Straight to the source: the LIGO-Virgo global network of interferometers opens a new era for gravitational wave science

The Virgo collaboration and the LIGO Scientific Collaboration report the three-detector observation of gravitational waves. This result highlights the scientific potential of a global network of gravitational wave detectors, by delivering a better localization of the source and access to polarizations of gravitational waves.

The two Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors, located in Livingston, Louisiana, and Hanford, Washington, USA and the Virgo detector, located at the European Gravitational Observatory (EGO) in Cascina, near Pisa, Italy, detected a transient gravitational-wave signal produced by the coalescence of two stellar mass black holes.

The three-detector observation was made on August 14, 2017 at 10:30:43 UTC. The detected gravitational waves – ripples in space and time – were emitted during the final moments of the merger of two black holes with masses about 31 and 25 times the mass of the Sun and located about 1.8 billion light-years away. The newly produced spinning black hole has about 53 times the mass of our Sun. This means that about 3 solar masses were converted into gravitational-wave energy during the coalescence.

This is the fourth detection of a binary black hole system. While this new event is of astrophysical relevance, its detection comes with an additional asset: this is the first significant gravitational wave signal recorded by the Virgo detector, which has recently completed its upgrade to Advanced Virgo.

"*It is wonderful to see a first gravitational-wave signal in our brand new Advanced Virgo detector only two weeks after it officially started taking data,"* says Jo van den Brand of Nikhef and VU University Amsterdam, spokesperson of the Virgo collaboration. *That's a great reward after all the work done in the Advanced Virgo project to upgrade the instrument over the past six years.*"

"*This is just the beginning of observations with the network enabled by Virgo and LIGO working together,"* says MIT's David Shoemaker, spokesperson of the LIGO Scientific Collaboration. *"With the next observing run planned for Fall 2018 we can expect such detections weekly or even more often."*

The discovery, accepted for publication in the journal *Physical Review Letters* (the journal article draft is available for download at these links: https://dcc.ligo.org/P170814 and https://tds.virgo-gw.eu/GW170814; it will appear tomorrow on arXiv) was made by the Virgo collaboration and the LIGO Scientific Collaboration, which includes the GEO Collaboration and OzGrav.

The global network for gravitational wave science

The Virgo detector joined the Network Observing Run 2 (O2) on August 1, 2017 at 10:00 UTC, after the multi-year Advanced Virgo upgrade program, and months of intense commissioning to improve its sensitivity. The real-time detection was triggered with data from all three LIGO and Virgo instruments. Even though Virgo is at present less sensitive than LIGO, two independent search algorithms based on all the information available from the three detectors demonstrated the evidence of a signal in the Virgo data as well.

The collaboration of LIGO and Virgo has matured over the last decade. Joint collaboration meetings and common data analyses have brought the community together. The coordinated scheduling of observing runs, with all detectors operational, is important to extract the maximum amount of science, and especially the vastly improved source localization holds great promise for the future of multimessenger astronomy. Additional results, based on data from the three-detector network, will be announced in the near future by the LIGO-Virgo collaboration; the analysis of the data is currently being finalized.

The Virgo collaboration

It consists of more than 280 physicists and engineers belonging to 20 different European research groups: six from Centre National de la Recherche Scientifique (CNRS) in France; eight from the Istituto Nazionale di Fisica Nucleare (INFN) in Italy; two in The Netherlands with Nikhef; the MTA Wigner RCP in Hungary; the POLGRAW group in Poland; Spain with the University of Valencia; and EGO, the laboratory hosting the Virgo detector near Pisa in Italy.

