Scientist instils new hope of detecting gravitational waves

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(PhysOrg.com) -- Direct evidence of the existence of gravitational waves is something that has long eluded researchers, however new research has suggested that adding just one of the proposed detectors in Japan, Australia and India will drastically increase the expected rate of detection.

In a study published today, Friday, 27 May, in IOP Publishing's journal *Classical and Quantum Gravity*, Professor Bernard Schutz, of the Albert Einstein Institute, Germany, demonstrated that an additional detector would more than double the detection rate of gravitational waves and could double the amount of sky being covered.

It was estimated last year that by 2016 the existing network of four detectors would be able to detect, on average, 40 neutron-star merger events per year by monitoring the gravitational waves they produce. Using a computer analysis, this study showed that by performing optimal coherent data analysis, the network could theoretically detect 160 events per year.

The positioning of the current network actually makes such a large increase in detection rate unlikely; however Schutz has shown that using any of the three additional locations would change this dramatically.

The addition of all three new detectors would enable the detection of around 370 events a year, which could increase to 500 events after a few years of operation.

These detectors are most likely to encounter 'short bursts' of gravitational waves that arise from two stars or two black holes orbiting each other. The sheer acceleration of these types of events cause a distortion in space time - known as a gravitational wave - that spreads outwards like ripples moving across a lake.

Professor Schutz said, "The improvements brought about by new detectors are much bigger than the proportionate extra investment required. Even moving an existing LIGO detector to Australia brings two to four times the number of good-quality detections and also dramatically improves the direction information for the events."

"The new detector in Japan, approved last year, would add extra sensitivity and reliability and greatly improve sky coverage. Not only would we be more certain than ever of making detections, we would begin to be able to study neutron stars and gamma ray bursts with information obtainable in no other way."

Einstein's theory of general relativity describes how objects with mass bend and curve space-time. One can imagine holding out a taut bed sheet and placing a football in the centre – the bed sheet will curve around the football, readily representing how space-time gets curved by objects with mass.

Just like the ripples moving across a lake, the distortion in space-time, caused by accelerating objects, gradually decreases in strength, so by the time they finally reach Earth they are very hard to detect.

Professor Schutz continued, "In my mind, detecting gravitational waves opens up a new way of investigating the universe. We expect frequent detections of gravitational waves from merging black holes, whose waves will carry an unmistakable signature. Since gravitational waves are the only radiation emitted by black holes, we will for the first time have a direct observation of a black hole."

"Beyond that, gravitational waves have great penetrating power, so they will allow us to see directly to the centre of the systems responsible for supernova explosions, gamma-ray bursts, and a wealth of other systems so far hidden from view."

At the moment, there are four detectors, currently being updated, that have the necessary sensitivity to measure gravitational waves. Three of these detectors exist as part of the LIGO project – two in Hanford, Washington, and one in Livingston, Louisiana, - whilst another detector exists in Cascina, Italy, as part of the VIRGO project.

Funding has begun for an additional detector located in Japan whilst there are further proposals for developing detectors in Australia and India. It has also been proposed to move one of the Hanford detectors to Australia.

A jointly owned British-German detector, located near Hanover, Germany, called GEO600 will begin observations for gravitational waves this summer, until the LIGO and VIRGO detectors become fully operational again.

More information: Networks of gravitational wave detectors and three figures of merit, Bernard F Schutz 2011 *Class. Quantum Grav.* 28 125023 doi:10.1088/0264-9381/28/12/125023

Abstract
This paper develops a general framework for studying the effectiveness of networks of interferometric gravitational wave detectors and then uses it to show that enlarging the existing LIGO–VIRGO network with one or more planned or proposed detectors in Japan (LCGT), Australia, and India brings major benefits, including much larger detection rate

increase than previously thought. I focus on detecting bursts, i.e. short-duration signals, with optimal coherent data-analysis methods. I show that the polarization-averaged sensitivity of any network of identical detectors to any class of sources can be characterized by two numbers—the visibility distance of the expected source from a single detector and the minimum signal-to-noise ratio (SNR) for a confident detection—and one angular function, the antenna pattern of the network. I show that there is a universal probability distribution function (PDF) for detected SNR values, which implies that the most likely SNR value of the first detected event will be 1.26 times the search threshold. For binary systems, I also derive the universal PDF for detected values of the orbital inclination, taking into account the Malmquist bias; this implies that the number of gamma-ray bursts associated with detected binary coalescences should be 3.4 times larger than expected from just the beaming fraction of the gamma burst. Using network antenna patterns, I propose three figures of merit (f.o.m.'s) that characterize the relative performance of different networks. These measure (a) the expected rate of detection by the network and any sub-networks of three or more separated detectors, taking into account the duty cycle of the interferometers, (b) the isotropy of the network antenna pattern, and (c) the accuracy of the network at localizing the positions of events on the sky. I compare various likely and possible networks, based on these f.o.m.'s. Adding any new site to the planned LIGO–VIRGO network can dramatically increase, by factors of 2–4, the detected event rate by allowing coherent data analysis to reduce the spurious instrumental coincident background. Moving one of the LIGO detectors to Australia additionally improves direction finding by a factor of 4 or more. Adding LCGT to the original LIGO–VIRGO network not only improves direction finding but will further increase the detection rate over the extra-site gain by factors of almost 2, partly by improving the network duty cycle. Including LCGT, LIGO-Australia, and a detector in India gives a network with position error ellipses a factor of 7 smaller in area and boosts the detected event rate a further 2.4 times above the extra-site gain over the original LIGO–VIRGO network. Enlarged advanced networks could look forward to detecting 300–400 neutron star binary coalescences per year.

Provided by Institute of Physics

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