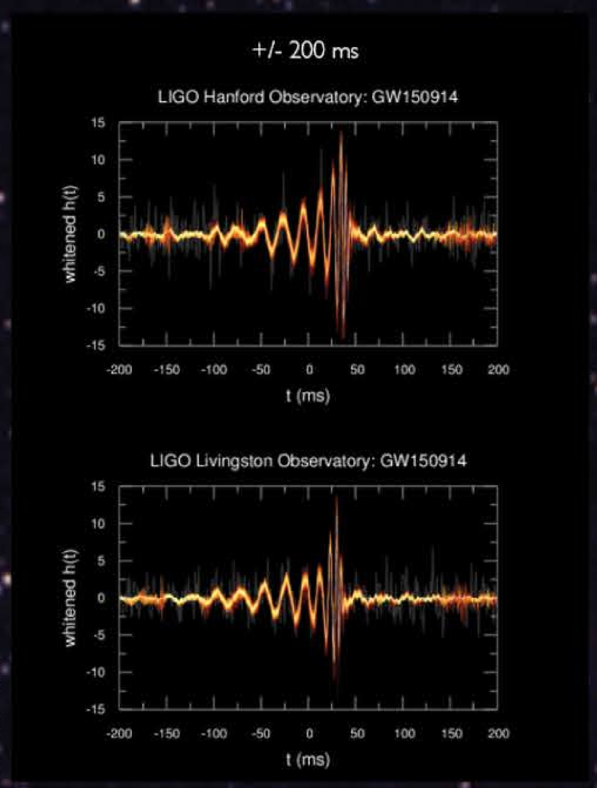
GRAVITATIONAL WAVES DISCOVERED

{GW150914: A BINARY BLACK HOLE MERGER}

Einstein's Last Prediction

One hundred years ago, Einstein published his general theory of relativity, which resulted in a set of remarkable predictions ranging from cosmological expansion to black holes to gravitational waves. The theory is among the most successful theories of nature: From its dramatic debut explaining the perihelion advance of Mercury and predicting the bending of light as it passes the sun, general relativity has passed every experimental test to date.

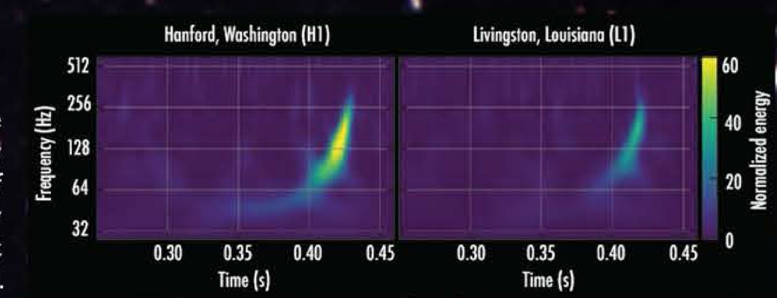
According to Einstein, gravitational waves are produced by accelerating masses. They are ripples in spacetime which travel at the speed of light and stretch and squeeze spacetime in an alternating pattern as they pass by. For decades scientists have been working to detect these ripples in order to verify the last prediction of general relativity.



