Physicists make rapid progress in bounding the speed of gravity

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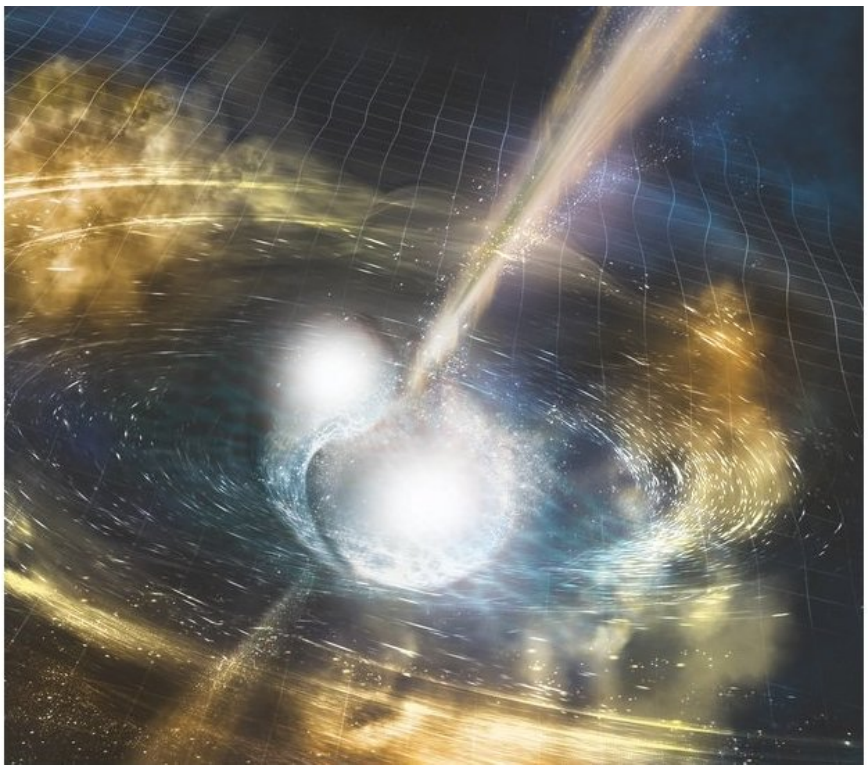

Artist's illustration of two merging neutron stars. Credit: NSF/LIGO/Sonoma State University/A. Simonnet

(Phys.org)—Recent gravitational wave detections have allowed physicists to confirm with greater and greater precision what Einstein predicted over 100 years ago in the theory of general relativity: that gravity does not act instantaneously as Newton thought, but instead propagates at the speed of light.

"The speed of gravity, like the speed of light, is one of the fundamental constants in the Universe," Neil Cornish, a physicist at Montana State University, told *Phys.org*. "Until the advent of gravitational wave astronomy, we had no way to directly measure the speed of gravity."

Over the past few months, physicists have made very rapid progress in bounding the speed of gravity using gravitational wave observations.

Initially, the first LIGO detections of gravitational waves constrained the speed of gravity to within 50% of the speed of light.

In a paper published last week in *Physical Review Letters*, Cornish and his coauthors Diego Blas at CERN and Germano Nardini at the University of Bern have combined the first three gravitational wave events reported by the LIGO and Virgo collaborations, allowing them to improve the original bounds to within roughly 45% of the speed of light.

Just two days later (and after the physicists mentioned above wrote their paper), another paper was published in *The Astrophysical Journal Letters* by the LIGO and Virgo collaborations, whose authors are affiliated with nearly 200 institutions around the world. By using data from the gravitational waves emitted by a binary neutron star merger detected in August, they were able to constrain the difference between the speed of gravity and the speed of light to between -3×10^{-15} and 7×10^{-16} times the speed of light.

The reason for the huge leap in precision is that the neutron star event did not emit only gravitational waves, but also electromagnetic radiation in the form of gamma rays. The simultaneous emission of both gravitational waves and light from the same source allowed the scientists to set bounds on the speed of gravity that is many orders of magnitude more stringent that what could be set using gravitational wave signals alone.

Depending on whether an astrophysical source emits both gravitational waves and light or only the former, scientists take different approaches to constraining the speed of gravity. When a source emits both gravitational waves and light, scientists can measure the difference (if any) in the arrival times of the two different types of signals at a single detector. In the *AJL* paper, the scientists measured an arrival delay of just a few seconds between signals that traveled a distance of more than one hundred million light years. Such a small delay across this distance is considered virtually nothing.

On the other hand, when a source emits only gravitational waves, scientists must detect the same signal in multiple Earth-based detectors and measure the (very slight) difference in arrival times. The scientists of the *PRL* paper did this by comparing signals detected by two LIGO detectors located 1800 miles apart: one in Hanford, Washington, and the other in Livingston, Louisiana.

As the physicists explain, it's possible to greatly improve the bounds on the speed of gravity using sources that emit only gravitational waves. For example, using four detectors located at different places on Earth, with five gravitational wave events for comparison, the constraints could improve to within 1% of the speed of light. But they could still not reach the degree of precision of experiments that have access to both gravity and light.

Overall, bounding the speed of light has many significant implications for fundamental physics and cosmology. One of the biggest implications is that the tight bounds provide a more precise test of general relativity and rule out proposed alternatives to general relativity.

"Many alternative theories of gravity, including some that have been invoked to explain the accelerated expansion of the Universe, predict that the speed of gravity is different from the speed of light," Cornish said. "Several of those theories have now been ruled out, thereby restricting the ways in which Einstein's theory can sensibly be modified, and making dark energy a more likely explanation for the accelerated expansion."

More information: Neil Cornish, Diego Blas, and Germano Nardini. "Bounding the Speed of Gravity with Gravitational Wave Observations." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.119.161102

B.P. Abbott, et al. (LIGO Scientific Collaboration and Virgo Collaboration, Fermi Gamma-ray Burst Monitor, and INTEGRAL.) "Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A." *The Astrophysical Journal Letters*. DOI: 10.3847/2041-8213/aa920c

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