How Einstein's general relativity passed a key test

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In February, the discovery of gravitational waves by a team of scientists known as the Ligo (Laser Interferometer Gravitational-Wave Observatory) collaboration made headlines around the world. Like many physicists, I was asked countless times to explain what had been discovered. The Q&A below will answer most of these questions.

What's the big deal about gravitational waves?

Einstein's general theory of relativity, formulated 100 years ago, predicts that space and time are not absolute, but can be distorted or warped by matter. In particular, a cataclysmic event such as the collapse of a star could send shockwaves through space, not unlike ripples on a pond moving outward from a disturbance.

But that's just a theory?

Yes, and a hard one to test because gravitational waves are predicted to be extremely small. However, the proposal that matter can warp space and time leads to many other predictions, notably that light passing a massive body will appear bent to a distant observer, whereas time will appear stretched. Each of these phenomena has been observed; the bending of distant starlight by the sun was first observed in 1919, and the synchronisation of clocks in GPS satellites with earthbound clocks has to take account of the fact that clocks on Earth are in a strong gravitational field.

Where do black holes fit in?

Another prediction of general relativity is that if enough matter is concentrated in a small volume, the space in its vicinity will be so warped that it will curve in on itself to the extent that even light cannot escape. Astronomical observations suggest that each galaxy has a supermassive black hole at its centre.

So what does Ligo bring to the table?

The bending of light and the slowing of time in a strong gravitational field are indirect effects, from which we infer that space and time are not independent of matter. The Ligo collaboration observed a direct effect: a minute stretching and squeezing of space by a cataclysmic cosmic event.

And what was the event?

The signal detected by Ligo is exactly that predicted for one of the most energetic collisions of all: the merging of two black holes (about a billion light years away).

Can you tell us a little about the Ligo experiment?

Two laser beams are sent down two 4km-long tunnels at right angles to one another. With the use of an extremely precise system of mirrors, the two beams arrive back exactly 180 degrees out of step, cancelling each other out. The slightest distortion of the distance travelled by either beam would show up as a positive signal. The signal Ligo found corresponds to a distortion of space many orders of magnitude smaller than the diameter of an atom.

How do they know it's not a spurious effect?

Ligo has two separate rigs – on the east and west coasts of the US – to eliminate that possibility. The exact same signal was picked up simultaneously in both experiments.

Is there more to come?

Yes, apparently Ligo has detected several other signals, although they are weaker. It seems a whole new way of studying the universe has opened up.

So more instruments like Ligo will be built?

Yes. A much larger, space-based version of the experiment is planned in which two laser signals will be sent along two perpendicular arms one million kilometres in length each. This experiment, called Lisa (Laser Interferometer Space Antenna), had a prospective launch date of 2034, but we can now expect that to be brought forward.

So Einstein is proved right again?

No. Even the best experiments can only offer supporting evidence for a theory. The case is never closed in science, because we don't know what effect might turn up in the future that could show that the theory is incomplete. All we can say is that the theory is right so far – that is, that general relativity has passed yet another test with flying colours.

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