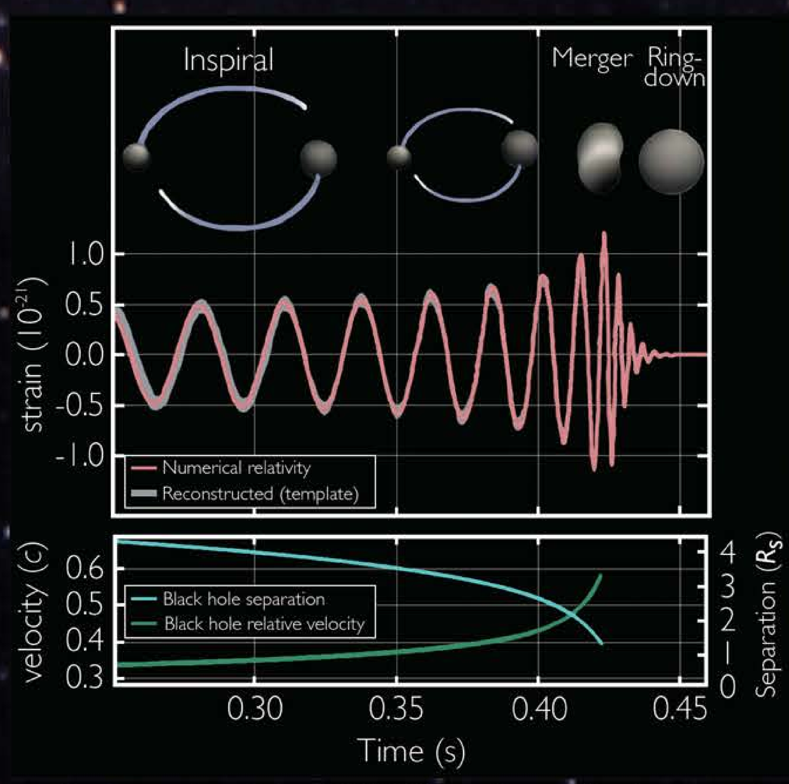
Reconstruction of the GW150914 waveform without making any assumptions about the astrophysical nature of the source. (credit: N. Cornish, J. Kanner, T. Littenberg, M. Millhouse)

What is GW150914?

On September 14, 2015 at 9:50 UTC (4:50 AM in Livingston, Louisiana; 2:50 AM in Hanford, Washington), the LIGO detectors sensed a passing gravitational wave. Scientists named this event GW150914 to indicate that a gravitational wave passed the detectors in 2015 on September 14. The wave arrived first at Livingston and then was detected at Hanford 7 milliseconds later. For less than half a second, the gravitational wave stretched and squeezed spacetime in the particular pattern expected from the merger of two black holes. It was detected by the LIGO search pipelines within three minutes of its arrival.



Time-frequency plot of the detector strain produced by GW150914. The frequency of GW150914 sweeps sharply upwards from 35 Hz to 150 Hz over two tenths of a second.



