LIGO-Virgo-KAGRA detect most massive black hole merger to date

Gravitational waves from massive black holes challenge current astrophysical models

The LIGO-Virgo-KAGRA (LVK) Collaboration has announced the detection of the merger of the most massive black holes ever observed with gravitational waves, using the US National Science Foundation funded LIGO Hanford and Livingston Observatories. The merger produced a final black hole more than 225 times the mass of our Sun. The signal, designated GW231123, was observed during the fourth observing run (O4) of the LVK network on November 23, 2023.

The two black holes that merged were approximately 103 and 137 times the mass of the Sun. In addition to their high masses they are also rapidly spinning, making this a uniquely challenging signal to interpret and suggesting the possibility of a complex formation history.

“The discovery of such a massive and highly spinning system presents a challenge not only to our data analysis techniques – says Ed Porter, researcher at the Astroparticle and Cosmology laboratory (APC) of CNRS in Paris – but will have a major effect on the theoretical studies of black hole formation channels and waveform modelling for many years to come. Actually, current models of stellar evolution do not allow the existence of such massive black holes, which could possibly have formed through previous mergers of smaller black holes.”

Approximately 100 black-hole mergers have previously been observed through gravitational waves, analysed and shared with the wider scientific community. Until now the most massive binary was the source of GW190521, with a much smaller total mass of “only” 140 times that of the sun.

Probing the limits of gravitational-wave astronomy

The high mass and extremely rapid spinning of the black holes in GW231123 pushes the limits of both gravitational-wave detection technology and current theoretical models. Extracting accurate information from the signal required the use of theoretical models that account for the complex dynamics of highly spinning black holes.

“This event pushes our instrumentation and data-analysis capabilities to the edge of what’s currently possible,” says Dr. Sophie Bini, a postdoctoral researcher at Caltech, previously at the University of Trento. “It’s a powerful example of how much we can learn from gravitational-wave astronomy—and how much more there is to uncover.”

Gravitational-wave detectors such as LIGO in the United States, Virgo in Italy, and KAGRA in Japan are designed to measure minute distortions in spacetime caused by violent cosmic events like black hole mergers. The fourth observing run began in May 2023 and observations from the first half of the run (up to January 2024) will be published later in the summer.

“With the longest continuous observation to date and enhanced sensitivity, the LIGO-Virgo-KAGRA fourth observing campaign is delivering invaluable new insights into our understanding of the universe –says Viola Sordini, researcher at the Institute of Physics of the 2 Infinities (IP2I) of CNRS in Lyon and deputy spokesperson of the Virgo Collaboration – This exciting discovery opens a new season of results, with many more expected throughout the summer and a continued stream of findings anticipated over the next two years. Publications are followed by release of the data, in support of the broader scientific community and open science”

GW231123 will be presented at the **24th International Conference on General Relativity and Gravitation (GR24)** and the **16th Edoardo Amaldi Conference on Gravitational Waves**, held jointly as the **GR-Amaldi meeting** in Glasgow, UK, from July 14-18 2025.

The LIGO-Virgo-KAGRA Collaboration

LIGO 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 1,600 scientists from around the world participate in the eQort through the LIGO Scientific Collaboration, which includes the GEO Collaboration. Additional partners are listed at https://my.ligo.org/census.php.

The Virgo Collaboration is currently composed of approximately 1.000 members from 175 institutions in 20 different (mainly European) countries. The European Gravitational Observatory (EGO) hosts the Virgo detector near Pisa in Italy, and is funded by Centre National de la Recherche Scientifique (CNRS) in France, the National Institute of Nuclear Physics (INFN) in Italy, the National Institute of Subatomic Physics (Nikhef) in the Netherlands, The Research Foundation – Flanders (FWO) e the Belgian Fund for Scientific Research (F.R.S.–FNRS). A list of the Virgo Collaboration groups can be found at: https://www.virgo-gw.eu/about/scientific-collaboration/. More information is available on the Virgo website at https://www.virgo-gw.eu.

KAGRA is the laser interferometer with 3 km arm-length in Kamioka, Gifu, Japan. The host institute is Institute for Cosmic Ray Research (ICRR), the University of Tokyo, and the project is co-hosted by National Astronomical Observatory of Japan (NAOJ) and High Energy Accelerator Research Organization (KEK). KAGRA collaboration is composed of over

400 members from 128 institutes in 17 countries/regions. KAGRA's information for general audiences is at the website https://gwcenter.icrr.u-tokyo.ac.jp/en/. Resources for researchers are accessible from http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA.

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