The Cosmos Is Thrumming With Gravitational Waves, Astronomers Find

Radio telescopes around the world picked up a telltale hum reverberating across the cosmos, most likely from supermassive black holes merging in the early universe.

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The Very Large Array on the Plains of San Agustin, N.M., one of three radio telescopes that worked with a global consortium to detect the timing of pulsars.NRAO/AUI/NSF

By Katrina Miller

Katrina Miller, a science reporter, recently earned a Ph.D. in particle physics from the University of Chicago.

On Wednesday evening, an international consortium of research collaborations revealed compelling evidence for the existence of a low-pitch hum of gravitational waves reverberating across the universe.

The scientists strongly suspect that these gravitational waves are the collective echo of pairs of supermassive black holes — thousands of them, some as massive as a billion suns, sitting at the hearts of ancient galaxies up to 10 billion light-years away — as they slowly merge and generate ripples in space-time.

“I like to think of it as a choir, or an orchestra,” said Xavier Siemens, a physicist at Oregon State University who is part of the North American Nanohertz Observatory for Gravitational Waves, or NANOGrav, collaboration, which led the effort. Each pair of supermassive black holes is generating a different note, Dr. Siemens said, “and what we’re receiving is the sum of all those signals at once.”

The findings were highly anticipated, coming more than 15 years after NANOGrav began taking data. Scientists said that, so far, the results were consistent with Albert Einstein's theory of general relativity, which describes how matter and energy warp space-time to create what we call gravity. As more data is gathered, this cosmic hum could help researchers understand how the universe achieved its current structure and perhaps reveal exotic types of matter that may have existed shortly after the Big Bang 13.7 billion years ago.

"The gravitational-wave background was always going to be the loudest, most obvious thing to find," said Chiara Mingarelli, an astrophysicist at Yale University and a member of NANOGrav, which is funded by the National Science Foundation. "This is really just the beginning of a whole new way to observe the universe."

Listen to the Background Hum of the Cosmos

Astronomers simulated what the murmur of gravitational waves originating from supermassive black hole-binaries might sound like, if it was sped up 40 million times. Recording by Michele Vallisneri/JPL-Caltech.

On Thursday, the NANOGrav collaboration streamed [a public news briefing] to officially announce their results. "Today's announcement shatters the perception of a static universe," said Sean Jones, assistant director for the Directorate of Mathematical and Physical Sciences at the National Science Foundation. "These observations reveal a rolling, noisy universe alive with the cosmic symphony of gravitational waves."

Gravitational waves are created by any object that spins, such as the rotating remnants of stellar corpses, orbiting black holes or even two people "doing a do-si-do," Dr. Mingarelli said. But unlike other types of waves, these ripples stretch and squeeze the very fabric of space-time, warping the distances between any celestial objects they pass by.

"It sounds very sci-fi," Dr. Mingarelli said. "But it's for real."

The discovery of gravitational waves was first announced in 2016 by the Laser Interferometer Gravitational-Wave Observatory, or LIGO, collaboration; the breakthrough solidified Einstein's theory of general relativity as an accurate model of the universe and earned the project's founders the Nobel Prize in Physics in 2017. But LIGO's signals were mostly in the frequency range of a few hundred hertz, and were created by individual pairs of black holes or neutron stars that were 10 to 100 times as massive as our sun.

In contrast, the researchers involved in this work were looking for a collective hum at much lower frequencies — one-billionth of one hertz, far below the audible range — emanating from everywhere all at once.

At the lowest frequencies, that hum is so loud "that it could be coming from hundreds of thousands, or possibly a million, overlapping signals from the cosmic merger history of supermassive black hole binaries," Dr. Mingarelli said.

The signal was discovered by studying the behavior of rapidly spinning stars called pulsars, using a method that in 1993 earned two scientists the Nobel Prize in Physics for indirectly measuring the effects of gravitational waves.

The NANOGrav team simultaneously published four studies in The Astrophysical Journal Letters, as well as two additional papers on the preprint server arXiv.org, detailing the collection and analysis of the data and the different interpretations of the result.

The Arecibo Observatory in Puerto Rico contributed observations before it collapsed in 2020.Brennan Linsley/Associated Press

If the signal does arise from orbiting pairs of supermassive black holes, studying the gravitational-wave background will shed light on the evolutionary history of these systems and the galaxies surrounding them. But the gravitational-wave background could also be coming from something else, like hypothetical cracks in space-time known as cosmic strings.

