GRAVITATIONAL WAVES DETECTED 100 YEARS AFTER EINSTEIN'S PREDICTION
LIGO Opens New Window on the Universe with Observation of Gravitational Waves from Colliding Black Holes
IISER Kolkata Scientists make significant contributions

For the first time, scientists have observed ripples in the fabric of spacetime called gravitational waves, arriving at the earth from a cataclysmic event in the distant universe. This confirms a major prediction of Albert Einstein's 1915 general theory of relativity and opens an unprecedented new window onto the cosmos.

Gravitational waves carry information about their dramatic origins and about the nature of gravity that cannot otherwise be obtained. Physicists have concluded that the detected gravitational waves were produced during the final fraction of a second of the merger of two black holes to produce a single, more massive spinning black hole. This collision of two black holes had been predicted but never observed.

The gravitational waves were detected on September 14, 2015 at 5:51 a.m. Eastern Daylight Time (9:51 UTC) by both of the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors, located in Livingston, Louisiana, and Hanford, Washington, USA. The LIGO Observatories are funded by the National Science Foundation (NSF), and were conceived, built, and are operated by Caltech and MIT. The discovery, accepted for publication in the journal *Physical Review Letters*, was made by the LIGO Scientific Collaboration (which includes the GEO Collaboration and the Australian Consortium for Interferometric Gravitational Astronomy) and the Virgo Collaboration using data from the two LIGO detectors. Based on the observed signals, LIGO scientists estimate that the black holes for this event were about 29 and 36 times the mass of the sun, and the event took place 1.3 billion years ago.

The early gravitational wave detectors pioneered by J. Weber in the 1960s - large metal bars operating at their resonance of natural vibrations - did not reach enough sensitivity to detect gravitational waves. Detectors based on the most precise technique known, optical interferometry, were conceived soon after and these are the only type of detectors operational today with enough sensitivity to detect the weak astrophysical gravitational waves from distant galaxies.

LIGO was originally proposed as a means of detecting these gravitational waves in the 1980s by Rainer Weiss, professor of physics, emeritus, from MIT; Kip Thorne, Caltech's Richard P. Feynman Professor of Theoretical Physics, emeritus; and Ronald Drever, professor of physics, emeritus, also from Caltech.

LIGO research is carried out by the LIGO Scientific Collaboration (LSC), a group of more than 1000 scientists from universities around the United States and in 14 other countries. More than 90 universities and research institutes in the LSC develop detector technology and analyze data; approximately 250 students are strong contributing members of the collaboration. The LSC detector network includes the LIGO interferometers and the GEO600 detector. The GEO team includes scientists at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute, AEI), Leibniz Universität Hannover, along with partners at the University of Glasgow, Cardiff University, the University of Birmingham, other universities in the United Kingdom, and the University of the Balearic Islands in Spain.

The Indian participation in the LSC, under the umbrella of the *Indian Initiative in Gravitational-Wave Observations* (IndIGO), involves sixty-one scientists from nine institutions - CMI Chennai, ICTS-TIFR Bengaluru, IISER-Kolkata, IISER-Trivandrum, IIT Gandhinagar, IPR Gandhinagar, IUCAA Pune, RRCAT Indore and TIFR Mumbai. The discovery paper has 35 authors from these institutions. IndIGO was formed in 2009 by a group of researchers with expertise in theoretical and experimental gravity, cosmology and optical metrology, who were keen to promote gravitational wave research in the country with a dream of realizing an advanced detector in India. Indian groups contributed significantly to understanding the response of the detector to the signals and terrestrial influences, to the method used for detecting the signal, bounding the orbital eccentricity, estimating the mass and spin of the final black hole and the energy and power radiated during merger, confirming that the observed signal agrees with Einstein's General Theory of Relativity, and to the search for a possible electromagnetic counterpart using optical telescopes. Some of these works were carried out on high performance computing facilities at IUCAA, Pune, and ICTS, Bengaluru.

