KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2017 with one half to **Rainer Weiss** and the other half jointly to **Barry C. Barish** and **Kip S. Thorne** "for decisive contributions to the LIGO detector and the observation of gravitational waves".

The Nobel Prize 2017 **in Physics**

A discovery that shook the world

On 14 September 2015, gravitational waves from the cosmos were observed for the very first time. These vibrations in spacetime, which were predicted by Albert Einstein a hundred years ago, came from a collision between two distant black holes. The gravitational waves had travelled through the universe for 1.3 billion years before they were discovered by the LIGO detectors in the USA.

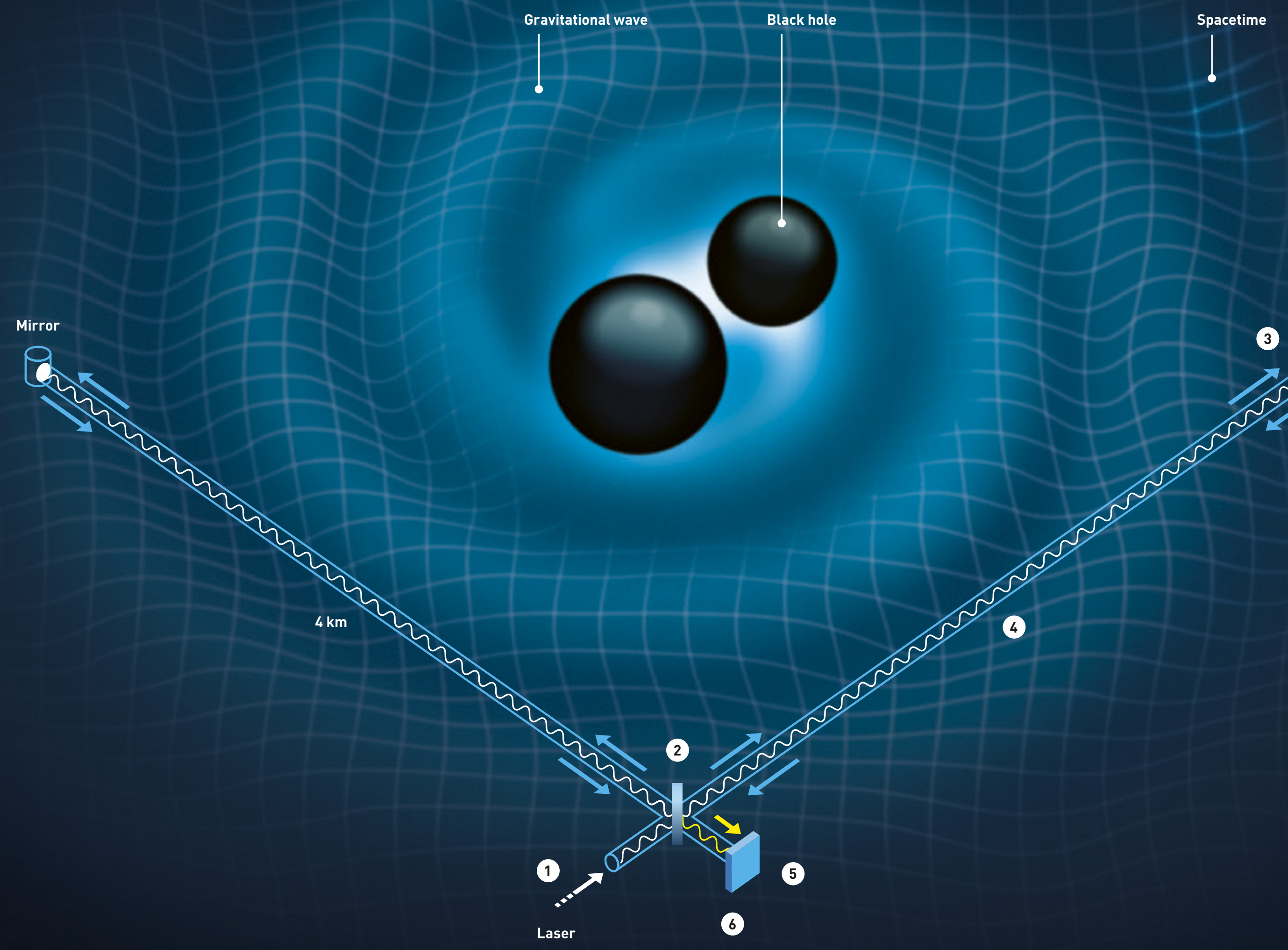
The gravitational wave signal was extremely weak when it reached Earth, but is promising a revolution in astrophysics. Gravitational waves are an entirely new way of observing the most violent events in the universe and testing the limits of our knowledge.

LIGO, the Laser Interferometer Gravitational-Wave Observatory, is a collaborative project with over one thousand researchers from more than twenty countries. Together, they have realised a vision that is almost fifty years old. The 2017 Nobel Laureates have, with their enthusiasm and determination, each been invaluable to the success of LIGO. Pioneers **Rainer Weiss** and **Kip S. Thorne,** together with **Barry C. Barish**, the scientist and leader who brought the project to completion, ensured that many decades of effort led to gravitational waves finally being observed.

As early as in the beginning of 1970s, Rainer Weiss had thoroughly analysed possible sources of background noise that would disturb measurements, and had also designed a detector, a laser-based interferometer, which would overcome this noise. Early on, both Kip Thorne and Rainer Weiss were firmly convinced that gravitational waves could bring about a revolution in our knowledge of the universe.

