2016 Year in Review

At first glance, the stories taking the top two spots in *Science News*' review of 2016 have little in common. Scientists began searching decades ago for gravitational waves. Discussions of these subtle signals from dramatic and distant phenomena appear dozens of times in the *SN* archive starting as early as the 1950s. Their long-awaited discovery, our No. 1 story of the year, touched off celebration of a new era in astronomy. Less expected, and far from subtle, was the sudden rise in Brazil of microcephaly cases, linked this year to Zika virus infections — our No. 2 story. Little was known about Zika before the outbreak, which delivered devastation and fear across the Americas. In fact, only a single previous mention of Zika exists in the *SN* archive, in a book review from the 1990s.

But the stories have at least one thing in common: Both highlight the power of scientific discoveries to trigger our deepest human emotions. Pure elation as well as overwhelming dread can accompany research advances. 2016 brought many more sentiments, too. There was enthusiasm for the discovery of the exoplanet Proxima b, concern for the prospects of three-parent babies and feelings of potential but also impending peril in the openings of Arctic passageways.

The editors and writers at *Science News* also recognize that some of the best and most moving stories are those that are still unfolding. So, in addition to the discoveries of 2016, we review milestones, setbacks and other tales of unsteady progress. Sonia Shah writes about a new wave of infectious diseases; Tom Siegfried explores convergent failures in the field of particle physics; and Laurel Hamers covers key challenges for self-driving cars. Then, *Science News* writers share what science news they're most excited about in the year to come. — *Elizabeth Quill*

Special Section

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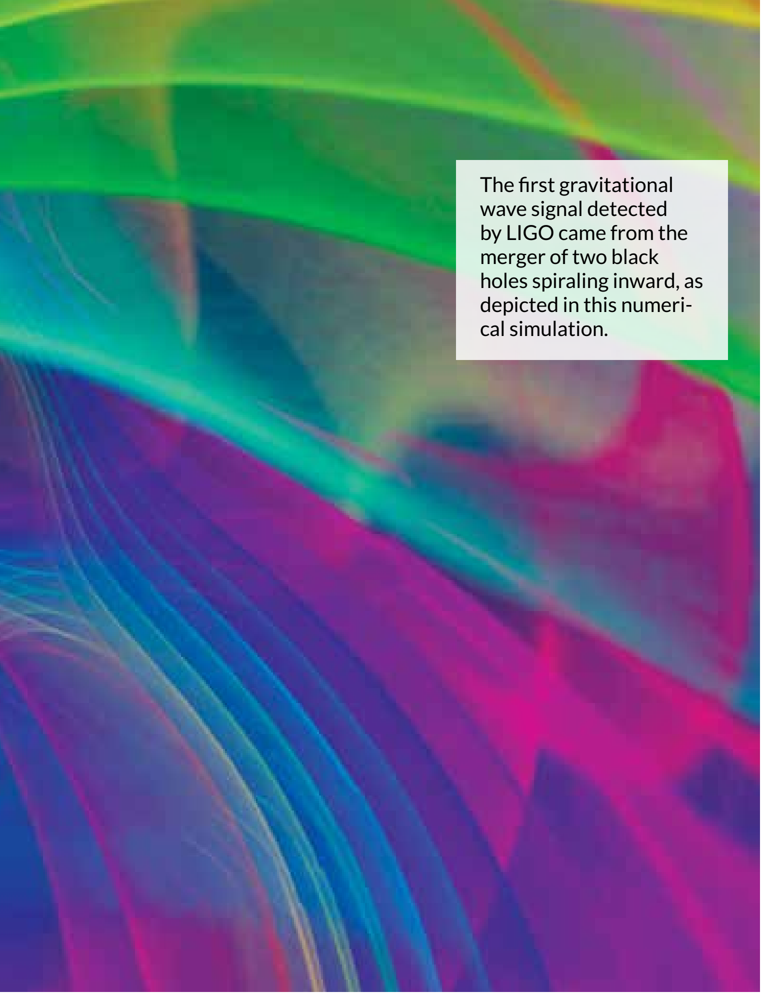


The first gravitational wave signal detected by LIGO came from the merger of two black holes spiraling inward, as depicted in this numerical simulation.

