LIGO-Virgo-KAGRA catalog reaches 390 gravitational wave detections, a new frontier for astronomy

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After a decade of observing the universe through the new discipline of gravitational-wave astronomy, the LIGO-Virgo-KAGRA (LVK) Collaboration released the results of the second half of its fourth observing run, adding 161 newly confirmed gravitational wave events to its catalog. The latest detections, combined with 11 additional signals recovered through reanalysis of earlier data, has brought the number of events seen to 390. The figure is 10 times the number of such detections only two years ago, and stands as a testament to internationally collaborative, publicly funded science.

Gravitational waves are minute disturbances that stretch and compress spacetime itself, caused when any object with mass accelerates. These ripples are tiny, even when produced from the collisions and mergers of extremely massive objects like neutron stars and black holes.

Moreover, the study of gravitational waves provide allows for a fundamentally new way of observing the Universe. Objects that have mass but do not emit any kind of light, such as black holes, still emit gravitational waves. And so, the data from LVK provides insight into what humans cannot see but can still detect through the science of general relativity, novel and incredibly precise measurements, and scientific and social planning on an international scale.

The release, formally titled the fifth Gravitational-Wave Transient Catalog, or GWTC-5.0, is the product of decades of theoretical work and technical labor by thousands of scientists and engineers across the world. It represents the accumulated work of four active detectors: the twin LIGO observatories in Hanford, Washington, and Livingston, Louisiana, the Virgo detector in Italy and the KAGRA detector in Japan. Each of these instruments detects gravitational waves through the same basic method: splitting a laser beam down two perpendicular tunnels and measuring the minute changes in their length as a wave passes through.

The scale of the achievement becomes clear against the history of the field. From 1916, when Albert Einstein derived the existence of gravitational waves from his general theory of relativity, until September 14, 2015, when the Advanced LIGO detectors recorded the first confirmed signal, a full century passed without a single direct detection. That first event, GW150914, was produced by the merger of two black holes, one 36 times the mass of the Sun and the other 29 times, into a single black hole of 62 solar masses.

The missing three solar masses were radiated away as gravitational wave energy in a fraction of a second, an amount of power that briefly exceeded the combined light output of every star in the observable universe. That such a signal, arriving as a change in distance smaller than a thousandth the width of a proton, could be captured and verified at all is one of the most exacting feats of measurement in the history of science.

In the decade since, the pace of detection has accelerated with each successive observing run, a direct expression of the compounding returns of sustained scientific investment in increased sensitivity. The first run recorded three confirmed events. The second, after Virgo joined the network, brought the total to eleven. The third run, cut short by the COVID-19 pandemic, raised the count to 90, with KAGRA joining the collaboration in early 2020. The fourth run, split into three segments running from May 2023 to November 2025, has so far produced 390 confirmed detections, with a third segment still to be analyzed. Researchers expect the total to surpass 500 once that data is released. A field that did not exist 12 years ago now catalogs cosmic collisions at a rate of dozens per month.

This growth reflects continuous technical improvement rather than a change in the underlying rate of cosmic mergers. Between observing runs, engineers have upgraded the vacuum systems the laser light travels through, refined the mirrors that reflect it, strengthened the suspension systems that isolate the instruments from vibration, and introduced quantum squeezed light to reduce noise below what was previously considered a fundamental limit. Each upgrade extends the distance over which the detectors can register a signal. Since detection volume grows with the cube of that distance, doubling the range increases the expected event rate eight-fold.

Detectors that once caught mergers only within a few billion light-years of Earth can now register events more than 20 billion light-years away. Each of these improvements is itself the outcome of painstaking, collective engineering labor, carried out over years, by people whose names will never appear in a headline. For the main LIGO instrument pair, that sensitivity has improved 11 times since construction, expanding the volume over which it can detect a given type of event by a factor of more than 1,000.

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The newest catalog also expands the known range of properties of black holes and neutron stars, deepening humanity's understanding of matter under conditions that cannot be reproduced on Earth. Among the events recorded in the current run are the heaviest black hole binary yet observed, GW231123_135430, involving two black holes each roughly 130 times the mass of the Sun, and a binary with the highest measured spin, GW231028_153006, in which both black holes rotate at about 40 percent the speed of light.

