Detecting gravitational waves at your desk

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Anthony Gormley should have put the Quantum Cloud in a box. Credit: lwr, CC BY-NC-SA

Physics is on the front pages of newspapers around the world. This time it is because of the announcement made by a team of scientists who seem to have found indirect evidence for the existence of "primordial gravitational waves".

However, a bigger breakthrough would be direct detection of gravitational waves. Many scientists are working on achieving this, but all of those efforts involve large and expensive experiments. New developments show that it may be possible to do so in a device not bigger than a box on a desk.

Gravitational waves are predictions of Einstein's theory of General Relativity. According to Einstein, apples don't fall because a force attracts them from the centre of the Earth. The actual reason is that the Earth modifies space and time in such a way that apples fall without feeling any force.

While freely falling, apples move along the shortest path of a single structure called space-time, which, as the name implies, is fabric of space and time. The mass of an object shapes the space-time around it. That is why, if an object with some mass moves, space-time would change based on its movement.

The upshot of the space-time theory is that the movement of massive objects in a particular way creates gravitational waves. In the small time after the Big Bang, when the universe grew from a the size of an atom to the size of a tennis ball, Einstein's theory predicts that gravitational waves would have formed. And the scale of the event was such that the ripples created by those waves could be detected even today. That is what the scientific collaboration called BICEP (Background Imaging of Cosmic Extragalactic Polarisation) found when they announced their results this week.

While other aspects of Einstein's General Relativity have many experimental confirmations to boast of, gravitational waves have not been directly observed so far. We have a lot of indirect evidence of their existence, BICEP's observation added to it.

But BICEP's results are akin to studying a fossil. While studying a fossil is interesting, catching a dinosaur going around is a different business.

This is what another scientific collaboration called LIGO (Laser Interferometric Gravitational-Wave Observatory) has been trying to do since this experiment started to run at 2002.

Gravitational waves are created when two massive objects are accelerating relative to each other, such as two objects orbiting each other. However, gravitational waves created by Earth's orbit around the sun are really hard to detect. That is why we need to rely on other sources, such as the merging of two black-holes, if we want to see a space-time ripple in action.

LIGO scientists believe they can detect tiny changes caused by gravitational waves. Their experiment involves two mirrors that have two lasers reflecting between them. If gravitational waves interact with these lasers, there will be a tiny distortion in the time it takes for one laser to reach the detector relative to the other

To improve their chances of detecting such tiny changes, the mirrors need to weigh 10kg, be suspended in a vacuum, separated by several kilometres and isolated from any possible source of vibration. Even after 12 years of operation and many upgrades, a successful observation event has not been reported so far.

While it is fortunate for life on Earth that events like the merging of black holes usually takes place far from our planet, it means that by the time gravitational waves from them reach Earth, they are extremely weak. To detect these waves, we need to be close to the event, in the same way as we need to be close to the source of sound waves (say, speakers) to hear music properly. That is why the Europe Space Agency plans to launch in 2034 a Laser Interferometer Space Antenna (LISA) to detect gravitational waves in space by using satellites separated by several millions of kilometres.

A different approach taken by researchers at the University of Nottingham (including myself) led by Ivette Fuentes involves hunting for a gravity ripple in a much smaller system, such as a Bose-Einstein Condensate (BEC). A BEC is a bunch of atoms, say a hundred million, forced to stay in a very small (smaller than the width of a human hair) and very cold (-273℃) space.

Typically, atoms are like crazy kids going around in random directions at tremendous speeds, however under the above circumstances they behave themselves because they don't have enough energy to act crazy. In a way, all the atoms hold their hands and become a single entity – and you can think of it as a peaceful, quantum sea. Waves on the quantum sea are collections of quantum particles called phonons that, under some conditions, look much like particles of light (photons), except that they are much slower.

Photons fly and phonons surf. The idea, executed by Ivette Fuentes, David Bruschi, Mehdi Ahmadi and myself, was to consider a particular wave in the BEC sea and analyse the changes that a gravitational wave would generate on it. The conclusion of our work is that the changes are large enough to be detected in an experiment, providing our proposed device with the ability of being, in principle, more sensitive than LIGO to the passing by of a tiny gravitational wave. And the whole setup could fit in a big box on a desk or at the most in a small room.

Although it is only a preliminary theoretical result, we think that is promising enough to initiate a new avenue of research, which would complement all the existing enterprises. The aim is to finally see the mysterious face of the space-time ripples, not only to provide an ultimate confirmation of Einstein's theory but also to widen our understanding of the fabric of the universe. If done properly, physics could soon be back on the front pages of newspapers around the world.

Source: The Conversation