Gravitational waves offer new view of dynamic cosmos

By Emily Conover

1 The secrets gleaned from the universe's most mysterious giants are incongruously subtle when witnessed at Earth: Detectors budge by a tiny fraction of a proton's breadth, outputting a feeble, birdlike chirp.

For centuries, astronomers have peered out into the universe almost exclusively by observing its light. But 2016's announcement of the first detection of gravitational waves, produced 1.3 billion years ago in the collision of two monstrous black holes, has given scientists a whole new way of observing the heavens.

The waves tore through the cosmos at the speed of light and arrived at Earth just in time for the start-up of the Advanced Laser Interferometer Gravitational-Wave Observatory, LIGO, which measured the minute stretching and squeezing of space. With a second detection already recorded and more expected in 2017, scientists hope to uncover new details about elusive black holes and their pairings. Soon, as more detectors come online, scientists will even be able to pinpoint where gravitational waves originate and inspect the sky for the aftermath of the cataclysms that caused them.

"This is a great success story of science," says astrophysicist Avi Loeb of Harvard University, who was not involved in the detection. It's the kind of major discovery that comes along only once in a few decades, he says.

On February 11, LIGO scientists announced the discovery at a news conference in Washington, D.C., and in a paper published in *Physical Review Letters*. Since publication, the paper has garnered around 100 citations a month, evidence of a newly intensified focus on the waves. Some physicists had dedicated entire careers to finding the spacetime tremors, which will be a boon for researchers for decades if not centuries to come.

The patterns of ripples appeared nearly simultaneously in LIGO's two enormous L-shaped detectors — in Hanford, Wash., and Livingston, La., — on September 14, 2015. The signal closely matched that expected from a pair of black holes that spiral around one another, getting closer and closer before merging into one. At the early stages of their do-si-do, the two black holes were about 35 and 30 times the mass of the sun. The behemoths melded together into a black hole 62 times the sun's mass, releasing three suns' masses worth of energy (*SN: 3/5/16, p. 6*; *SN: 7/9/16, p. 8*). When scientists converted the gravitational waves into sound waves, the waves produced something like the everyday chirp of a bird, quickly rising in pitch and volume before cutting off. The sound felt like a plaintive question, as if the universe was asking, "Hello? Is anyone there?" This time, the answer was yes.

Taken on its own, the discovery was a blockbuster — confirming Einstein's prediction that spacetime can ripple, providing an intimate new glimpse of black holes and verifying astrophysicists' calculations for how two black holes can fuse into one. But the detection's landmark status is largely because of its future promise. LIGO is expected to usher in a new era of astronomy, in which gravitational wave detections could become commonplace. Black holes, previously dark to humankind, will regularly communicate their coalescences to Earth.

In pursuit of this new type of astronomy, scientists have been chasing gravitational waves for decades. After such a long search, it was "incredibly gratifying," says David Shoemaker, leader of LIGO's efforts at MIT, "to wake up in the morning and know in my bones" that gravitational waves had finally been detected.

Almost as soon as LIGO's updated detectors were turned on, the gravitational waves rippled by, slightly altering the length of LIGO's ultrasensitive detectors. "We flipped the switch and said, 'OK, we're going to start running,' and boom," says LIGO laboratory executive director David Reitze of Caltech. That quick detection raised hopes among astrophysicists who daydream of datasets with tens or hundreds of such events.

With each new coalescence, scientists will learn more about how common black hole pairs are, as well as the properties of black holes and the dying stars that collapsed into oblivion to create them. "What we're really learning about when we study these black holes is the stars that were their progenitors," says LIGO member Daniel Holz of the University of Chicago. "From the stars, we then are learning about the early universe."

Scientists hope to reconstruct how pairs of black holes find one another in the lonely universe. There are two main competing theories: Two stars could be born together like twins, with each later collapsing into a black hole, or the black holes could meet up later in life, in dense systems where many black holes and stars interact (*SN Online: 6/19/16*).

