CLOCKWORK COSMOS: The Antikythera Mechanism
PAGE 22

HOW-TO: Photograph the Planets
PAGE 28

TEST REPORT: Astro-Tech AT90CFT Refractor
PAGE 66

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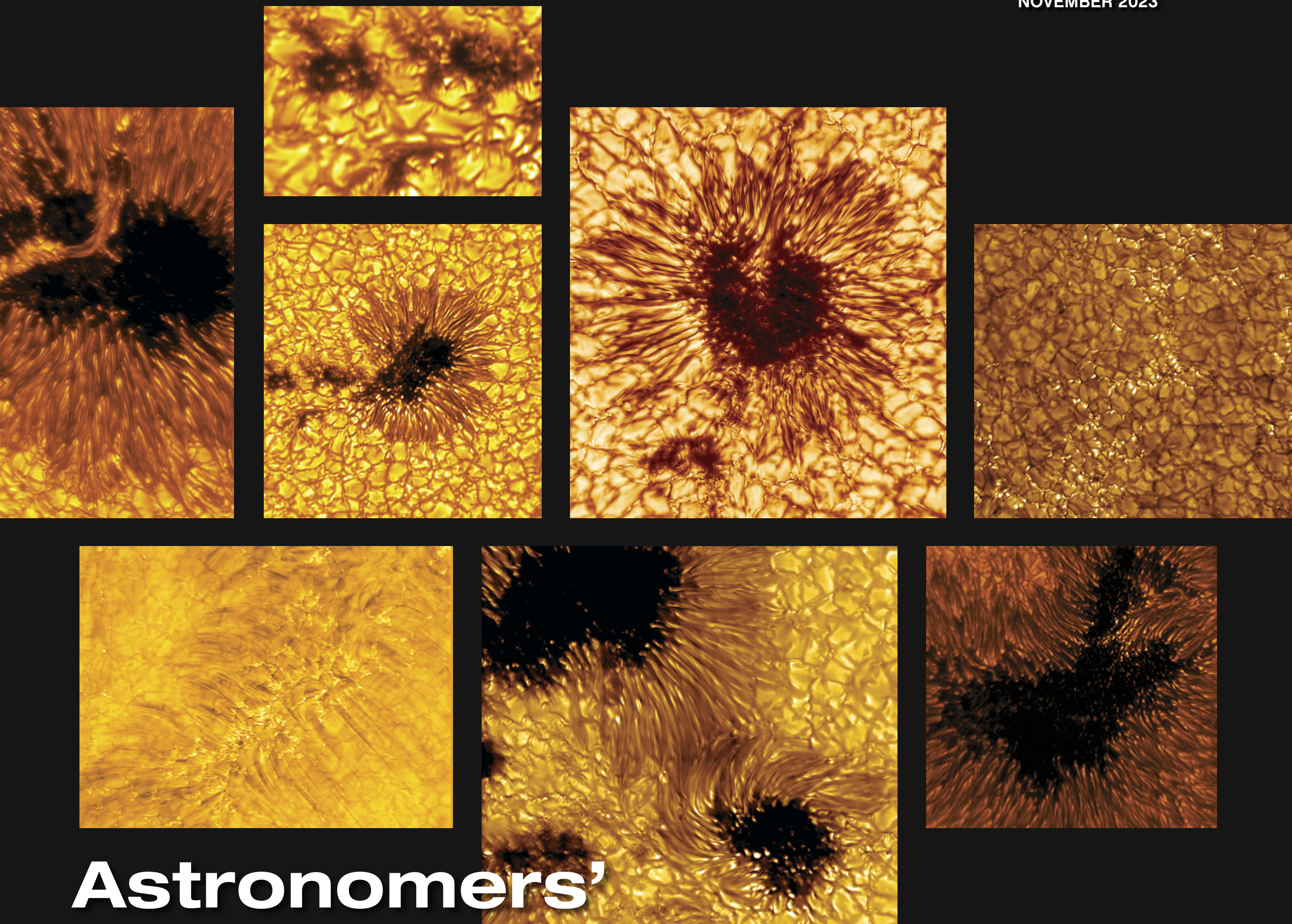