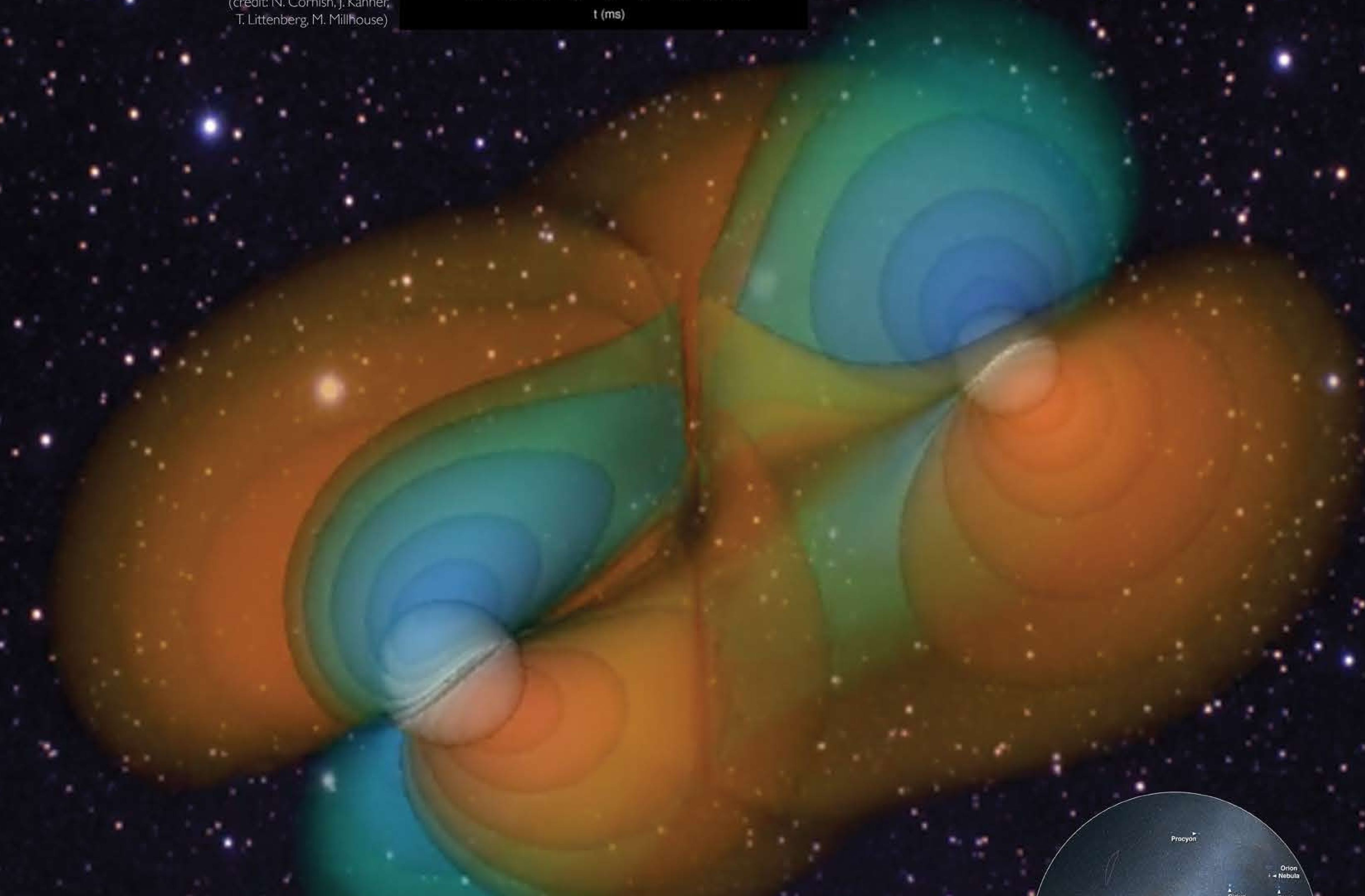
Reconstruction of the GW150914 waveform under the assumption it describes the inspiral, merger, and ringdown of a binary black hole system. The waveform shows excellent agreement with numerical calculations of general relativity.

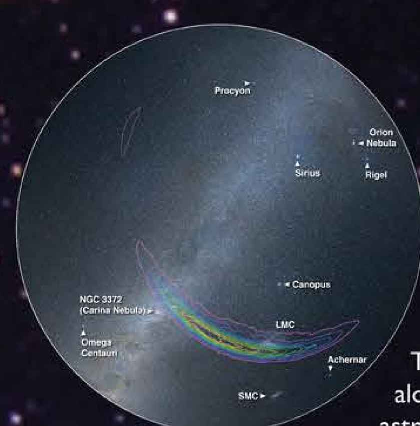
What have we learned from GW150914?

This is the first detection of gravitational waves as they pass the Earth. It is the culmination of a century-long quest that began with Einstein's prediction. It also represents the dawn of a new era in astronomy. The shape of the signal tells scientists a great deal about the cataclysmic event that caused it. Some key facts:

- The increasing frequency and amplitude are characteristic of two black holes, with masses of about 36 and 29 times that of our sun, spiraling together as they radiate gravitational waves.
- GW150914 provides the first evidence that binary black holes can form in nature and merge between the time of the Big Bang and today. These mergers should occur about once every fifteen minutes in the observable universe, though most will be too far away for Advanced LIGO to detect.
- The black holes merged in the manner predicted by general relativity and settled down to a spinning black hole of about 62 times the mass of the sun.
- The discrepancy between the initial and final black hole masses means that the merger converted about three times the mass of the sun into gravitational-wave energy in just a fraction of a second. The peak gravitational-wave power radiated by GW150914 was more than ten times greater than the combined luminosity of every star and galaxy in the observable universe.
- The merger happened approximately 1.3 billion light years from Earth.
- The direction from which GW150914 came can only be determined very roughly; see the skymap below. LIGO alerted astronomers of the potential source locations shortly after the event so that they could look for electromagnetic counterpart signals, though no such counterpart is expected for binary black hole mergers.