Proving that the detection was no fluke, LIGO scientists reported June 15 that they had spotted the quivers of a smaller pair of merging black holes (*SN: 7/9/16, p. 8*). LIGO shut down for upgrades following the two detections, but restarted again in November. Further improvements to the LIGO detectors will boost their sensitivity, allowing them to catch even fainter ripples. When those upgrades are complete — perhaps by 2019 — scientists could glimpse black hole mergers as frequently as once a day.

With the first detections, physicists used LIGO's data to confirm Einstein's general theory of relativity in a more extreme environment than ever before. "That's a triumph," says Loeb. But future detections will add even more precision to tests of general relativity. Any deviation from expectations could signal some way in which Einstein's theory breaks down. The equations of general relativity also suggest that black holes have no "hair," or distinguishing characteristics aside from mass, electric charge and angular momentum. But this leads to a conundrum about what happens to information swallowed up by the black hole (*SN: 10/3/15, p. 10*). In the future, scientists could use gravitational waves to test whether the no-hair theorem is true.

The discovery "injected a lot of momentum in the field," says Emanuele Berti, an astrophysicist at the University of Mississippi in Oxford.

Another gravitational wave detector, Virgo, in Italy, is undergoing upgrades and should be switched on in 2017 (*SN: 3/5/16, p. 24*). The trio of detectors — Virgo, plus LIGO's two — will give scientists the ability to locate the sources of gravitational waves on the sky. The government of India is also taking steps toward creating a gravitational wave observatory. And related projects are garnering more attention: Results announced in June from the European Space Agency's LISA Pathfinder satellite demonstrated the technological capabilities needed to search for gravitational waves not from the ground but from space (*SN Online: 6/7/16*).

If researchers can triangulate the source of the waves, they can point telescopes in that direction to spot any luminous aftermath. Such a signal would be unexpected for shadowy black holes, but they aren't the only source. Scientists expect to find undulations from smashups of neutron stars, which might produce detectable light. If luck is on LIGO's side and a star explodes within the Milky Way, LIGO may be able to spot its gravitational fallout, too.

Combining gravitational waves with other messengers from space, including various wavelengths of light and particles such as neutrinos, will create a diverse toolkit for observing the cosmos. Scientists may even find unforeseen sources of gravitational waves, says Loeb. "There is a chance that our imagination is limited." ■

Public health checkup

Drug use continued to threaten the health and safety of the American public in 2016, while a hidden menace in drinking water remained a major worry for the people of Flint, Mich.

Teen vaping

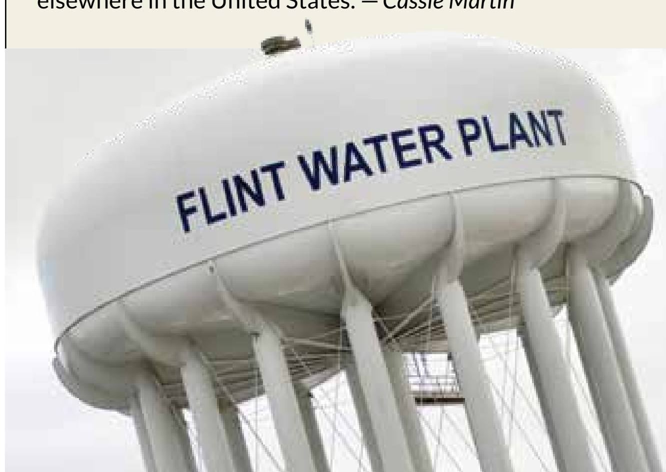
Vaping has surpassed cigarette smoking among U.S. high school students, according to a report released in 2016 from the National Youth Tobacco Survey. Estimates suggest that some 2.39 million U.S. high school kids vaped in 2015, compared with an estimated 1.37 million who smoked cigarettes (*SN: 5/28/16, p. 4*). The popularity of e-cigarettes has increased recently despite a lack of evidence showing that they are safer than conventional tobacco products, according to the U.S. Food and Drug Administration, which in May extended its regulatory authority to e-cigarettes. Studies reported in 2016 show a host of potential health risks, including effects on the brain, immune system and fertility (*SN: 3/5/16, p. 16*).

