

## SEARCHING FOR PERSISTENT GRAVITATIONAL WAVES WITH ADVANCED LIGO DATA FROM THE SECOND OBSERVING RUN

LIGO's first detection of a binary [black hole](#) merger, [GW150914](#), opened a gravitational-wave window on the Universe. We are now able to resolve tiny ripples in space and time coming from far away galaxies and explore the frontiers of physics. Nine black hole merger detections have followed, and, so far, LIGO and its partner detector, [Virgo](#), have made one detection of a [binary neutron star merger](#) in 2017. Gravitational-wave signals from black hole and neutron star mergers only last for a short period of time and are well-modelled by Einstein's [General Theory of Relativity](#). However, theoretical studies offer a motivation to look for long-lasting gravitational waves with minimal assumptions about the signal model, and that is what we have done in this work. We also call these long-lasting signals persistent.

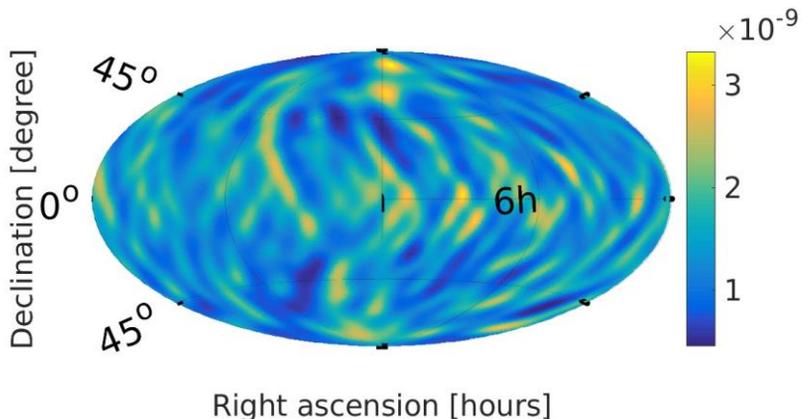
In order to look for persistent signals with Advanced LIGO, we employ a technique known as radiometry. In this work, we apply radiometry to look for persistent gravitational wave signals from different directions in the sky using Advanced LIGO data from the second observing run (O2).

Astronomers think that [neutron stars](#) in our Milky Way galaxy may not be perfectly spherical and thus emit gravitational radiation as they spin. At the same time, theoretical [axion](#) particles, if they exist, can potentially interact with black holes by a process called super-radiance, which leads to the emission of gravitational waves. From theorists' point of view, these are examples of phenomena that could emit strong enough gravitational waves to be detected and studied in the future. From an observer's perspective, these are examples of gravitational waves that would be emitted almost at the same frequency, from a particular point in the sky (point source). We employ radiometry to search for arbitrary narrowband signals from three interesting directions: [the Galactic Centre](#), [Supernova 1987A](#), and [Scorpius X-1](#), the brightest [extrasolar](#) X-ray source in the sky. We report on a feature in the data that may look like a signal (Figure 3), but it turns out to be not consistent with a persistent gravitational-wave source. We also set limits on the amount of gravitational waves coming from each of these three directions.

Gravitational waves that are too weak to be detected come in great numbers. Although these waves can not be individually resolved, they sum up to produce a background signal that scientists call a [stochastic background](#). We search for the background of gravitational waves coming from extended areas of the sky. We also run an all-sky search for point sources emitting gravitational radiation at a broad range of frequencies. In this regime, we assume different gravitational-wave [spectrum](#) models, backed up by theoretical work in cosmology and astrophysics.

### FIGURES FROM THE PUBLICATION

Please see the [arXiv preprint](#) for a more detailed description of figures.



**Figure 1.** Sky map of maximum gravitational-wave flux from point sources that cannot be ruled out during Advanced LIGO O2 run.

[In a separate study](#), we also searched for a gravitational-wave background that is the same in all directions.

Even though we have not detected gravitational waves with this particular search, we can put constraints on the maximum strength of gravitational-wave signals that could have been missed. This work improves on previous results by a factor of 1.5. The sky maps show the maximum possible energy density of the gravitational-wave background that is compatible with our observations. Persistent gravitational waves, if detected in following LIGO observing runs, could help us to learn more about the Universe. Minimal assumptions about the signal model could potentially lead us to the unexpected discovery, which is even more exciting!