The current Indian gravitational wave scientific community has arisen out of research programmes carried out over three decades at several research institutes, with seminal contributions. The group led by Bala Iyer (currently at ICTS-TIFR) at the Raman Research Institute in collaboration with scientists in France had pioneered the mathematical calculations used to model gravitational wave signals from orbiting black holes and neutron stars. The group led by Sanjeev Dhurandhar at IUCAA initiated and did foundational work on developing data-analysis techniques to detect these weak signals buried in the detector noise by looking for the best match between the calculated waveforms and the detector signal and led the solo Indian group in the LSC in the initial era of LIGO for a decade. Theoretical work that combined black holes and gravitational waves was published by C. V. Vishveshwara in 1970. These contributions are prominently cited in the discovery paper.

Over the last decade the Indian gravitational wave community, mainly consisting of researchers trained in these groups, has spread to a number of educational and research institutions in India. As members of the LSC, they have made major contributions to the development of novel techniques to identify the weak gravitational wave signals, enabling gravitational wave astrophysics. Other Indian researchers in the LSC have expertise in precision metrology, laser and optics development, ultra-high vacuum techniques and control systems. A prototype detector is being built for training and research at TIFR, Mumbai

The discovery paves the road to the possibility of observing our universe in gravitational waves if one can locate their source with additional detectors placed far from the LIGO detectors, forming one or more large triangles. Such a network of detectors will enable the new scientific field of “Gravitational wave Astronomy”.

As a part of LIGO Scientific Collaboration(LSC), a primary interest of gravitational wave research group at (IISER) Kolkata is to test the Einstein's theory of gravity itself using gravitational waves. One of the most likely sources of gravitational waves is coalescing binary stars or black holes. In the last phase of the coalescence, when the speed of the stars is close to the speed of light, the system is said to be in the strong field limit. The gravitational waves can help us to probe this region and test the theories of gravity. We will be able to study how well the Einstein’s theory of gravity match to reality and whether there are small deviations that demand a revision of his theory. The research team at IISER Kolkata includes Dr. Rajesh Kumble Nayak and Ms. Anuradha Samajdar at the Department of Physical Sciences and Center of Excellence in Space Sciences, India(CESSI), as part of IndIGO-LSC.
In short, next few years are going to be a very exciting phase of gravitational wave astronomy.

Another large scale interferometer detector operated by a European consortium, called Virgo, is being upgraded and is expected to be ready for joint operation with the LIGO detectors early next year. Virgo research is carried out by the Virgo Collaboration, consisting of more than 250 physicists and engineers belonging to 19 different European research groups: 6 from Centre National de la Recherche Scientifique (CNRS) in France; 8 from the Istituto Nazionale di Fisica Nucleare (INFN) in Italy; 2 in The Netherlands with Nikhef; the Wigner RCP in Hungary; the POLGRAW group in Poland and the European Gravitational Observatory (EGO), the laboratory hosting the Virgo detector near Pisa in Italy.

The discovery was made possible by the enhanced capabilities of Advanced LIGO, a major upgrade that increases the sensitivity of the instruments compared to the first generation LIGO detectors, enabling a large increase in the volume of the universe probed—and the discovery of gravitational waves during its first observation run. The US National Science Foundation leads in financial support for Advanced LIGO. Funding organizations in Germany (Max Planck Society), the U.K. (Science and Technology Facilities Council, STFC) and Australia (Australian Research Council) also have made significant commitments to the project. Several of the key technologies that made Advanced LIGO so much more sensitive have been developed and tested by the German UK GEO collaboration. Significant computer resources have been contributed by the AEI Hannover Atlas Cluster, the LIGO Laboratory, Syracuse University, and the University of Wisconsin-Milwaukee. Several universities designed, built, and tested key components for Advanced LIGO: The Australian National University, the University of Adelaide, the University of Florida, Stanford University, Columbia University in the City of New York, and Louisiana State University.

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With the direct detection of gravitational waves by the LSC in the LIGO detectors, we enter a new era of astronomy, of stellar evolution and energetic events involving black holes and neutron stars, some of which are not visible to any other type of telescope. When the LIGO detectors reach their full sensitivity in the coming years and as more detectors are added into the network, such detections will become frequent and varied, opening up a whole new world of astrophysics.

More information available at the website of IndIGO Consortium: www.gw-indigo.org
For-the-press website link

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