Opioid epidemic

Against a backdrop of rising prescription opioid addiction, deaths related to opioid use have become an issue of national importance. A surge in fentanyl-spiked drugs emerged as a primary concern in 2016 (*SN: 9/3/16, p. 14*). U.S. deaths from synthetic opioids rose from 3,105 in 2013 to 5,544 in 2014, a change that could not be explained by fentanyl prescription rates, according to a report released in August by the Centers for Disease Control and Prevention. Drug enforcement seizures involving fentanyl more than doubled from 2014 to 2015.

Fallout in Flint

After lead in the drinking water in Flint, Mich., launched a public health crisis (*SN: 3/19/16, p. 8*), a federal state of emergency remained in effect into August. The most recent tests conducted by the U.S. Environmental Protection Agency show that levels of lead, which is toxic to the brain, are below those considered dangerous and that filtered tap water is safe to drink. Many residents are still relying on bottled water, however. There's also growing concern that lead contamination and testing is not being taken seriously elsewhere in the United States. — *Cassie Martin*



LINDA PARTON/SHUTTERSTOCK

News

ATOM & COSMOS

Physicists detect gravitational waves

LIGO experiment's discovery opens new window to the cosmos

BY ANDREW GRANT

WASHINGTON — Tremors in the cosmic fabric of space and time have finally been detected, opening a new avenue for exploring the universe.

The historic discovery of those tremors, known as gravitational waves, comes almost exactly a century after Albert Einstein first posited their existence. Researchers with the Advanced Laser Interferometer Gravitational-Wave Observatory, or Advanced LIGO, announced the seminal detection February 11 at a news conference and in a paper in *Physical Review Letters*. The gravitational swell originated more than 750 million light-years away, where the high-speed dance of two converging black holes shook the very foundation upon which planets, stars and galaxies reside.

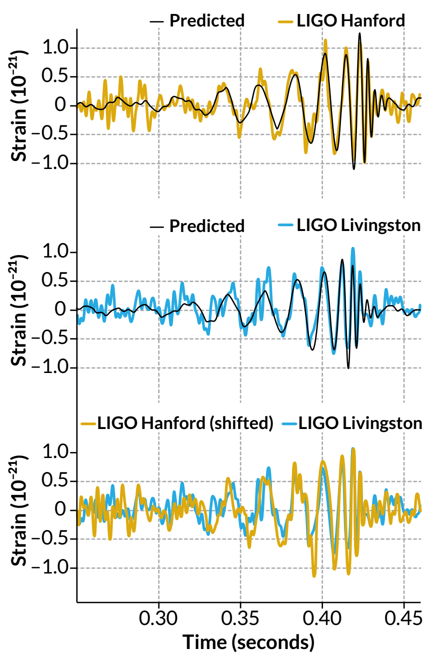
"It's the first time the universe has spoken to us through gravitational waves," LIGO laboratory executive director David Reitze said.

The discovery immediately becomes a likely candidate for a Nobel Prize, and not just because it ties a neat bow around decades of evidence supporting a major prediction of Einstein's 1915 general theory of relativity. "Gravitational waves allow us to look at the universe not just with light but with gravity," says astrophysicist Shane Larson of Northwestern University in Evanston, Ill. Gravitational waves can expose the gory details of black holes and other extreme phenomena that can't be obtained with traditional telescopes. With this discovery, the era of gravitational wave astronomy has begun.

The detection occurred September 14, 2015, four days before the official start of observations for the newly upgraded LIGO. Striking gold so quickly raises hopes for an impending flurry of sightings.