Or it could be a relic of the Big Bang, akin to the cosmic microwave background, which led to fundamental discoveries about the structure of the universe to within 400,000 years of its beginning. The gravitational-wave background would be an even better primordial probe, Dr. Mingarelli said, because it would have been emitted almost instantaneously.

To detect the gravitational-wave background, researchers took advantage of the lighthouse-like nature of pulsars spread across the Milky Way. “Our detector isn’t something you can build in a lab or even launch into space,” said Thankful Cromartie, an astronomer at Cornell University, during Thursday’s news conference. “It’s closer to the size of the galaxy.”

Pulsars act like cosmic clocks, emitting beams of radio waves that can be periodically measured on Earth. Einstein’s theory of general relativity predicts that as gravitational waves sweep past pulsars, they should expand and shrink the distance between these objects and Earth, changing the time it takes for the radio signals to arrive at observers. And if the gravitational-wave background is indeed everywhere, pulsars across the universe should be affected in a correlated way.

Rather than build a dedicated instrument, the NANOGrav team took advantage of existing radio telescopes around the world: the Very Large Array in New Mexico, the Green Bank Telescope in West Virginia and Arecibo Observatory in Puerto Rico (before its fateful collapse three years ago).

In 2020, after more than 12 years of gathering data, the NANOGrav team released results from monitoring the timing of 45 pulsars. Even then, Dr. Siemens said, the researchers saw tantalizing hints of a gravitational-wave background, but they needed to track more pulsars for longer amounts of time to confirm that they were indeed correlated, and to claim a discovery. So the NANOGrav team approached colleagues through the International Pulsar Timing Array — an umbrella organization that includes collaborations based in India, Europe, China and Australia — and coordinated an effort to uncover the gravitational-wave background together.

Fast-forward to Wednesday: Each collaboration is now publishing results from independently collected data, all of which support the existence of a gravitational-wave background. The NANOGrav team has the largest data set, with 15 years of measurements from 67 pulsars, each monitored for at least three years.

The findings carry a confidence level in the range of 3.5- to 4-sigma, just shy of the 5-sigma standard generally expected by physicists to claim a smoking-gun discovery. That means the odds of seeing a result like this randomly are about 1 in 1,000 years, Dr. Mingarelli said. "That's good enough for me, but other people want once in a million years," she said. "We'll get there eventually."

Marcelle Soares-Santos, an astrophysicist at the University of Michigan who was not involved in the work, acknowledged that while this was early evidence, the results were enticing. “This is something that the community has been anticipating for quite a while,” she said, adding that independent measurements from other pulsar timing collaborations strengthened the findings.

Still, Dr. Soares-Santos said, it was too soon to tell what impact a gravitational-wave background might have on future research. If the signal really was from the slow, inward spiraling of supermassive black holes, as many NANOGrav collaborators believe, it would augment what scientists understand about the way early galaxies merged, forming ever-larger systems of stars and dust that eventually settled into the complex structures observed today.

But if the ripples originated with the Big Bang, they might instead provide insight into the expansion of the cosmos or the nature of dark matter — the invisible glue scientists think holds the universe together — and perhaps even reveal new particles or forces that once existed. (Experts noted that the gravitational-wave background could also originate from multiple sources, in which case the challenge would be to disentangle how much comes from where.)

The NANOGrav team is already working on analyzing all the data from gravitational-wave collaborations around the world, equaling around 25 years' worth of measurements from 115 pulsars. These results will be unveiled in a year or so, Dr. Siemens said, adding that he expected them to exceed the 5-sigma discovery level.

But a few more years may be needed to confirm the source of the gravitational-wave background. Researchers have already begun using their data to piece together maps of the universe and to look for intense, nearby regions of gravitational-wave signals indicative of an individual supermassive black hole binary. That's where the fun starts, said Dr. Mingarelli, who is looking forward to analyzing those maps and searching for even more exotic phenomena, like galactic jets, cosmic strings or wormholes.

"This could lead to something really groundbreaking," Dr. Soares-Santos said, comparing it to the discovery of the cosmic microwave background in the 1960s, which has since transformed physicists' knowledge about the early universe.

At Thursday's news conference Maura McLaughlin, a NANOGrav collaborator at West Virginia University, was enthusiastic about the next phase of research. "We are certainly expecting the unexpected," she said. "All we have to do is keep listening."

Dennis Overbye contributed reporting.

A correction was made on

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Because of an editing error, an earlier version of this article misstated when gravitational waves were discovered. They were first detected in 2015, not 2016. Additionally, the article misstated how the waves were first detected. They were observed in data, not as audible chirps.