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Twin LIGOs detect another Binary Black Hole merger

Marking an eventful beginning of Gravitational Wave Astronomy!

While the celebrations for the first detection of gravitational waves are still ringing down, we are excited to announce the observation of yet another binary black hole merger by LIGO. On December 26, 2015 at 09:09AM IST the LIGO detectors in Hanford, Washington and Livingston, Louisiana detected a signal from the coalescence of two black holes, with masses 14 and 8 times the mass of the sun, merging into a more massive, rapidly rotating black hole that is 21 times the mass of the sun. The event happened 1.4 billion years ago, lasted in LIGO's frequency band for about a second and released about 1 solar mass worth of energy in that short period. For comparison, only a tiny fraction of the sun's mass gets converted to light in its entire lifetime, which is enough to keep the earth warm for billions of years.

Compared to the first binary black hole merger event announced in February-2016, the present one is much less massive -- 65 solar mass vs 22 solar mass. This is of the kind that was expected to be much more abundant in the universe. Detection of such events is however far more challenging, as these signals are intrinsically weaker and the power is distributed over a longer stretch of time hiding the signal deep inside the noise. Unlike the first event, the signal does not stand out of the noise like a short duration burst. One needs to use sophisticated data analysis techniques, namely matched filtering, to find such signals—needles in a haystack!

Matched filtering is a technique invented by Wiener in 1949 to find signals of known shape buried inside noise. The foundational work to introduce matched filtering in gravitational wave research was pioneered at IUCAA, under the leadership of Prof. Sanjeev Dhurandhar, twenty five years ago. Over time this method has been refined, by a number of researchers from IUCAA, IISER Trivandrum, IIT Gandhinagar, and many other renowned institutions across the world, but the method has remained fundamental, and no alternatives were necessary. Notable Indian contributions were made in handling instrumental artefacts and for including multiple detectors for a more sensitive search. Matched filtering requires accurate models of the expected signals, which requires solving the Einstein's equations for gravity using complex mathematical and computational techniques. A group of Indian scientists led by Prof. Bala Iyer, then at RRI, in collaboration with physicists in France played a major role in this activity during the last three decades. In recent years the technique was mastered by scientists at ICTS, CMI, and TIFR by successively increasing the accuracy of the approximations, including the effects of black hole spins and orbital eccentricity, combining the mathematical calculations with large-scale numerical relativity simulations, etc. Prof. Iyer's group, which involves researchers who are currently at CMI and ICTS, proposed a method to test General Relativity theory which has been carried out on the detected signal. Scientists at CMI, ICTS, IISER-Kolkata, IISER Trivandrum, and TIFR, along with scientists from the international collaboration, were involved in establishing the consistency of the observed signal with the predictions of Einstein's General Theory of Relativity. Scientists from ICTS and IUCAA significantly contributed to the estimation of the mass and the spin of the final black hole as well as the amount of energy radiated as gravitational waves. The CZT Imager instrument onboard the Indian astronomy satellite AstroSat performed its first follow up of a gravitational wave event for this binary. A number of scientists in IPR, IUCAA and RRCAT are currently engaged in building a third LIGO detector in India, LIGO-India, that will significantly aid the detection of such events and dramatically improve the accuracy in estimating the location and orientation of the binaries in the sky using multiple detectors. A total of 39 researchers, including 6 students and 8 postdoctoral fellows, from 9 Indian institutions have been involved in this discovery through the IndIGO consortium.

Two detections in quick succession, well before the detectors reaching their target sensitivity, accentuates that there is a whole new world out there to explore with gravitational waves. With the rapid progress towards the LIGO-India detector (the MoU between DAE-DST, India and NSF, USA for LIGO-India was signed on March 31, 2016 and a Joint Oversight Committee was formed), which is expected to be fully operational in the early next decade, the Advanced Virgo (Italy) and the KAGRA (Japan) detectors on the horizon, the maturing Pulsar Timing Arrays and the possibility of a space borne detector following the much more than anticipated success of the LISA pathfinder mission, we can now hope to have enough "gravitational wave eyes" to look at the sky in different frequencies, which translates to different kinds of astrophysical sources, heralding a new era of multi-band gravitational-wave astronomy.

Most importantly, the appreciation that the gravitational wave community received from the people, including the government and the media, is truly overwhelming. The first detection has already received some of the prestigious awards in Physics, e.g., a Special Breakthrough Prize in Fundamental Physics, the Gruber prize, the Kavli prize and the Shaw prize. This endeavour for opening a new window onto the universe would not have been possible without constant public support.

An international collaboration of scientists

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.

Advanced LIGO's next data-taking run will begin this fall. By then, further improvements in detector sensitivity are expected to allow LIGO to reach as much as 1.5 to 2 times more of the volume of the universe. The Virgo detector is expected to join in the latter half of the upcoming observing run.

LIGO research is carried out by the LIGO Scientific Collaboration (LSC), a group of more than 1,000 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.

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 MTA 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.

In addition to the above funding agencies, Indian researchers, who were part of this discovery, were benefitted by the support from the Council of Scientific and Industrial Research (CSIR), the Department of Science and Technology (DST), the Science & Engineering Research Board (SERB), the Ministry of Human Resource Development (MHRD), the Department of Atomic Energy (DAE) and the University Grants Commission (UGC). Several Indian researchers made extensive use of the High Performance Computing facilities at IUCAA and ICTS.

The NSF 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, the ARCCA cluster at Cardiff University, the University of Wisconsin-Milwaukee, and the Open Science Grid. Several universities designed, built, and tested key components and techniques for Advanced LIGO: The Australian National University, the University of Adelaide, the University of Western Australia, the University of Florida, Stanford University, Columbia University in the City of New York, and Louisiana State University. 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 Germany, and the University of the Balearic Islands in Spain.

Contact persons

- IndIGO Expert (Source Modelling): Bala Iyer (bala.iyer@icts.res.in)
- IndIGO Expert (Data Analysis): Sanjeev Dhurandhar (sanjeev@iucaa.in)

- CMI: K.G. Arun (kgarun@cmi.ac.in)
- ICTS: P. Ajith (ajith@icts.res.in)
- IISER-Kolkata: Rajesh Nayak (rajesh@iiserkol.ac.in)
- IISER-Tvm: Archana Pai (archana@iisertvm.ac.in)
- IIT-Gn: Anand Sengupta (asengupta@iitgn.ac.in)
- IUCAA: Sanjit Mitra (sanjit@iucaa.in)
- TIFR: A.Gopakumar (gopu@tifr.res.in)

- LIGO-India: IPR: Ziauddin Khan (ziauddin@ipr.res.in)
- LIGO-India: IUCAA: Tarun Souradeep (tarun@iucaa.in)
- LIGO-India: RRCAT: Sendhil Raja (sendhil@rrcat.gov.in)