The fleeting burst of waves arrived on Earth long after two black holes, one about 36 times the mass of the sun and the other roughly 29, spiraled toward each other and coalesced. If Isaac Newton had been right about gravity, then the mass of the two black holes would have exerted an invisible force that pulled the objects together. But general relativity maintains that those black holes merged because their mass indented the fabric of space and time (*SN: 10/17/15, p. 16*). As the black holes drew near in a deepening pit of spacetime, they also churned up that fabric, emitting gravitational radiation (or gravity waves, as scientists often call them). Unlike more familiar kinds of waves, these gravitational ripples don't travel "through" space; they are vibrations of spacetime itself, propagating outward in all directions at the speed of light.

Nearly every instance of an object accelerating generates gravity waves — you produce feeble ones getting out of bed in the morning. Advanced LIGO is fine-tuned to home in on more detectable (and scientifically relevant) fare: waves emitted from regions where a lot of mass is packed into small spaces and moving very quickly. The colliding black holes certainly qualify. Their tremendous mass was packed into spheres about 150 kilometers in diameter. By the time the black holes experienced their final unifying plunge, they were circling each other at about half the speed of light. On September 14 at 4:50 a.m. Eastern time, the gravity waves emitted by the black holes during their last fractions of a second of independence encountered the two L-shaped LIGO detectors.



Clear signal The LIGO detectors registered nearly identical signals (top and middle) almost simultaneously as gravity waves from a black hole collision passed by the Earth. The signals closely match predictions.

LIGO

LIGO's detectors in Hanford, Wash., and Livingston, La., newly reactivated after five years of upgrades, each consist of a powerful laser that splits into two perpendicular, 4-kilometer-long beams (see Page 22). When the gravitational waters of spacetime are calm, the beams recombine at the junction and cancel each other out — the troughs of one beam's 1,064-nanometer waves of laser light completely negate the crests of the second beam's waves.

But the gravitational disturbance from the black hole pair distorted spacetime, slightly squeezing one arm of the detector while stretching the other (*SN: 1/8/00, p. 26*). When the beams recombined, the light no longer matched up perfectly. The detectors sensed that crest missed trough by the tiniest of distances, about a thousandth the diameter of a proton.

The LIGO facilities registered the signal just 7 milliseconds apart, indicating a light-speed pulse from deep space rather than a slower-moving vibration from an underground quake or a big rig rumbling along the highway. Physicists used the combined measurements to estimate a distance of 750 million to 1.8 billion light-years to the black holes, with 1.3 billion light-years as the best estimate. At least one more detector, preferably two, would have been needed to triangulate the precise location of the black holes in the sky.

While the black hole rendezvous was millions of years in the making, only the final two-tenths of a second produced gravity waves with the requisite intensity and frequency for detection by Advanced LIGO. Those two-tenths of a second told quite a story. At first, the black holes were circling each other about 17 times a second; by the end, it was 75. The gravity wave frequency and intensity reached a peak, and then the black holes merged.

Combining the wave measurements with computer simulations, the scientists determined that a pair of 36- and 29-solar-mass black holes had become one 62-solar-mass beast. The missing mass had been transformed into energy and carried away as gravity waves. The power output during that mass-energy conversion was 50 times greater than that of all the stars in the universe combined.

The observed LIGO signal matches what physicists expected from a black hole merger almost perfectly. Ingrid Stairs, an astrophysicist at the University of British Columbia in Vancouver who was not involved with LIGO, says she and colleagues were "bowled over by how beautiful it was." Translated into sound, the signal resembled a rumbling followed by a chirp. "It stood out like a sore thumb," says Rainer Weiss, one of the primary architects of LIGO. The 83-year-old physicist had visited Livingston just days before and almost shut down the detector to fix some minor problems. Had he done so, "we would have missed it."

Despite the seeming no-doubt signal, LIGO researchers conducted a series of rigorous statistical tests. The signal survived. "I have great confidence in the team as a whole and everything they've done with the data," Stairs says.

LIGO's announcement falls between two relevant centennials: Einstein's introduction of general relativity (November 1915) and his prediction of gravitational waves (June 1916, though he had to fix the math two years later). Russell Hulse and Joseph Taylor Jr. won the 1993 Nobel Prize in physics for deducing gravity wave emission based on the motion of a stellar corpse called a neutron star and a closely orbiting companion. Now Advanced LIGO has sealed the deal with the first direct measurement.

