Refining the search for the largest gravitational waves

Ask many astronomers, and they will tell you that gravitational waves are the greatest scientific discovery of the 21st century so far. In his research, Miguel Holgado at the University of Illinois studies the clever astronomical techniques which can be used to observe the very largest of these elusive ripples, originating from supermassive black holes as they orbit around each other. His results suggest that these binaries are likely far rarer than astronomers originally thought, but could also help them to refine their observation techniques.

In September 2015, the world of astronomy was changed forever, as ripples in spacetime, first theorized by Einstein over a century ago, were directly observed for the first time. The gravitational wave, discovered by a global team of researchers at the LIGO-Virgo collaboration, was created as two black holes spiralled into each other and merged, releasing colossal amounts of energy.

Using kilometre-scale interferometers, accurate to within the widths of single atoms, physicists picked up the wave as it passed through Earth, minutely stretching and squeezing the fabric of spacetime as it went. Nearly a dozen more gravitational wave observations have been made since then, and again this year, astronomers are turning their attention to detecting mergers of black holes, neutron stars, and more.

LIMITATIONS IN LIGO’S DETECTIONS

So far, every gravitational wave LIGO has detected has originated from mergers of black holes and neutron stars with similar masses to our Sun. However, astronomers predict that far larger waves could originate from ‘supermassive’ black holes – objects many millions of times heavier than the Sun, which are thought to occupy the centres of many galaxies.

As Holgado explains, these waves can form when two galaxies merge together, causing each of their supermassive black holes to orbit each other. ‘Some of the loudest gravitational waves are expected from the orbital motion of supermassive black hole binaries that may form within the centres of merged galaxies,’ he says. ‘Yet despite their enormous size, these waves are notoriously difficult to detect. Where the ripple observed by LIGO-Virgo in 2015 dramatically completed a cycle in fractions of a millisecond, those waves from supermassive black hole binaries with periods of years to decades can endure for thousands to millions of years.

‘LIGO cannot detect gravitational-waves from these sources because the frequencies from spiralling supermassive black hole binaries are expected to be of order nanohertz,’ Holgado continues. ‘LIGO is only sensitive to gravitational wave frequencies of order tens to thousands of hertz, which mostly correspond to the mergers of stellar-mass black hole binaries and neutron-star binaries.’

A GROWING LIST OF BINARY CANDIDATES

This technique is vital for detecting low-frequency gravitational waves that LIGO is not sensitive to. ‘However, observations of PTA signal shifts have yet to yield concrete evidence of the low-frequency ripples. All the same, researchers have now begun the search in earnest, paying particular attention to the dense, bright clusters of gas which collect at the centres of some galaxies.

If gravitational waves pass through a pulsar and the Earth, the observed pulse times-of-arrival are shifted due to the stretching and squeezing of spacetime, he says.

Astronomers are now using these theorised shifts to monitor changes in groups, or arrays, of these distorted pulsar signals, over periods of several years. ‘In order to detect gravitational waves, we can time an array of pulsars and correlate the observed shifts of the pulse arrival times for each pulsar,’ Holgado continues. ‘A pulsar timing array (PTA) is a particular type of gravitational wave detector that is sensitive to nanohertz gravitational waves from supermassive black hole binaries.’

‘Even though PTAs have yet to detect nanohertz gravitational waves, their upper limits are of astrophysical relevance and importance,’ Holgado says. ‘A number of telescopes have been finding and observing active galactic nuclei (AGN), which are the centres of galaxies that are observed to be very bright compared to normal galaxies due to a supermassive black hole feeding on hot gas.’

In several of these bright galactic centres, astronomers have found that the light they emit dips and rises at regular intervals. As Holgado explains, ‘some AGN have light curves that show some periodic behaviour, which is sometimes thought to come from the orbital motion of a supermassive black hole binary.’

If the orbit of the black hole binary is inclined relative to our perspective, then each black hole would routinely move towards and away us as they orbit each other. This motion relative to our line of sight would cause the bright material surrounding the black holes to become even brighter when the motion is towards us and to become dimmer when
Behind the Research
A. Miguel Holgado

Research Objectives
A. Miguel Holgado’s research focuses on the gravitational wave signatures of compact objects such as black holes, neutron stars, and white dwarfs.

Detail
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Bio
A. Miguel Holgado completed his undergraduate studies at Texas A&M University. He is now a PhD Candidate at Urbana-Champaign researching gravitational wave astrophysics. Miguel will be attending the 69th Lindau Nobel Laureate Meeting, which will focus on Physics.

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References


Personal Response
There is increased effort towards finding potential supermassive black hole binaries. With pulsar timing arrays improving their upper limits, you must be excited about the future in this field.

Very much so! Even without a direct detection of nanohertz gravitational waves, we can still do messenger astrophysics, where electromagnetic observations from telescopes tell us about the possible presence of binaries from periodic AGN and gravitational-wave upper limits tell us what fraction of these binary candidates may be real. Once pulsar timing arrays finally detect nanohertz gravitational waves, we hope to gain a clearer picture of how supermassive black hole binaries form and how this is tied to the evolution of galaxies over cosmic time.

Behind the Research
A. Miguel Holgado

Using PTA upper limits, we have shown that only a small fraction of blazars may be binaries.

An artist’s depiction of a pulsar timing array, where a set of pulsars are observed for evidence of gravitational waves from the cosmic population of supermassive black hole binaries with year-like orbital periods.

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