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Gravitational lenses could pin down black hole mergers with unprecedented accuracy

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Example of a gravitational lens. Credit: Hubble Telescope / NASA / ESA

Gravitational wave astronomy has been one of the hottest new types of astronomy ever since the LIGO consortium officially detected the first gravitational wave (GW) back in 2016. Astronomers were excited about the number of new questions that could be answered using this sensing technique that had never been considered before.

But a lot of the nuance of the GWs that LIGO and other detectors have found in the 90 gravitational wave candidates they have found since 2016 is lost.

Researchers have a hard time determining which galaxy a gravitational wave comes from. But now, a new paper from researchers in the Netherlands has a strategy and developed some simulations that could help narrow down the search for the birthplace of GWs. To do so, they use another darling of astronomers everywhere—gravitational lensing.

Importantly, GWs are thought to be caused by merging black holes. These catastrophic events literally distort space-time to the point where their merger causes ripples in gravity itself. However, those signals are extraordinarily faint when they reach us—and they are often coming from billions of light-years away.

Detectors like LIGO are explicitly designed to search for those signals, but it's still tough to get a strong signal-to-noise ratio. Therefore, they're also not particularly good at detailing where a particular GW signal comes from. They can generally say, "It came from that patch of sky over there," but since "that patch of sky" could contain billions of galaxies, that doesn't do much to narrow it down.

But astronomers lose a lot of context regarding what a GW can tell them about its originating galaxy if they don't know what galaxy it came from. That's where gravitational lensing comes in.

Gravitational lenses are a physical phenomenon whereby the signal (in most cases light) coming from a very faraway object is warped by the mass of an object that lies between the further object and us here on

Earth. They're responsible for creating "Einstein Rings," some of the most spectacular astronomical images.

Light is not the only thing that can be affected by mass, though—gravitational waves can, too. Therefore, it is at least possible that gravitational waves themselves could be warped by the mass of an object between it and Earth. If astronomers are able to detect that warping, they can also tell which specific galaxy in an area of the sky the GW sign is coming from.

Once astronomers can track down the precise galaxy, creating a gravitational wave, the sky is (not) the limit. They can narrow down all sorts of characteristics not only of the wave-generating galaxy itself but also of the galaxy in front of it, creating the lens. But how exactly should astronomers go about doing this work?

That is the focus of the new paper from Ewoud Wempe, a Ph.D. student at the University of Groningen, and their co-authors. The paper, published in the *Monthly Notices of the Royal Astronomical Society*, details several simulations that attempt to narrow down the origin of a lensed gravitational wave. In particular, they use a technique similar to the triangulation that cell phones use to determine where exactly they are in relation to GPS satellites.

Using this technique can prove fruitful in the future, as the authors believe there are as many as 215,000 potential GW lensed candidates that would be detectable in data sets from the next generation of GW detectors. While those are still coming online, the theoretical and modeling worlds remain hard at work trying to figure out what kind of data would be expected for different physical realities of this newest type of astronomical observation.

More information: Ewoud Wempe et al, On the detection and precise localization of merging black holes events through strong gravitational lensing, *Monthly Notices of the Royal Astronomical Society* (2024). DOI: 10.1093/mnras/stae1023

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