Astronomers' New Eye on the Sun

Page 14

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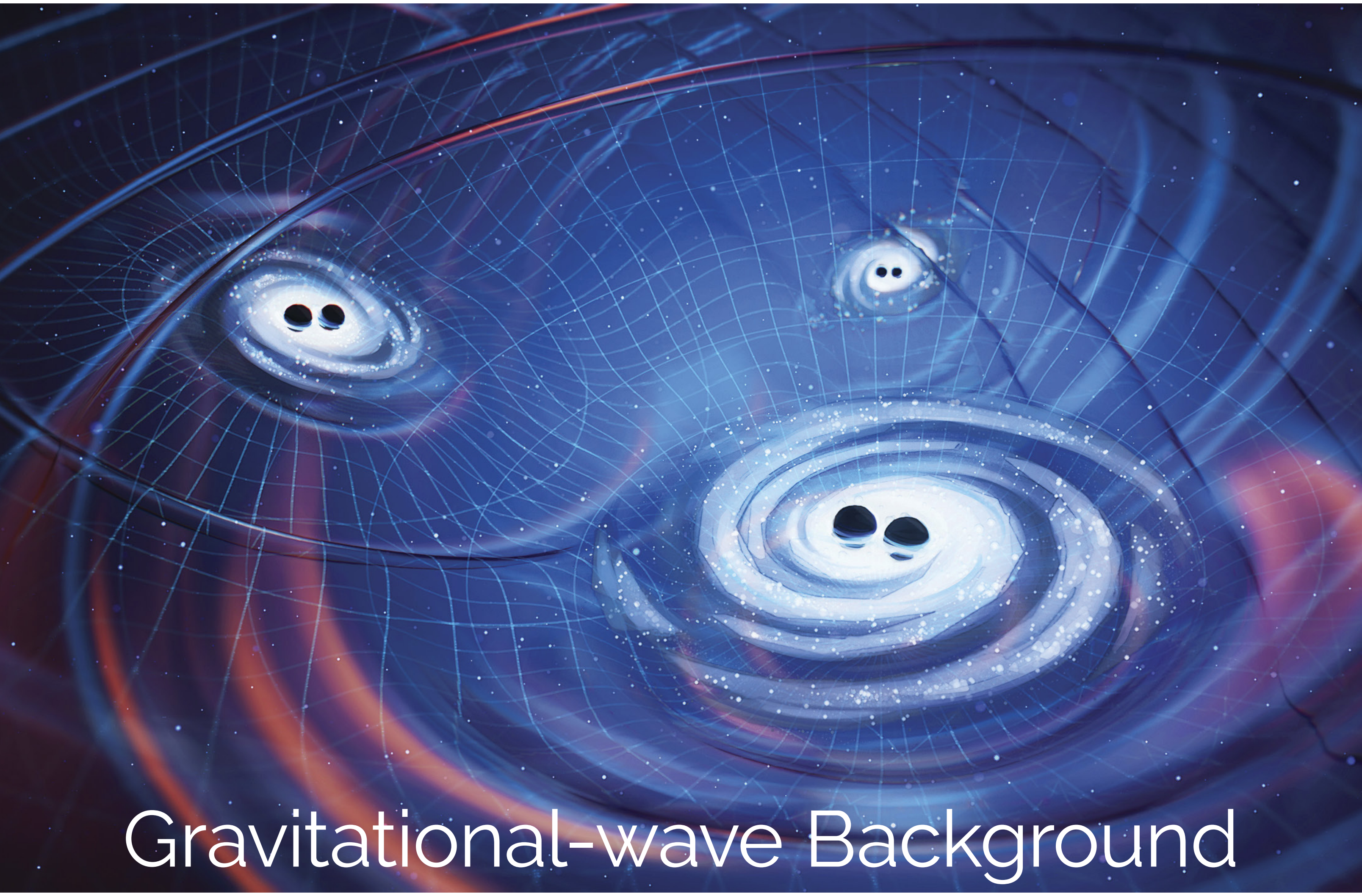


Gravitational-wave Background REVEALED

Observations of more than 100 pulsars show evidence for a new type of spacetime ripple: a sea of waves from pairs of supermassive black holes.

Radio observatories across the globe have found compelling evidence for a background hum of low-frequency *gravitational waves*, the slow and minuscule undulations of spacetime thought to be produced by distant supermassive black hole pairs.

"After years of work, [we are] opening an entirely new window on the gravitational-wave universe", says Stephen Taylor (Vanderbilt University), chair of the North American Nanohertz Observatory for Gravitational Waves (NANOGRAV) collaboration.

Albert Einstein predicted gravitational waves' existence more than a century ago, but only in 2015 did the Laser Interferometer Gravitational-wave Observatory (LIGO) first detect them. Ever since, U.S. LIGO scientists and their international collaborators have found dozens of short bursts produced by the collisions of stellar-mass black holes or neutron stars (*S&T:* June 2022, p. 12). These signals have high frequencies up to a few thousand hertz, or ripples per second.

However, the universe is also expected to bathe in a sea of continuous, low-frequency gravitational waves, with spacetime slightly expanding and contracting only once every couple of decades or so. As reported by multiple groups on June 28th in the *Astrophysical Journal Letters*, *Astronomy*

▲ **GRAVITATIONAL SYMPHONY** Supermassive black hole binaries at the cores of galaxies create a background hum of spacetime ripples that suffuses the universe.

OLENA SHMAHALO / NANOGRAV

& Astrophysics, *Publications of the Astronomical Society of Australia*, and *Research in Astronomy and Astrophysics*, this long-sought background signal is now finally emerging in high-precision radio observations.

"It's as if LIGO can only hear the high pitch of a piccolo, while we listen to the low vibrations of a contrabass," explains Gemma Janssen (ASTRON Netherlands Institute for Radio Astronomy). "To understand the whole symphony, you obviously need both."