LIGO

It is funded by the NSF, and operated by Caltech and MIT, which conceived and built the project. Financial support for the Advanced LIGO project was led by NSF with Germany (Max Planck Society), the U.K. (Science and Technology Facilities Council) and Australia (Australian Research Council) making significant commitments and contributions to the project. More than 1,200 scientists from around the world participate in the effort through the LIGO Scientific Collaboration, which includes the GEO Collaboration. Additional partners are listed at http://ligo.org/partners.php

Localization

Overall, the Universe volume which is likely to contain the source shrinks by more than a factor 20 when moving from a two-detector network to a three-detector network. The sky region for GW170814 has a size of only 60 square degrees, more than 10 times better than for the two LIGO interferometers alone; in addition, the accuracy with which the source distance is measured benefits from the addition of Virgo. Being able to point to a smaller volume is important as many compact object mergers – for example when neutron stars are involved – are expected to produce broadband electromagnetic emission in addition to gravitational waves. The precision pointing information enabled 25 facilities to perform follow-up observations based on the LIGO-Virgo detection but no counterpart was identified – as expected for black holes.

Polarization

Virgo doesn't respond in the exactly same way to passing gravitational waves as the LIGO detectors because of its orientation on Earth, meaning that one can test another prediction of general relativity, which is concerned with polarizations of gravitational waves. Polarization describes how space-time is distorted in the three different spatial directions as a gravitational wave propagates. Initial tests based on the transient GW170814 event compare extreme cases: on the one hand, pure general relativity-allowed polarizations; on the other hand, pure polarizations forbidden by Einstein's theory. The analysis of the data shows that Einstein's prediction is strongly favored. "*The Virgo collaboration and the LIGO Scientific Collaboration have been working together for many years to analyze the data and extract precious information from the observed signals. A three-detector network opens up a new potential, allowing further fundamental tests of theoretical predictions,*" says Frédérique Marion, senior scientist at LAPP, Annecy. In addition to this new result, other tests of general relativity already performed for the previous detections show an overall agreement between observations and general relativity.

Advanced Virgo

It is the second generation instrument built and operated by the Virgo collaboration to search for gravitational waves. Giovanni Losurdo of the INFN, who led the Advanced Virgo project to completion: "*This detection is a milestone for all the people who have dedicated their time to conceive, realize and operate Virgo and Advanced Virgo, first among them Alain Brillet, and Adalberto Giazotto. The whole enterprise was based, since its start, on a visionary goal: the creation of a network capable of localizing the sources in the sky and start the era of the multi-messenger investigation of the universe. And finally, after decades, we are there.*" Advanced Virgo's initial design was completed 10 years ago while the initial Virgo detector was taking its first data. The founder funding agencies of the Virgo project, CNRS and INFN, approved the project in December 2009, and significant contributions were made by Nikhef. With the end of observations with the initial Virgo detector in October 2011, the realization of the Advanced Virgo detector began.

The new facility was dedicated in February 2017 while its commissioning was ongoing. In April, the control of the detector at its nominal working point was achieved for the first time. During the following months, the instrument's sensitivity underwent dramatic improvements, thanks to an extensive noise hunting campaign. Once the sensitivity reached by Advanced Virgo allowed to probe a volume of the Universe more than 10 times larger than for the initial Virgo detector, on August 1st, Advanced Virgo joined the two LIGO detectors for the final four weeks of the O2 data taking period. "*The Virgo upgrade to Advanced Virgo had an ambitious objective: to significantly improve the sensitivity of our detector, in order to maximize the probability to detect gravitational wave signals,"* says Federico Ferrini, director of the European Gravitational Observatory. "*Reaching a level of performance to realize a three-detector network for a common data taking period took many years of intense and innovative work. As Virgo has observed its first event, I wish to recognize the dedication of the members of the Virgo collaboration, of the EGO staff and of the participating laboratories."*

Advanced LIGO

It is a second generation gravitational-wave detector consisting of two identical interferometers located in Hanford, WA and Livingston, LA. It uses precision laser interferometry similar to Advanced Virgo to detect gravitational waves. Beginning operating in September 2015, Advanced LIGO has conducted two observing runs. The second 'O2' observing run began on Nov. 30, 2016 and ended on Aug. 25, 2017. David Reitze of Caltech, the executive director of the LIGO Laboratory that built and operates the LIGO observatories, adds "*With this first joint detection by the Advanced LIGO and Virgo detectors, we have taken one step further into the gravitational-wave cosmos. Virgo brings a powerful new capability to detect and better locate gravitational-wave sources, one that will undoubtedly lead to exciting and unanticipated results in the future."*