

PROBING THE UNIVERSE FOR PERSISTENT GRAVITATIONAL WAVES

Using data from [LIGO, Virgo, and KAGRA's](#) first four observing runs (through the first portion of the fourth observing run, known as O4a), we searched for persistent [gravitational waves](#) across the sky — both from specific known sources and from a possible background of unresolved signals. We did not detect any signals, but we set the most stringent limits to date on the strength of such waves, improving previous results by up to about a factor of two.

WHY SEARCH FOR PERSISTENT GRAVITATIONAL WAVES?

Gravitational waves are ripples in spacetime, often produced by massive, fast-moving cosmic objects. While we have detected short bursts of waves from colliding [black holes](#) and [neutron stars](#), there may also be long-lasting (“persistent”) gravitational-wave signals. These could come from spinning neutron stars, dense clusters of stars, or even from processes in the early universe. If many of these signals overlap, they will form a diffuse gravitational-wave background. Importantly, this background is unlikely to be uniform — its strength can vary across the sky depending on where sources are located.

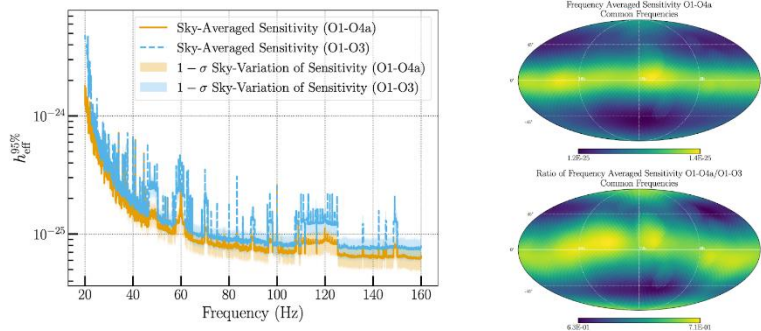


Figure 1. *Left panel* - Sky-averaged upper limits (UL) given by the all-sky all-frequency search using the O1 - O4a and O1 - O3 datasets, respectively. The shaded regions represent the [noise](#) level in the upper limits across the sky. *Top Right Panel* - Sky map of frequency-averaged upper limits using O1–O4a data. The observed pattern reflects the typical sky sensitivity of an HL-dominated network. *Bottom Right Panel* - Sky map showing the ratio of frequency-averaged upper limits from O1–O4a to those from O1–O3.

By searching for these persistent and directional signals, we aim to open a new window into the local and distant universe, revealing populations of neutron stars, galaxy clusters, or even unexplored phenomena in the early Universe like [cosmic strings](#) or [inflation](#).

HOW DID WE CONDUCT THE SEARCH?

We used LIGO data from Observing Runs O1 to O4a, as well as Virgo data from the third Observing Run, to look for persistent signals. We employed a gravitational-wave radiometer — a technique that [cross-correlates](#) data between detectors to map out possible gravitational-wave power across the sky.

Our search included four complementary analyses:

- **All-sky all-frequency search:** scanning for continuous signals across the full sky and frequency range.
- **Narrowband targeted search:** focusing on specific astrophysical locations, like [Scorpius X-1](#) and the [Galactic Center](#).
- **Broadband search:** looking for wide-frequency gravitational-wave backgrounds from point-like sources.
- **Extended-source search:** using [spherical harmonics](#) to probe broad, diffuse sources.

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Visit our www.ligo.org
websites: www.virgo-gw.eu
gwcenter.icrr.u-tokyo.ac.jp/en/



WHAT DID WE FIND?

We did not find evidence of persistent gravitational waves in any of the analyses. However, we placed the **tightest upper limits ever** on these types of signals.

- **All-sky search** (see [Figure 1](#)): Sensitivity estimates between 3×10^{-26} and 8.4×10^{-24} .
- **Targeted search** (see [Figure 2](#)): For key sources like Scorpius X-1 and [SN 1987A](#), strain amplitudes were constrained to lie between $\sim 1.1 \times 10^{-25}$ and 6.5×10^{-24} .
- **Broadband search**: [Energy flux](#) limits were improved by factors of 1.4–1.7 over previous results.
- **Extended-source search** (see [Figure 3](#)): Constraints on the gravitational-wave [angular power spectrum](#) were also tightened by up to a factor of two.

These results are built upon searches for new, persistent gravitational-wave sources, as well as improved analysis techniques, and set the stage for future discoveries.

LOOKING AHEAD

As LIGO, Virgo, and KAGRA continue observing with improved sensitivity, we expect to increase our chances of detecting persistent gravitational waves. In future analyses, we will include more data to analyze and refine our constraints even further on this persistent background of gravitational waves.

FIND OUT MORE:

Visit our websites:

www.ligo.org
www.virgo-gw.eu
gwcenter.icrr.u-tokyo.ac.jp/en/

Read a free preprint of the full scientific article [here](#) or on arXiv [here](#).

