1993). This system contains two neutron stars that orbit around each other, and the energy that they lose through the emission of gravitational waves determines the spiral movement with which they approach each other (to find out more: "Searching for gravitational waves").
Recently, 14 September 2015: scientists of the American LIGO (Laser Interferometer Gravitational-wave Observatory) detector team, led by physicists Rainer Weiss, Kip Thorne and Ronald Drever, reported the detection of gravitational waves associated with one of the most violent events of the Universe: the merger of two blacks holes. LIGO is an observatory, operating in the United States since 2002, specifically designed to capture gravitational waves; it consists of two identical structures, each of which is a laser interferometer, situated at 3000 km from each other, one in Hanford (Washington State) and the other in Livingston (Louisiana, to find out more: "Searching for gravitational waves").
Approx. one billion light years from us, the two blacks holes (with masses of 36 and 29 times that of the Sun), linked in an increasingly close binary system (see YouTube video: " Black Hole Merger Simulation"), collided at a speed of approx. 150,000 km/s (half the speed of light) and merged to form a single massive body with a mass of 62 solar masses. The gravitational waves were emitted in the moments prior to the merger and received on 14 September 2015 at 09:51 (Universal Time, UTC) by both LIGO detectors.

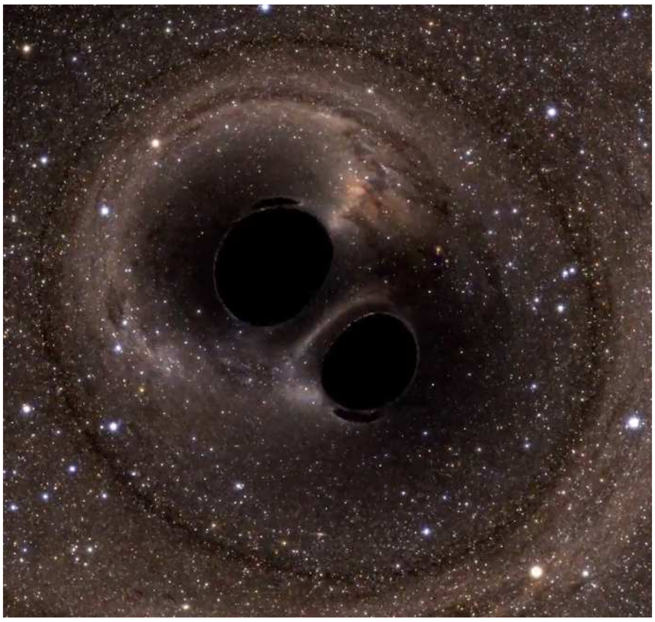

Image taken from:http://www.ligo.org/

Shortly before merging, therefore, the black holes emitted a large amount of energy in the form of gravitational waves, which can be calculated by noting that the resulting black hole has a mass 3 solar masses less than the sum of the individual black holes forming it. According to Einstein's famous equation E = mc2 (see first paragraph of the article), the missing mass was therefore transformed into energy, i.e. in just a few moments a mass equivalent to three Suns was converted into gravitational waves.
The news was officially announced and made public about 5 months later, on 11 February 2016. During the press conference held in Washington, the LIGO spokesman presented the sensational discovery, showing the world the charts (below) that for the first time revealed the form of gravitational waves. Both the excellent detection confidence level compared to the background noise as well as the perfect overlap of data from both LIGO interferometers were evident. The moment the two blacks holes are about to merge, they start emitting gravitational waves of increasing frequency, in a crescendo which concludes with their merger.

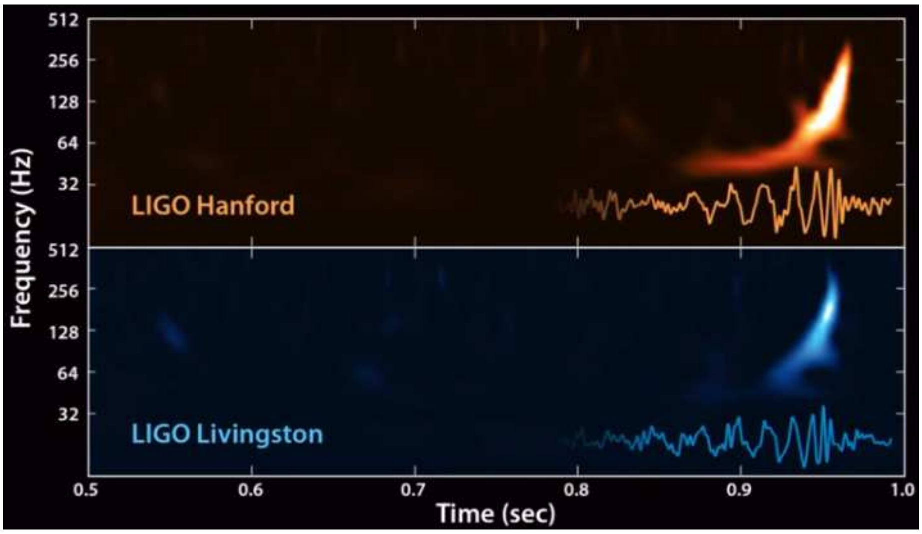

Image taken from: [LIGO detects gravitational waves - announcement at press conference]

Keep your eye on gravitational waves

14 September 2015 represented the start of a new era. The detection of gravitational waves opens up a Pandora's box that will allow us to observe reality from a new and totally different point of view than before: from now on, we will be able to see what until yesterday was invisible to us. Not only has the theory of General Relativity been confirmed, i.e. the basic principles on which we interpret the phenomena of the universe, but we will be able to shed light on the most violent phenomena of the Universe, which until now we have only begun to understand with the limited aid of electromagnetic waves. We will be able to better decipher collisions between blacks holes, the formation of galaxies, the birth and the properties of the Universe itself, the existence of dark matter and energy. Perhaps it will also soon be possible to solve a puzzle that the minds of scientists worldwide have been grappling with, i.e. what is inside neutron stars characterised by very high density (many solar masses concentrated in just 10 km of diameter).
In addition it may also be possible to understand how the force of gravity behaves in conditions and environments not artificially reproducible in the laboratory and to confirm our current physical knowledge on the force that dominates the entire Universe. It is as if until now we have been looking at the world through a small porthole and now we have full-field, three hundred and sixty degree vision available to us.

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Image taken from: http://www.ligo.org/ - Journey of a Gravitational Wave - Created by LIGO/SXS/R. Hurt/T. Pyle

We conclude by noting with pride that in Italy, and specifically in the municipality of Cascina, near Pisa, the VIRGO observatory (to find out more: "*Searching for gravitational waves*") has been working in tandem with the American LIGO since 2007, having established a network of implementations aimed at sharing information and at the joint processing of detected data. This has led to the creation of a single international network for the detection of gravitational waves and to the first direct observation of gravitational waves, officially announced on 11 February 2016.

by Enzo Scasciamacchia

Bibliography, website links and to find out more

- Stephen W. Hawking (1988), "*A brief history of time*".
- LIGO (Laser Interferometer Gravitational-wave Observatory)
- Black Hole Merger Simulation
- Warped Spacetime and Horizons of GW150914
  Simulating eXtreme Spacetimes Collaboration/Canadian Institute for Theoretical Astrophysics/SciNet. Warped Space and Time Around Colliding Black Holes (Courtesy Caltech-MIT-LIGO Laboratory, produced by SXS project)
- Stephen Hawking, Space-Time Theory
- Journey of a Gravitational Wave - Created by LIGO/SXS/R. Hurt/T. Pyle