The studies employ pulsars across the Milky Way as their detector. As low-frequency gravitational waves stretch and squeeze our home galaxy, they affect our observations of *millisecond pulsars*. These pulsars are rapidly spinning neutron stars that, like cosmic lighthouses on steroids, sweep beams of radio waves through space at a rate of several hundred pulses per second. Gravitational waves create tiny variations in the pulses' travel times that become apparent only over the course of many years.

Now, after decades of observations, astronomers are finally registering these slow spacetime ripples.

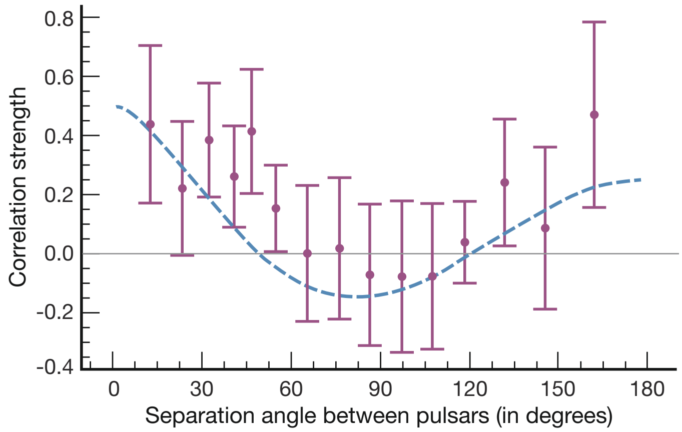
"When I first saw [the evidence], I was awestruck. It was a magical moment," says Maura McLaughlin (West Virginia University), codirector of the NANOGRAV collaboration. "For the first time, we now have good evidence for the existence of nanohertz gravitational waves. It's very difficult to explain [the observations] by any other process."

The NANOGRAV collaboration combined observations of 68 millisecond pulsars taken over the past 15 years by the 305-meter Arecibo Telescope in Puerto Rico, the 100-meter Green Bank Telescope in West Virginia, and the 27-element Very Large Array in New Mexico.

Likewise, the European Pulsar Timing Array (EPTA) collaboration combined data on 25 pulsars from the largest European radio observatories: Jodrell Bank Observatory in the United Kingdom, the Effelsberg radio telescope in Germany, Nançay Radio Observatory in France, the Sardinia Radio Telescope in Italy, and the Westerbork Synthesis Radio Telescope in the Netherlands. Scientists from India and Japan are also part of the EPTA.

Both the NANOGRAV and the EPTA collaborations report a nanohertz gravitational-wave signal in their data. According to NANOGRAV member Michael Lam (SETI Institute), the likelihood that the observed signal is due to chance is only about one in 1,000, corresponding to a better than three-sigma statistical significance. Similar projects carried out with the 64-meter Parkes radio telescope (Murriyang) in Australia and with the Five-hundred-meter Aperture Spherical Telescope (FAST) in China find consistent results.

While it's not yet possible to identify individual sources for these low-frequency waves, that may yet change. "The observed signal may well be dominated by just a handful of relatively nearby systems," explains EPTA member Alberto Sesana (University of Milano-Bicocca, Italy). "Right now, the evidence is inconclusive, but within a few years, we hope to get a better handle on this."



▲ **GALACTIC-SCALE DETECTOR** Gravitational waves should imprint a distinctive pattern of correlated timing variations, indicated by the dashed blue line. NANOGRAV results are shown in purple. Whereas the correlation should be strongest for pulsars near each other on the sky (with angles near 0°), variations in the signals from those separated by 90° on the sky will cancel out. In this way, the pulsars distributed across the Milky Way act like a many-armed gravitational-wave detector.

NANOGRAV

The detection is at the limits of what's currently possible, because even without gravitational waves pulse arrival times vary ever so slightly due to the motions of Earth and any individual pulsar through space. The pulsars themselves are also not perfectly stable rotators. To be sure of the detection, astronomers looked for patterns in the timing measurements for ensembles of pulsars. As gravitational waves ripple through our galaxy, pulsars near each other on the sky exhibit similar variations, while pulsars separated by 90° on the sky behave "out of sync."

A combined analysis of all the various pulsar timing array projects will continue to improve the result's statistical significance over the next one or two years. Additional pulsar data are also incoming. Astronomers add newly discovered millisecond pulsars to the roster on a regular basis.

New facilities are also entering the fray. While the 14-dish Westerbork array is no longer available for pulsar timing measurements, and the collapse of the Arecibo dish was a huge loss for NANOGRAV, other telescopes are under construction or already taking data. The Canadian Hydrogen Intensity Mapping Experiment (CHIME) joined NANOGRAV in 2019, and the Deep Synoptic Array-2000 (*S&T:* Sept. 2023, p. 14), to be built in Nevada, may also join. Meanwhile, China's FAST telescope continues to time pulsars, as does the 64-element MeerKAT array in South Africa. Before the end of the decade, the mid-frequency part of the giant Square Kilometre Array (*S&T:* June 2017, p. 24), which will incorporate MeerKAT, will become the most powerful observatory for these kinds of measurements.

■ Contributing Editor **GOVERT SCHILLING** is the author of *Ripples in Spacetime: Einstein, Gravitational Waves, and the Future of Spacetime* (Harvard University Press, 2017).