The observatory achieved what its predecessor, which ran from 2001 to 2010, could not because of an upgrade that enhanced sensitivity by at least a factor of three. Increased sensitivity translates to identifying more distant objects: If the search area of first-generation LIGO included all the space that could fit within a baseball, Advanced LIGO could spot everything inside a basketball. Advanced LIGO's range extends up to 5 billion light-years in all directions for merging objects about 100 times the mass of the sun, project leader David Shoemaker of MIT says. That extended reach, plus a boost in sensitivity at the wave frequencies associated with black holes, enabled the detection.

This ability to examine black holes and other influential dark objects without actually "seeing" them with light has scientists excited about the gravitational wave era. Black holes gobble up some matter and launch the rest away in powerful jets, scattering atoms within and between galaxies; pairs of neutron stars, also targets of Advanced LIGO, may ultimately trigger gamma-ray bursts, among the brightest and most energetic explosions known in the universe.

Yet while the influence of these cosmic troublemakers is sometimes visible with traditional telescopes, the objects themselves are not. Gravity waves offer a direct probe, and as a bonus they don't get impeded by gas, dust and other cosmic absorbers as light does. "It opens up a new window into astronomy that we never had," says John Mather, a Nobel-winning astrophysicist in attendance at the news conference. Before this discovery, scientists had never observed a pair of black holes orbiting each other. A big next step, scientists say, is to observe a nearby supernova or the collision of neutron stars via both gravity waves and light.

Gravitational wave astronomy has begun with the Advanced LIGO detection, but there's lots more to come. LIGO scientists still have three months of data to sort through from their first round of observing, and the analysis of the signal suggests similar events should occur multiple times a year. The researchers are further upgrading the detectors so that

Gravity waves from a black hole collision came from about 1.3 billion light-years away, probably in the direction of the Magellanic clouds.

LIGO

they can spot neutron star and black hole collisions even farther away. The observatory should be back up and running by late summer, says LIGO chief detector scientist Peter Fritschel.

Later this year, European partners of the LIGO collaboration plan to restart their revamped gravity wave observatory, Advanced VIRGO, near Pisa, Italy, providing a crucial third ultrasensitive detector for pinpointing gravity wave sources. Similar detectors are in the works for Japan and India.

LIGO was designed to spot waves in the sweet spot for converging black holes and neutron stars, with a frequency ranging from tens of hertz to several thousand. But just as scientists use radio and gamma-ray telescopes to probe different frequencies of light, physicists are building detectors sensitive to a range of gravity wave frequencies. The eLISA mission, consisting of three satellites, will hunt for waves with frequencies under 1 hertz when it launches in the 2030s. The satellite trio should be able to resolve black holes from the early universe and ones millions of times the mass of the sun.

The LIGO result is distinct from the 2014 claim of a gravity wave detection, since rescinded, by scientists with the BICEP2 telescope (*SN: 2/21/15, p. 13*). BICEP2 hunts for gravity waves with a much lower frequency, signaling reverberations from a split-second span just after the Big Bang called inflation, when space expanded very rapidly. Not detectable directly, these inflation-era gravity waves should be encoded in the universe's earliest light.