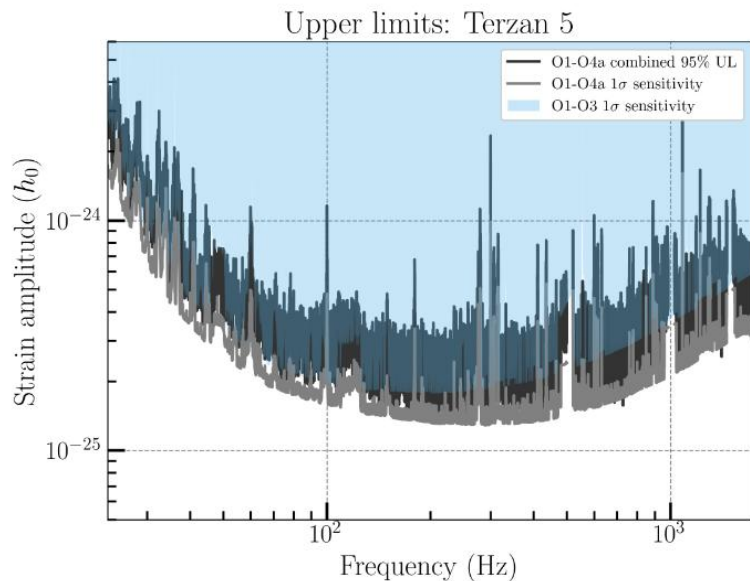


Figure 2: Upper limits of the narrowband radiometer search, using O1 - O4a datasets for a globular cluster Terzan 5, a new target that is explored in this work. The black solid line shows the Bayesian upper limits, while the gray line shows an estimation of the sensitivity under the hypothesis of no signal being present.

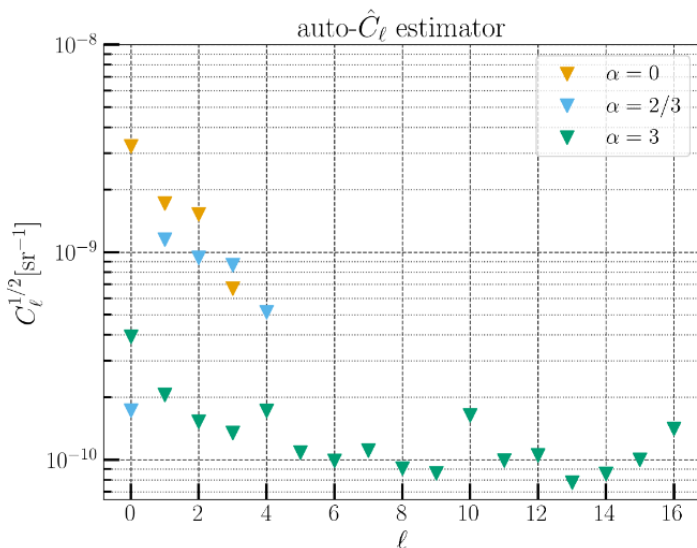


Figure 3: 95% confidence upper limits on the [angular power spectrum](#) for the extended-source search using the O1 - O4a datasets. The different colors represent three [power-law](#) spectral models, each of which has differing maximum angular scales we explored.

GLOSSARY

Bayesian inference: Method that allows us to combine new data with some knowledge that we already have (commonly known as prior information), expressed as probability. The combination is used to update our current knowledge and is also expressed as a probability (the posterior probability).

Black hole: A region of space-time with gravity so intense that it prevents anything, including light, from escaping. Black holes come in different sizes: the stellar-mass black holes originate from stellar collapse and their masses range from a few solar masses to about 65 solar masses. The intermediate-mass black holes range in mass from around 100 solar masses to 10^5 solar masses. Finally, the supermassive black holes range from more than 10^5 solar masses to more than 10^9 solar masses.

Cross-correlation: Measure of the similarity of two (or more) sets of data. If the data from two separate gravitational wave detectors is found to be correlated, this may indicate the presence of the gravitational wave background (provided other possible sources of correlation are ruled out).

Energy flux: A measure of how much energy is reaching a detector per unit area per unit time. For example, energy flux can have units of ergs per square centimeter per second. This definition is useful when the detector is very far from the source because then the amount of energy gathered by a detector is proportional to its size (area) and to how long it waits. However, the energy flux may be present for only a fraction of a second in a transient astrophysical event.

Neutron star: A relic of a massive star. When a massive star has exhausted its nuclear fuel, it dies in a catastrophic way—a supernova—that may result in the formation of a neutron star: an object so massive and dense (though not as much as a black hole) that atoms cannot sustain their structure as we normally perceive them on Earth. These stars are about as massive as our sun, but with a radius of about ten kilometers.

Strain: The fractional change in the distance between two reference points due to the deformation of spacetime by a passing gravitational wave. The typical strain of even the strongest gravitational waves reaching Earth is very small—typically less than 10^{-21} .

Upper limit: A statement about the maximum value some quantity can have while still being consistent with the non-detection. We typically use a 95% degree-of-belief limit, i.e., given the data there is a 95% probability that the quantity is below this limit.