## READ MORE

LIGO multimedia: <https://www.ligo.org/multimedia.php>

Interactive sky maps showing the O1 results for the search for extended sources in the gravitational wave background:

[ArXiv preprint](#) of the paper describing the details of full analysis and results: <https://arxiv.org/abs/1903.08844>

[ArXiv preprint](#) of the paper with results from the O1 run

[ArXiv preprint](#) of the paper with results from Initial LIGO run

[Search for the isotropic gravitational wave background](#)

## GLOSSARY

**Neutron star:** a dense stellar collapse remnant where nuclear matter pressure is in balance with remnant's gravitational pull on itself.

**Black hole:** a stellar collapse remnant, where remnant's self-gravitation is greater than matter's nuclear pressure. In this case, the object collapses on itself, leaving an event horizon, an area that light and matter particles cannot escape.

**Compact binary:** a pair of neutron stars or black holes, orbiting each other, and heading for collision due to an emission of gravitational waves.

**Radiometry:** a method of searching for persistent signals, based on time delay between detectors that potential signals would induce.

**Energy Density:** the amount of energy stored in a given system or region of space per unit volume.

**Upper limit:** the maximum value of an observable not ruled out by the current experiment.

**Narrowband gravitational waves:** gravitational waves emitted at approximately the same frequency.

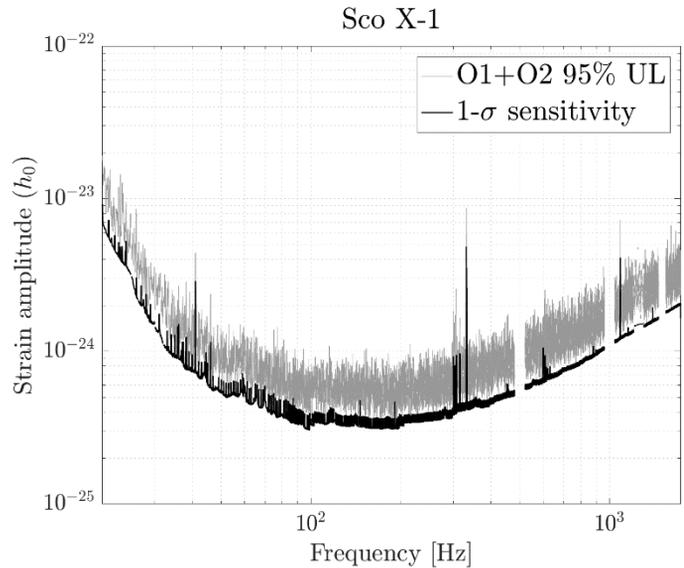
**Gravitational-wave strain:** a measure of deformation of space-time by a passing gravitational wave.

**Point source:** a source of gravitational waves where the size of a source is negligible, when compared to the distance to the source.

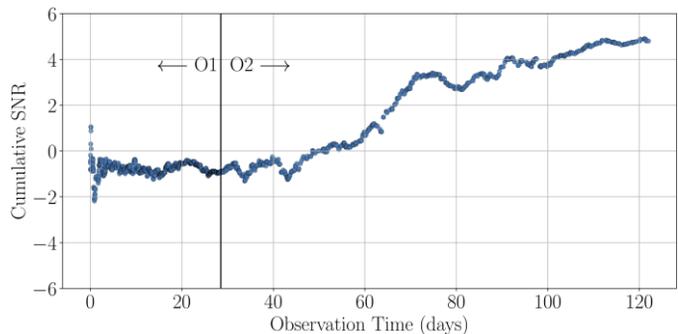
**Axion:** a hypothesised lightweight elementary particle proposed in 1977.

**Axion black hole superradiance:** a process in which axions extract energy from a black hole, and a black hole emits gravitational waves in return.

**Gravitational-wave spectrum:** a representation of how strong is a gravitational wave signal at different frequencies.



**Figure 2.** Grey color represents maximum gravitational-wave strain at different frequencies that can not be ruled out coming from the direction of Scorpius-X1 during O1 and O2 runs with 95% confidence. Black line represents our measurement background noise values in units of gravitational-wave strain within one [standard deviation](#).



**Figure 3.** Time evolution of the ratio of signal to noise for the outlier reported in the search for narrowband signals. The outlier does not appear in combined data from O1 and O2 runs, but it will be monitored in future observing runs.

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