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Gravitational waves

Hunting for source of cosmic hum

A series of exotic options have been put forward to explain the discovery of low-level ripples in space-time that appear to be spread throughout the universe, reports **Alex Wilkins**

THEORETICAL physicists have leapt upon the recent discovery of a background hum of gravitational waves permeating the entire universe, with some claiming the signal could be a sign of dark matter or even shed new light on the earliest moments of existence.

"There has been a lot of excitement in the high-energy physics community," says Andrea Mitridate at the California Institute of Technology, who is part of the team that discovered the gravitational wave background. "To be honest, I have had some trouble to follow all the papers that have appeared."

On 29 June, astronomers at the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) announced they had detected low-frequency ripples in space-time across the entire universe. The leading explanation for this background hum is that it comes from the merging of colossal black holes found at the centre of many galaxies. These ripples affect every massive object, including fast-rotating neutron stars called pulsars, which act like near-perfectly timed galactic lighthouses. Astronomers can use these stars to find gravitational waves by looking for tiny timing differences they create in the pulsars' light.

The pattern of timing differences seen by NANOGrav is a very close match to the one predicted by Albert Einstein's general theory of relativity, which says the timing from pulsar pairs should become broadly less similar as the angle between them grows, but the strength of the signal also grew unexpectedly at higher frequencies of gravitational wave.

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Gravitational waves are ripples in space-time made by massive objects

"What these pulsar timing array observations show is qualitatively consistent with what the models predicted, but not precisely with the original predictions," says John Ellis at King's College London. "That frequency dependence wasn't quite what was expected."

In physical terms, it appears the supermassive black holes are producing more, or more powerful, gravitational waves as they move closer to merging, but it isn't clear why this should happen. Ellis and his colleagues have suggested that the black holes may initially be having to plough through nearby gas and stars as they begin to merge, causing them to lose energy that would otherwise have been emitted as part of the gravitational waves. But as the black holes spiral ever closer, and the frequency of the gravitational waves increases, the gas and stars have less of an effect and more energy goes into the waves (arXiv, doi.org/kh9v).

Other explanations are more exotic, like a shroud of dark matter around the merging black holes. Tom Broadhurst at the University of the Basque Country and his colleagues simulated this idea using an earlier NANOGrav data set and found a close match, but they struggled to produce the high-frequency data seen in the most recent measurements.

A further wrinkle in the data is what appears to be a small peak at the lower end of NANOGrav's frequency range, in what is otherwise a relatively smooth line. While it isn't statistically significant enough for astronomers to be certain it is real, it is unexpected, says NANOGrav team member Nihan Pol at Vanderbilt University in Tennessee. This spike could be from an unknown nearby supermassive black hole merger emitting that particular frequency, but confirming this will require at least five more years of data-gathering, says Pol.

> "There has been a lot of excitement in the high-energy physics community"

But if these explanations don't bear out, theorists might need to turn towards very different sources. One possibility being looked at is cosmic strings, theorised objects that are light-years long, but with a width less than that of a proton. These strings, if they exist, would have been produced when the early universe went through a dramatic phase transition, similar to the cracks that form when water freezes into ice. Ellis and his colleagues have predicted that, when these strings collide, they should produce a gravitational wave signature detectable by groups like NANOGrav, but again the stronger signal at higher frequencies doesn't quite fit the bill (arXiv, doi.org/kh9w).

Primordial black holes – another theorised denizen of the early universe formed from clusters of subatomic matter so dense that they collapsed space-time – are also being considered as a possibility. These black holes would have produced their own unique gravitational wave signal, different from the proposed supermassive black hole mergers of today.

In simulations, Kai Schmidt-Hoberg at the German Electron Synchrotron and his colleagues found primordial black holes can only match the observed NANOGrav signal if they are distributed in clumps through the early universe, rather than found uniformly across the cosmos, but it is unclear why this would happen (arXiv, doi.org/kh9x).

There is also the possibility that several of these scenarios are true at once, but disentangling them will require new tools that have yet to begin operation. One such tool is the Laser Interferometer Space Antenna (LISA), a set of three spacecraft designed to detect higher frequencies than NANOGrav. At these frequencies, the predictions from cosmic strings and supermassive black holes are very different, says Ellis, but as LISA won't launch until the late 2030s, we could be waiting for some time. ▮