Another event, GW231118_005626, involved black holes of markedly unequal mass, one twice as large as the other. Scientists suspect that unusually massive or fast-spinning black holes like these are themselves the products of earlier mergers, evidence of a hierarchy of collisions building up larger black holes over cosmic timescales.

The catalog has also sharpened tests of general relativity itself, a theory now approaching its second century of unbroken confirmation. One of the loudest and clearest signals ever recorded, GW230814_230901, allowed physicists to search for any deviation from Einstein's equations under the most extreme conditions available for study, the collision of two black holes. The theory passed.

A separate event, GW250114, provided the most precise confirmation to date of a prediction made by Stephen Hawking, that the total surface area of black holes cannot decrease, a result announced by LIGO in September 2025. The best sky localization achieved with gravitational waves alone, for the event GW240615, narrowed the source to within six square degrees of sky, a dramatic improvement over the thousands of square degrees typical of earlier detections.

Beyond individual events, the accumulated catalog is being used to address open questions in cosmology. By analyzing the full population of detected mergers, LVK scientists have produced an independent estimate of the Hubble constant, the rate at which the universe is expanding, of 76 kilometers per second per megaparsec. Because the distance to a merging black hole binary can be calculated directly from its gravitational wave signal, without reliance on the layered assumptions required by other methods, each new detection adds to the precision of this measurement.

Researchers have also used the growing catalog to estimate the total population of black holes across the observable universe, arriving at a figure of roughly 40 quintillion, accounting for a small but measurable fraction of the universe's total mass and energy.

Construction began in April on a fifth major detector, LIGO India, built with the same four-kilometer laser arms as the original Hanford and Livingston observatories. Situated in a region chosen for its low seismic noise, the facility is expected to begin operations by 2030, in time for a planned fifth observing run. A network of five detectors positioned across the globe will allow scientists to triangulate the origin of a gravitational wave with far greater precision than is currently possible, potentially reaching single-square-degree localization for the strongest signals.

What this catalog demonstrates, above all, is the power of collaborative, publicly funded international science organized around the pursuit of knowledge rather than private gain. The LVK collaboration draws on the labor of thousands of scientists and engineers across the United States, Europe and Asia, coordinating through shared standards and open data rather than national rivalry.

Facilities in Italy and Japan operate alongside those in the United States not as competitors but as components of a single instrument, each expanding what the others can measure. The National Institute of Standards and Technology in the US calibrates the auxiliary lasers LIGO uses to verify its own measurements, a role now shared with Germany's Physikalisch-Technische Bundesanstalt. Every improvement made by one detector becomes an improvement available to all.

This model stands in open and growing contradiction to the priorities of capitalist governments. The Trump administration continues to attempt to slash the funding of the National Science Foundation, which funded LIGO's original construction and continues to support its operation, by more than 50 percent. The proposal, if passed by Congress, would result in a "reduced tempo" for LIGO and likely shut down one of the sites.

This is part and parcel of the broader attack by the administration on fundamental science. The Democrats, for their part, oppose Trump not out of principle, but because they are very concerned by the ongoing flight of highly skilled scientists, engineers, researchers and technicians to America's geopolitical rivals in Europe and China.

LIGO is the spearhead of a brand new scientific discipline capable of measuring changes in distance far smaller than an atomic nucleus, of confirming predictions made a century ahead of the observations, and of surveying the mergers of hundreds of black holes across billions of years of cosmic history. Its development and operation since 1994 have cost an estimated $1.4 billion—the cost of a single B-2 Stealth bomber.

At the same time there is no shortage of funding for the wars abroad, which are slated to cost $1,500 billion next year, much less the trillions given to bailout the major banks and corporations in 2008 and 2020.

Gravitational wave astronomy promises in the future, if funded, to measure the very ripples in the fabric of spacetime generated in the earliest moments of the Big Bang. Whether or not such discoveries occur is not a technical matter, but a question of what society chooses to value. It will only be resolved by a struggle by the working class against the private appropriation and squandering of humanity's collective resources and for a socialist future.

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