The detection of gravitational waves produced by colliding black holes is the crowning glory of Einstein's theory, yet it is just the first step in realizing the promise of gravitational waves as a new astronomical tool.



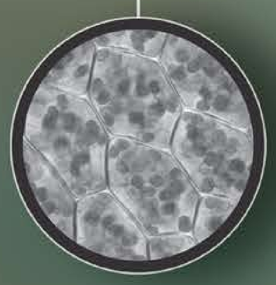


Sky at the time of GW150914, seen from the South Atlantic Ocean with north at the top. The probable location of the signal is shown along with the Milky Way and other familiar astronomical objects. (credit: S. Larson, R. Williams, T. Boch)

(simulation credit: M. Clark, K. Jani, M. Kinsey)
(visualization credit: M. Kinsey)

1.3 billion years ago

GW150914 is generated by the merger of two black holes and begins its journey to Earth. (credit: NASA)



800 million years ago

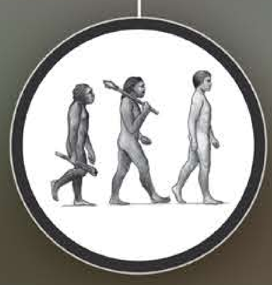
The first multicellular lifeforms evolve on Earth. (credit: Kristian Peters)

65 million years ago

The Cretaceous-Paleogene extinction event wipes out three-quarters of the plant and animal species on Earth, including the dinosaurs. (credit: Allie Caulfield)

2.5 million years ago

GW150914 is as far from Earth as the Andromeda Galaxy, our nearest neighbor galaxy. (credit: Adam Evans)



200,000 years ago

The first anatomically modern humans (Homo sapiens sapiens) evolve from archaic humans. (credit: MagneticHyena)

50,000 years ago

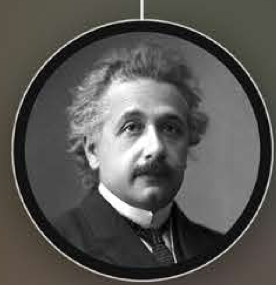
GW150914 enters our own galaxy, the Milky Way. (credit: Bruno Gilli/ESO)

10,000 years ago

Humans begin to form permanent settlements.

400 years ago

GW150914 is as far from Earth as Polaris, the North Star.



100 years ago

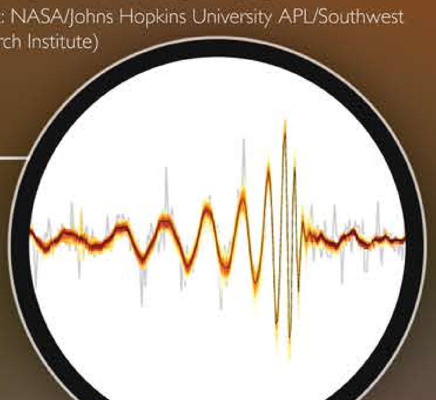
Albert Einstein develops the theory of general relativity, which includes a description of gravitational waves.

5 years ago

The initial LIGO and Virgo detectors complete their final science runs and shut down for upgrades to their advanced versions. (credit: LIGO Laboratory)

4.5 hours to go

GW150914 enters the Solar System and is as far from Earth as Pluto. (credit: NASA/Johns Hopkins University APL/Southwest Research Institute)



September 14, 2015

GW150914 reaches Earth and is detected by Advanced LIGO before continuing its journey through the cosmos. (credit: N. Cornish, J. Kanner, T. Littenberg, M. Millhouse)

LSC LIGO Scientific Collaboration

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