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The Einstein Revolution

For three centuries, Sir Isaac Newton and his laws of motion and gravity were the final word in physics dogma. Then along came Albert Einstein with a newfangled and revolutionary theory of general relativity that turned Newton on his head. Rather than perceiving space and time as fixed entities as Newton did, Einstein imagined space and time as dynamic, dependent on frames of reference. And he formulated the equations to prove it.

Fast-forward to the 21st century and Einstein's fingerprints are all over the modern world: Photoelectric cells, television, nuclear power, space travel and semiconductors all bear his signature in some way. Even the global positioning system (GPS) people tap into on their smartphones relies on Einstein's theory of general relativity to function accurately.

Since 1915, when Einstein published his first paper on general relativity, his theory has guided many of the major developments in physics. "In cosmology, relativity gave us the framework to study the universe as a whole and all of our modern theories of cosmology are based on it," said Gary Horowitz, a professor in UC Santa Barbara's Department of Physics. "In astrophysics, relativity predicts gravitational lensing, the bending of light that allows us to see very distant objects more clearly because of the relativistic effects."

Now, 100 years after Einstein predicted their existence in theory, gravitational waves have been directly observed for the first time by twin Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors located in Livingston, Louisiana,

and in Hanford, Washington. What's more, some of Einstein's own work in quantum mechanics led to the technique of laser interferometry, the essential tool behind the measurements that confirmed them.

"The discovery of gravitational waves opens up new directions, a new window on the universe," said physics research professor James Hartle. "It confirms one of the great theories of all time."

To accomplish this great feat, LIGO used a chirp from two massive black holes that merged more than one billion years ago in a distant galaxy. The signal was minuscule, and so weak that until now no equipment was sensitive enough to detect it. The LIGO team, which worked for more than two decades to refine its instrumentation, was able to achieve the sensitivity to measure the mind-bogglingly small movements in masses separated by 4 kilometers produced by the gravitational wave, which passed in less than one-tenth of a second.

"The discovery is profound not only because it confirms a large part of Einstein's theory of relativity, but it also tells us many things in astrophysics that we actually didn't know," said astrophysicist Lars Bildsten, the director of the Kavli Institute for Theoretical Physics.

The largest black hole of this type ever observed in the disc of our galaxy was about 15 times the mass of our sun, Bildsten noted. "The two black holes that created the observed gravitational wave were each nearly 30 times the mass of the sun," he explained. "We had no idea that normal stellar evolution could make black holes that large. So that alone was an astronomical discovery."

Gravitational waves provide an entirely new medium for exploration and offer novel ways for physicists to probe the universe, opening up whole new cosmic frontiers.

"Parts of the universe are opaque to electromagnetic waves — like light and its longer and shorter wavelengths — so we've never been able to see them directly," Horowitz said. "Gravitational waves can be used to tell us about the universe and areas we haven't been able to see before."

Gravitational waves — a consequence of the theory of general relativity — stand poised to take their place next to another great theory Einstein helped usher into the 20th century: quantum mechanics. Although somewhat incompatible, both relativity and quantum mechanics underpin theoretical physics 100 years later. In fact, a

deeper understanding of gravitational waves may one day help guide the discovery of a more fundamental theory that reconciles the two.

“We have good reason to believe general relativity is not a complete theory and, in particular, that it’s going to break down in the context of describing black holes,” said physics professor Steve Giddings. “That’s very much an important problem in physics today.

“The direct observation of gravitational waves from colliding black holes really constrains the possible departures from general relativity that we know are there and limits where modifications can be made,” he continued. “But the discovery is still spectacular and its announcement was one of those moments in science that you live for.”

About UC Santa Barbara

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