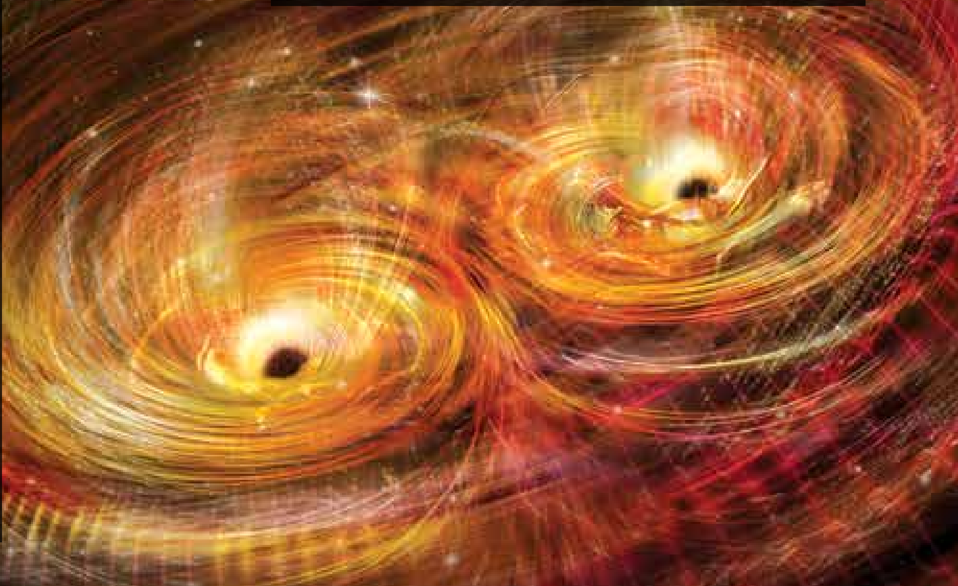
Scientists may well detect those flavors of gravity waves soon. But for now, they can bask in a discovery 100 years in the making. "This was truly a scientific moonshot," Reitze said. "We did it. We landed on the moon." ■

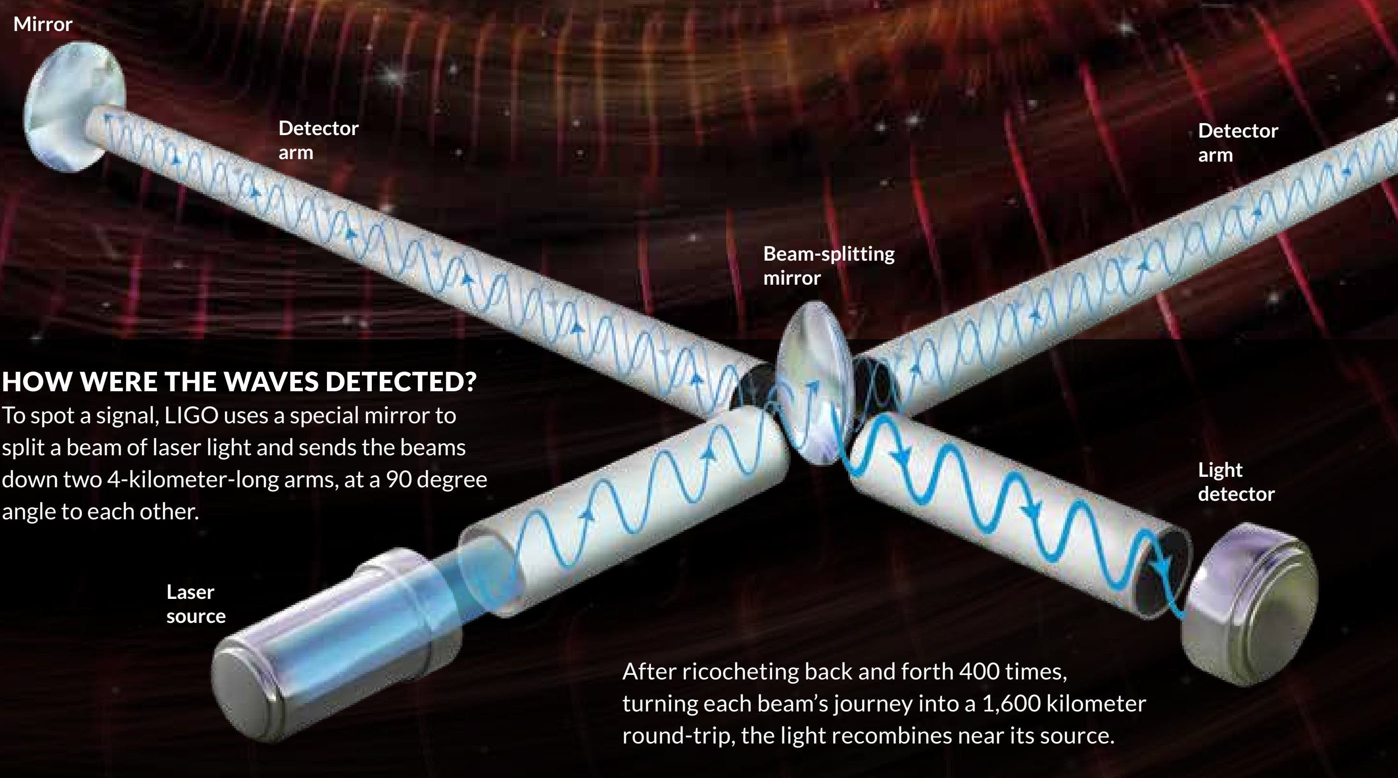
Cosmic **shake-up**

A century after Albert Einstein rewrote our understanding of space and time, physicists have confirmed one of the most elusive predictions of his general theory of relativity. In another galaxy, a billion or so light-years away, two black holes collided, shaking the fabric of spacetime. Here on Earth, two giant detectors on opposite sides of the United States quivered as gravitational waves washed over them. After decades trying to directly detect the waves, the recently upgraded Laser Interferometer Gravitational-Wave Observatory, now known as Advanced LIGO, appears to have succeeded, ushering in a new era of astronomy (see Page 6). —*Christopher Crockett*

WHAT ARE GRAVITATIONAL WAVES?

Colossal cosmic collisions and stellar explosions can rattle spacetime itself. General relativity predicts that ripples in the fabric of spacetime radiate energy away from such catastrophes. The ripples are subtle; by the time they reach Earth, some compress spacetime by as little as one ten-thousandth the width of a proton.





HOW WERE THE WAVES DETECTED?

To spot a signal, LIGO uses a special mirror to split a beam of laser light and sends the beams down two 4-kilometer-long arms, at a 90 degree angle to each other.

After ricocheting back and forth 400 times, turning each beam's journey into a 1,600 kilometer round-trip, the light recombines near its source.

NICOLLE RAGER FULLER

WHERE WERE THE WAVES DETECTED?

LIGO has one detector in Louisiana and another in Washington to ensure the wave is not a local phenomenon and to help identify its source.

WHAT ABOUT OTHER SOURCES?

By studying computer simulations of astrophysical phenomena, scientists can figure out what type of signals to expect from various gravitational wave sources.

Spinning neutron stars

A single spinning neutron star, the core left behind after a massive star explodes, can whip up spacetime at frequencies similar to those produced by colliding black holes.

Supernovas

Powerful explosions known as supernovas, triggered when a massive star dies, can shake up space and blast the cosmos with a burst of high-frequency gravitational waves.

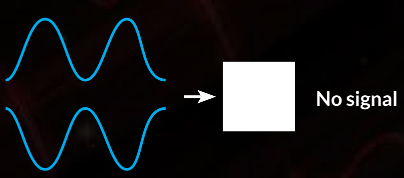
Supermassive black hole pairs

Pairs of gargantuan black holes, more than a million times as massive as the sun and larger than the ones Advanced LIGO detected, radiate long, undulating waves. Though Advanced LIGO can't detect waves at this frequency, scientists might spot them by looking for subtle variations in the steady beats of pulsars.

Big Bang

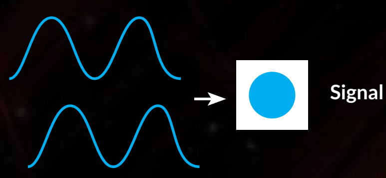
The Big Bang might have triggered universe-sized gravitational waves 13.8 billion years ago. These waves would have left an imprint on the first light released into the cosmos 380,000 years later, and could be seen today in the cosmic microwave background.

Normal situation



The experiment is designed so that, in normal conditions, the light waves cancel one another out when they recombine, sending no light signal to the nearby detector.

Gravitational wave detection



But a gravitational wave stretches one tube while squeezing the other, altering the distance the two beams travel relative to each other. Because of this difference in distance, the recombining waves are no longer perfectly aligned and therefore don't cancel out. The detector picks up a faint glow, signaling a passing wave.