Gravitational waves spread at the speed of light, through the universe, as Albert Einstein described in his general theory of relativity. They are created when a mass accelerates, like when an ice-skater pirouettes or two black holes rotate around each other. Einstein was convinced it would never be possible to measure them. LIGO's achievement was to build a pair of gigantic laser interferometers and measure a change thousands of times smaller than an atomic nucleus, as the gravitational wave passed the Earth.

So far, light and other electromagnetic radiation as well as particles, such as cosmic rays or neutrinos, have been used to explore the universe. Gravitational waves are direct testimony to disturbances in spacetime itself. This is something completely new and different, opening up unknown worlds. A wealth of discoveries awaits those who succeed in capturing the waves and interpreting their message.



The two gigantic LIGO interferometers

LIGO consists of two identical interferometers. The gravitational wave first hit the interferometer in Livingston and then passed its twin in Hanford, just over 3,000 km away, seven milliseconds later. The signals were almost identical, and were a good match with the predicted signal for a gravitational wave. Using the signals, an area in the southern skies could be identified as the area the waves came from.

$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Albert Einstein was right again. It took a hundred years to detect the gravitational waves predicted by his equations in the general theory of relativity. The theory describes gravitation as a curvature of the four-dimensional spacetime.

Rainer Weiss
LIGO/Virgo Collaboration
Born 1932 in Berlin, Germany. Professor of Physics, MIT, Cambridge, MA, USA.

Barry C. Barish
LIGO/Virgo Collaboration
Born 1936 in Omaha, NE, USA. Linde Professor of Physics, California Institute of Technology, Pasadena, CA, USA.

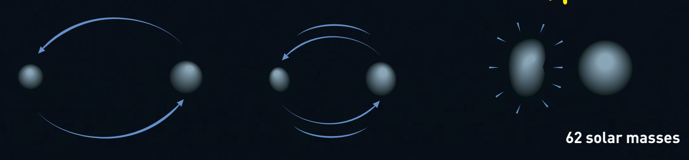
Kip S. Thorne
LIGO/Virgo Collaboration
Born 1940 in Logan, UT, USA. Feynman Professor of Theoretical Physics, California Institute of Technology, Pasadena, CA, USA.

The two black holes emitted gravitational waves for billions of years as they rotated around each other. As the waves carried away energy, they caused the black holes to move closer to one another in an ever-accelerating dance. At the very end, the horizons of the black holes touched each other, the holes swung at half the speed of light and merged in a fraction of a second. Energy equivalent to three solar masses was emitted and was later detected by the LIGO detectors on Earth, 1.3 billion light years away. All the vibrations faded away, leaving behind one big black hole.

The first gravitational wave ever detected

LIGO Hanford

Black holes



Two black holes collided after rotating ever-closer to each other for billions of years.

1. Laser light is sent into the instrument.

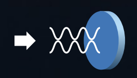
2. A beam splitter splits the light and sends out two identical beams along the 4 km long arms.

3. The light waves bounce and return.

4. A gravitational wave affects the interferometer's arms differently; as they are passed by the peaks and troughs of the gravitational waves, one extends and the other one contracts.

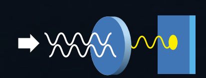
5. Normally, the light returns unchanged to the beam splitter from both arms and the light waves cancel each other out.

Light waves cancel each other out



6. If the arms are disturbed by a gravitational wave, the light waves will have travelled different distances. Light then escapes through the splitter and hits the detector.

Light waves hit the light detector



FURTHER READING More information on the Nobel Prize in Physics 2017: *www.kva.se/nobelphysics2017* and *www.nobelprize.org* **LIGO WEBSITES:** ● www.ligo.org ● www.ligo.caltech.edu ● www.advancedligo.mit.edu **BOOKS:** ● **Collins, H.** (2017) *Gravity's Kiss: The Detection of Gravitational Waves*, MIT Press. ● **Bartusiak, M.** (2017) *Einstein's Unfinished Symphony: The Story of a Gamble, Two Black Holes, and a New Age of Astronomy*, Yale University Press ● **Levin, J.** (2016) *Black Hole Blues and Other Songs from Outer Space*. Knopf ● **Kennefick, D.** (2007) *Traveling at the Speed of Thought: Einstein and the Quest for Gravitational Waves.* Princeton University Press ● **Collins, H.** (2004) *Gravity's Shadow: The Search for Gravitational Waves.* University of Chicago Press ● **Thorne, K. S.** (1994) *Black Holes and Time Warps: Einstein's Outrageous Legacy*. W. W. Norton & Company **SCIENTIFIC ARTICLE:** ● **Abbott, B. P. et al** (2016) *Observation of Gravitational Waves from a Binary Black Hole Merger*, Physical Review Letters, vol. 116, 061102 ● **More references can be found in the Scientific Background:** *www.kva.se/nobelphysics2017*

Editors: Olga Botner, Ulf Danielsson, Gunnar Ingelman and Nils Mårtensson, The Nobel Committee for Physics, The Royal Swedish Academy of Sciences; Joanna Rose, Science Writer; Clare Barnes, Translator; Carl-Victor Heinold, Editor, and Anna Nyhlén, Nobel Assistant, The Royal Swedish Academy of Sciences. **Graphic design**: IVY Agency AB
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