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Feb. 2016

Gravitational Waves Detected, as Einstein Predicted

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In 1687, Newton developed his theory of gravity and later identified a problem with it that was solved by Einstein's theory of general relativity in 1915, which included the prediction of gravity waves. Einstein recognized that they would be so small that they would be difficult to detect, and indeed it has taken a century to do that, with their detection announced on 11 Feb 2016. The figure shows comparisons of predicted and observed gravitational waves recorded on September 14, 2015 at 09:51 UTC from two merging black holes in the southern sky, each about 30 times the mass of our sun, lying 1.3 billion light-years away, i.e. the collision occurred 1.3 billion years ago at the distance from Earth that light travels in 1.3 billion years. About 3 times the mass of the sun was converted into gravitational waves in a few tenths of a second—with a peak power output about 50 times that of the whole visible universe.

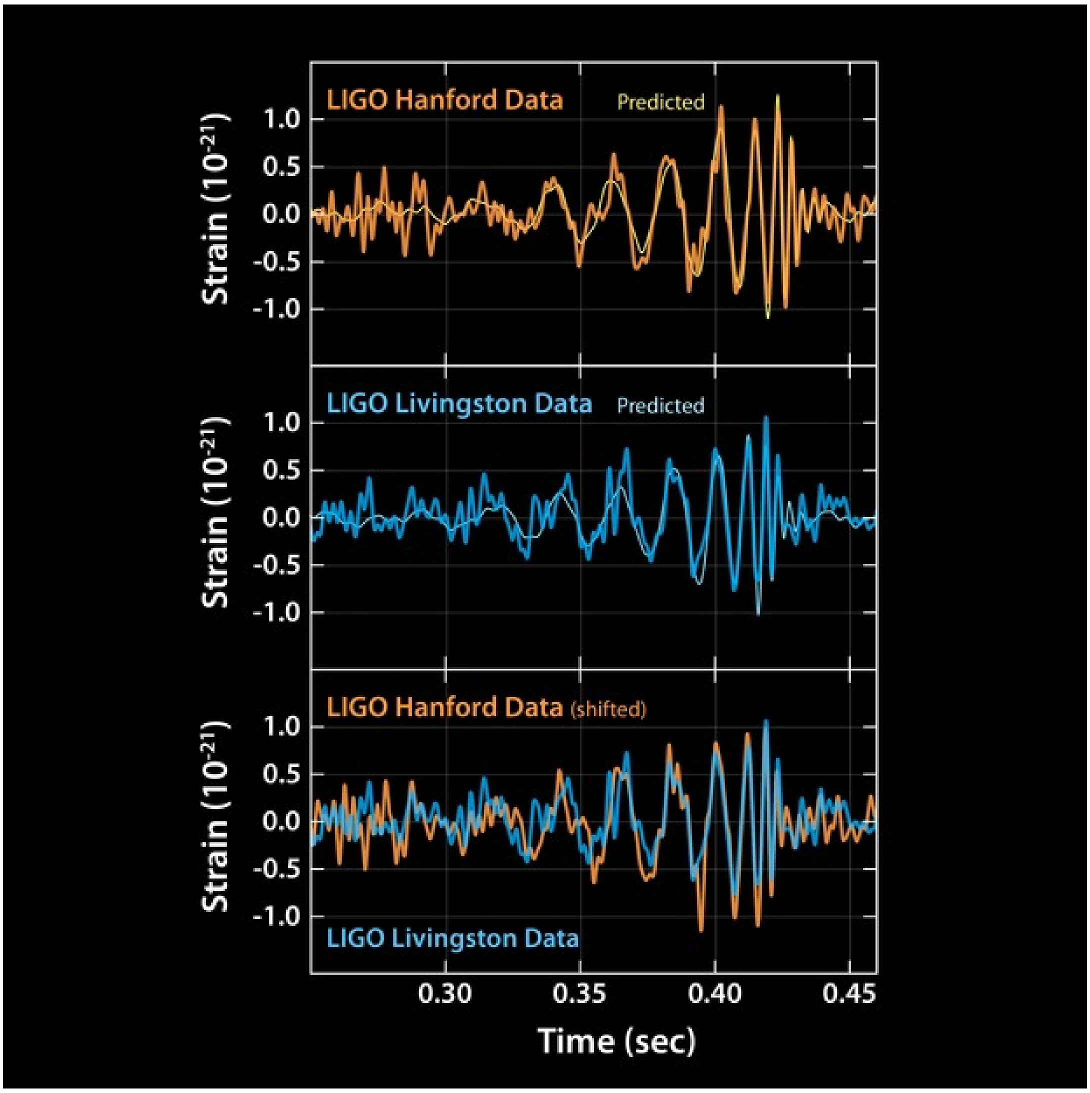

Figure 1. Recorded and predicted gravitational wave strain on the LIGO observatories. Source: https://www.ligo.caltech.edu/image/ligo20160211a

These observations were made fortuitously only one week after the newly enhanced observatory was turned on, at a time when calibrations were still being done. Figure 1 shows the signals of gravitational waves detected by the twin LIGO observatories at Livingston, Louisiana, and Hanford, Washington. The top two plots show data received at Livingston and Hanford, along with the predicted shapes for the waveform. These predicted waveforms show what two merging black holes should look like according to the equations of Albert Einstein's general theory of relativity, along with the instrument's ever-present seismic noise. Time is plotted on the X-axis and strain (change in length of a long tube) on the Y-axis. The strain is measured using interferometry in tubes that are 4 km long and about 1.2 metres in diameter. Strain represents the fractional amount by which distances are distorted. The measured strain is miniscule – 1 zepto strain, which is 1 part in 10 raised to the power of 21, equivalent to about 1% of the diameter of a proton over the 4 km length of the tubes, and the ratio of the diameter of an atom compared to the diameter of the earth's orbit. The frequency and amplitudes of the waves increase due to the increasing relative speed of the two black holes as they spiral into and coalesce with each other at close to the speed of light, releasing gravitational energy equivalent to the mass of three suns in the space of a few tenths of a second.

As the plots reveal, the LIGO data closely match Einstein's predictions. The bottom plot compares data from both detectors. The Hanford data have been inverted for comparison, due to the differences in orientation of the detectors at the two sites. The data were also shifted to correct for the travel time of the gravitational-wave signals between Livingston and Hanford (the signal first reached Livingston, and then, traveling at the speed of light, reached Hanford seven thousandths of a second later). As the plot demonstrates, both detectors recorded the same event, confirming the detection.

The strains caused by gravitational waves are so small that they have no practical impact on the human or built environment. But they may prove to be the best means available for seeing how the universe evolved from the big bang and understanding many mysteries such as dark energy and dark matter, which are invisible but seem to make up a large part of the Universe. Roughly 68% of the Universe is dark energy, and dark matter makes up about 27%. The rest - everything on Earth, everything ever observed in space with all of our instruments, all normal matter - adds up to less than 5% of the Universe.

https://www.ligo.caltech.edu/

https://www.ligo.caltech.edu/image/ligo20160211a

http://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy/