After the discovery: Researchers study implications of gravitational waves

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Rochester Institute of Technology researchers continue exploring gravitational waves in a series of upcoming papers. Their reports follow the first direct detection of these waves, predicted by Albert Einstein's general theory of relativity.

The international collaboration of scientists associated with the Laser Interferometer Gravitational Wave Observatory published its findings on Feb. 11 in *Physical Review Letters*. Six scientists from RIT's Center for Computational Gravitation and Relativity were co-authors on the discovery publication. They are John Whelan, associate professor in RIT's School of Mathematical Sciences and principal investigator of RIT's group in the LIGO Scientific Collaboration; Richard O'Shaughnessy, assistant professor in the School of Mathematical Sciences; Carlos Lousto, professor in the School of Mathematical Sciences and an American Physical Society Fellow; James Healy, post-doctoral research fellow; and graduate students in RIT's astrophysical sciences and technology program Jacob Lange and Yuanhao Zhang.

Several of the RIT researchers are listed on the 12 companion papers, including "Astrophysical Implication of the Binary Black-hole Merger GW150914," published in *Astrophysical Journal Letters*. Upcoming publications listing the RIT authors investigate properties of the binary black hole merger and infer the rate of such mergers based on their implications for the gravitational wave background.

LIGO's discovery is consistent with the specific method O'Shaughnessy and his collaborators use to predict how massive stars evolve into black holes and form merging pairs.

"LIGO has just proved that binary black holes merge frequently throughout the universe, much more than many people expected," O'Shaughnessy said. "But the discovery of a black hole merger is only the tip of the iceberg."

The scope of gravitational wave astronomy will widen as the international network of detectors becomes fully operational. Scientific runs at increasing levels of sensitivity are planned for the U.S.-based LIGO detectors and the Italian counterpart, Advanced Virgo, Whelan noted.

"We're looking not just for binary mergers, but for a range of signals from unexplained bursts to a background 'hum' from many weak signals from the distant universe or even the big bang," said Whelan, graduate program coordinator of RIT's astrophysical sciences and technology program. "Closer by, our own galaxy is also full of potential strong sources such as rapidly spinning neutron stars."

Neutron stars are stellar remnants that have collapsed under their own weight but are not massive enough to form into black holes. Merging pairs of neutron stars produce a fainter signal than binary black holes, but are expected to be more common in nearby galaxies. Whelan predicts that these mergers will be detected as the network's sensitivity improves.

An individual rapidly spinning neutron star can produce weaker gravitational waves generated by irregularities in its structure. A single neutron star can continuously emit periodic signals in contrast to the short-lived "chirps" that merging pairs of black holes or neutron stars emit.

Whelan develops and implements methods to search for gravitational waves. He and Ph.D. student Zhang lead an effort targeting Scorpius X-1, a neutron star that emits X-rays as it "steals" matter from a companion star. Their method, reported in 2015 in Physical Review D, has the potential to detect gravitational waves from this neutron star once Advanced LIGO and Advanced Virgo have reached design sensitivity, Whelan said.

"At RIT, we have developed the current-best strategy to find gravitational waves from Scorpius X-1, one of the most promising sources of long-lived gravitational waves from our galaxy," Whelan said. "One of the strengths of the center is that we now play a major role in both the simulation of gravitational waves and the scientific analysis of the LIGO data itself."

Gravitational wave science in RIT's Center for Computational Relativity and Gravitation is a complementary effort of mathematically modeling astronomical systems, analyzing and interpreting gravitational waveforms in the LIGO data and creating scientific visualizations to illustrate their research.

"LIGO has just provided the first glimpse into the gravitational wave sky, but not the last," said Manuela Campanelli, director of the RIT center and an American Physical Society Fellow. "At RIT, we're working on a wide range of gravitational wave astrophysics. We're one of a handful of groups worldwide developing the tools and performing the simulations needed to interpret phenomena dominated by strong-field physics in Einstein's theory of gravity."

The LIGO Scientific Collaboration cites Campanelli's team as one of three groups that advanced modeling of black hole mergers on supercomputers and accurately predicted gravitational waveforms. Campanelli's 2005 method, the moving puncture approach, played an important role in enabling and interpreting the LIGO discovery. Lousto, a member of the original team, and Healy used the method to independently calculate the gravitational waves observed by the Advanced LIGO detectors on Sept. 14, 2015.

Lousto is confident in RIT's role in the new field of gravitational wave astronomy.

"Only by solving Einstein's theory on supercomputers can we fully capture the complexity that his theory allows," he said. "Simulations like those we perform at RIT are critical to extract all the information from these fantastic new observations, and put Einstein's theory to the test."

More information: B. P. Abbott et al. ASTROPHYSICAL IMPLICATIONS OF THE BINARY BLACK HOLE MERGER GW150914, *The Astrophysical Journal* (2016). DOI: 10.3847/2041-8205/818/2/L22

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