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

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 on to 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.

A Sensational Discovery

The long-awaited observation of gravitational waves could have the same significance for gravity as the discovery of electromagnetic radiation in the 19th century, which heralded the age of wireless communication.

"This is a momentous discovery. From the dawn of time, humankind has observed the Universe using light. Now a completely new way, using gravitational waves instead, has opened up. Who knows what mysteries of the Universe will be uncovered using it?" wonders Sandip Trivedi, Director, Tata Institute of Fundamental Research (TIFR).

All earlier attempts to detect gravitational waves had failed, as they are very weak and require a suitably sensitive experiment to observe them. They also require a very violent disturbance of the spacetime continuum to provide signals strong enough to be seen. Such a strong disturbance can be provided by the impact and coalescence of two supermassive black holes, where a substantial proportion of the black holes' mass gets converted to energy, according to Einstein's formula $E = mc2$, which is then radiated away in the form of a brief but intense burst of gravitational waves. It is precisely such an effect that has been seen. In fact, based on the observed signals, LIGO scientists estimate that two black holes of about 29 and 36 solar masses merged to produce a single black hole of 62 solar masses. In the final fraction of a second, about 3 times the mass of the Sun was converted into energy as gravitational waves. The corresponding ripples in spacetime have now spread out over a radius of 1.3 billion light-years and left tiny – but unmistakable – impressions on the LIGO detectors.

While the actual experiments were located in the USA, the ICTS-TIFR group at Bengaluru, under the leadership of P. Ajith, made significant direct contributions to obtaining estimates of the mass and spin of the final black hole, and the energy and peak power radiated by the binary in gravitational waves. These were obtained by applying fits to supercomputer simulations of binary black holes to the estimates of the binary's initial masses and spins. Ajith's group has also contributed to the astrophysical interpretation of the event.

Kip Thorne of Caltech, an eminent theoretical physicist and one of the founders of the LIGO project has gone on record to say *"I am so grateful for the major contributions, by Indian scientists... These include contributions from experimenters who have contributed to the observational technology, by data analysts who have developed and implemented techniques for finding gravitational wave signals amidst noise, and by theorists who have computed to high accuracy the shapes of the gravitational wave signals that we seek.*"

The Indian participation in the LIGO Scientific Collaboration, under the umbrella of the Indian Initiative in Gravitational-Wave Observations (IndIGO), includes scientists from CMI Chennai, ICTS-TIFR Bangalore, IISER Kolkata, IISER Trivandrum, IIT Gandhinagar, IPR Gandhinagar, IUCAA Pune, RRCAT Indore and TIFR Mumbai.

About the LIGO collaboration

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.

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.

Contacts

TIFR, Mumbai
● Sandip Trivedi (Director, TIFR).
E-mail: sandip@theory.tifr.res.in

ICTS-TIFR, Bengaluru
● Rajesh Gopakumar (Director, ICTS-TIFR).
E-mail: rajesh.gopakumar@icts.res.in

● Spenta R. Wadia (Professor Emeritus and Founding Director, ICTS-TIFR).
E-mail: spenta.wadia@icts.res.in

● Parameswaran Ajith (Group leader in Astrophysical Relativity, ICTS-TIFR).
E-mail: ajith@icts.res.in

IndIGO consortium

● Bala R. Iyer (Chairperson, IndIGO consortium).
E-mail: bala.iyer@icts.res.in

● Tarun Souradeep (Spokesperson, IndIGO consortium).
E-mail: tarun@iucaa.in