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 detected the merger of the most massive black holes ever observed with gravitational waves, using the US National Science Foundation-funded (NSF) 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 100 and 140 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.

“This is the most massive black hole binary we’ve observed through gravitational waves, and it presents a real challenge to our understanding of black hole formation,” says Professor Mark Hannam, from Cardiff University and a member of the LIGO Scientific Collaboration. “Black holes this massive are forbidden through standard stellar evolution models. One possibility is that the two black holes in this binary formed through earlier mergers of smaller black holes.”

To date, approximately 300 black-hole mergers have been observed through gravitational waves, including candidates identified in the ongoing O4 run. Until now the most massive confirmed black-hole binary was the source of GW190521, with a much smaller total mass of “only” 140 times that of the sun.

A record-breaking system

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.

“The black holes appear to be spinning very rapidly—near the limit allowed by Einstein’s theory of general relativity,” explains Dr Charlie Hoy at the University of Portsmouth. “That makes the signal difficult to model and interpret. It’s an excellent case study for pushing forward the development of our theoretical tools.”

Researchers are continuing to refine their analysis and improve the models used to interpret such extreme events. "It will take years for the community to fully unravel this intricate signal pattern and all its implications" states Dr Gregorio Carullo, Assistant Professor at the University of Birmingham. "Despite the most likely explanation remaining a black hole merger, more complex scenarios could be the key to deciphering its unexpected features. Exciting times ahead!"

Probing the limits of gravitational-wave astronomy

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 part of the run (up to January 2024) will be published later in the summer.

“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. “It’s a powerful example of how much we can learn from gravitational-wave astronomy—and how much more there is to uncover.”

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 calibrated data used to detect and study GW231123 will be made available for other researchers to analyse through the Gravitational Wave Open Science Center (GWOSC).

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 effort 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 880 members from 152 institutions in 17 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 Istituto Nazionale di Fisica Nucleare (INFN) in Italy, and the National Institute for Subatomic Physics (Nikhef) in the Netherlands. 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.

Media Contacts:

LIGO-Virgo-Kagra Collaboration
LVK Communications Group
Lead Susanne Milde +49 172 3931349
susanne.milde@ligo.org

Caltech
Whitney Clavin
wclavin@caltech.edu
626-390-9601

MIT
Abigail Abazorius
abbya@mit.edu
617-253-2709

Virgo
Isabel Cordero
isabel.cordero@uv.es

EGO
Vincenzo Napolano
napolano@ego-gw.it
+393472994985

NSF
Jason Stoughton
Staff Associate for Science Communications
703-292-7063
jstought@nsf.gov

KAGRA
Shinji Miyoki
kagra-pub@icrr.u-tokyo.ac.jp
+81-578-85-2623

GR24-Amaldi16 Conference
Ross Barker
Ross.Barker@glasgow.ac.uk