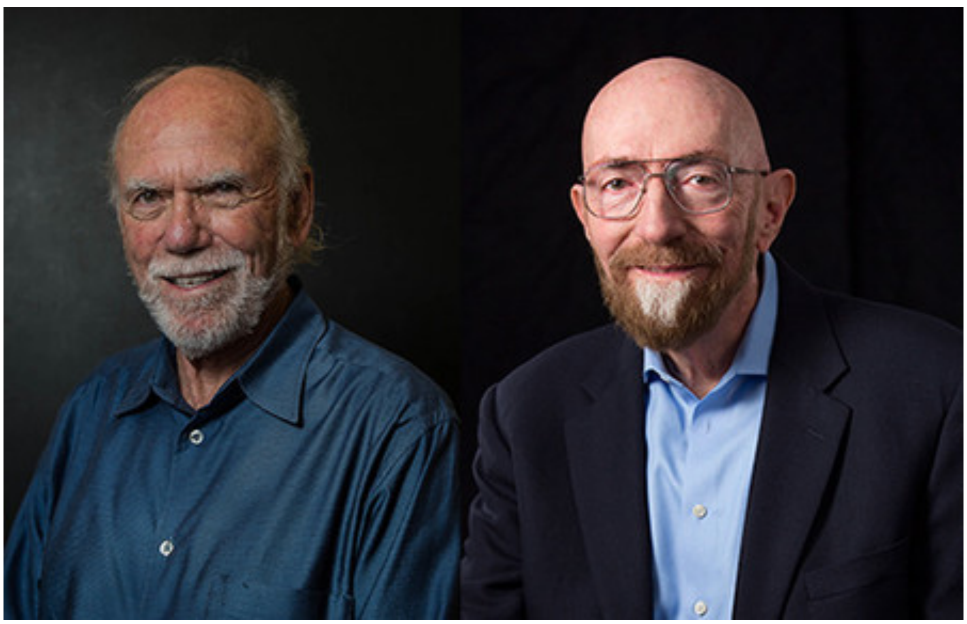
Caltech | Alumni

Caltech Scientists Awarded 2017 Nobel Prize in Physics



The 2017 Nobel Prize in Physics has been awarded to three key players in the development and ultimate success of the Laser Interferometer Gravitational-wave Observatory (LIGO). One half of the prize was awarded jointly to Caltech's Barry C. Barish, the Ronald and Maxine Linde Professor of Physics, Emeritus and Kip S. Thorne (BS '62), the Richard P. Feynman Professor of Theoretical Physics, Emeritus; and the other half was awarded to MIT's Rainer Weiss, professor of physics, emeritus.

Caltech will hold a press briefing at 10:00 am Pacific, which you can view at http://www.ustream.tv/caltech (also linked to the Caltech homepage). We will also go live on both the private alumni facebook group and Instagram.

On September 14, 2015, the National Science Foundation (NSF)-funded LIGO made the first-ever direct observation of gravitational waves—ripples in the fabric of space and time predicted by Albert Einstein 100 years earlier. The public announcement took place on February 11, 2016, in Washington, D.C. Each of the twin LIGO observatories—one in Hanford, Washington, and the other in Livingston, Louisiana—picked up the feeble signal of gravitational waves generated 1.3 billion years ago when two black holes spiraled together and collided. Two additional detections of gravitational waves, once again from merging black-hole pairs, were made on December 26, 2015, and January 4, 2017, and, on August 14, 2017, a fourth event was detected by LIGO and the European Virgo gravitational-wave detector.

The detections ushered in a new era of gravitational-wave astronomy. LIGO and Virgo provided astronomers with an entirely new set of tools with which to probe the cosmos. Previously, all astronomy observations have relied on light—which includes X-rays, radio waves, and other types of electromagnetic radiation emanating from objects in space—or on very-high-energy particles called neutrinos and cosmic rays. Now, astronomers can learn about cosmic objects through the quivers they make in space and time.

The Nobel Prize recognizes Weiss, Barish, and Thorne for their "decisive contributions to the LIGO detector and the observation of gravitational waves."

"I am delighted and honored to congratulate Kip and Barry, as well as Rai Weiss of MIT, on the award this morning of the 2017 Nobel Prize in Physics," says Caltech president Thomas F. Rosenbaum, the Sonja and William Davidow Presidential Chair and professor of physics. "The first direct observation of gravitational waves by LIGO is an extraordinary demonstration of scientific vision and persistence. Through four decades of development of exquisitely sensitive instrumentation—pushing the capacity of our imaginations—we are now able to glimpse cosmic processes that were previously undetectable. It is truly the start of a new era in astrophysics."

Thorne received the call from the Nobel committee this morning at 2:15 a.m. Pacific Daylight Time.

"The prize rightfully belongs to the hundreds of LIGO scientists and engineers who built and perfected our complex gravitational-wave interferometers, and the hundreds of LIGO and Virgo scientists who found the gravitational-wave signals in LIGO's noisy data and extracted the waves' information," Thorne says. "It is unfortunate that, due to the statutes of the Nobel Foundation, the prize has to go to no more than three people, when our marvelous discovery is the work of more than a thousand."

Barish received the call from the Nobel committee this morning at 2:45 a.m. Pacific Daylight Time.

"I am humbled and honored to receive this award," says Barish. "The detection of gravitational waves is truly a triumph of modern large-scale experimental physics. Over several decades, our teams at Caltech and MIT developed LIGO into the incredibly sensitive device that made the discovery. When the signal reached LIGO from a collision of two stellar black holes that occurred 1.3 billion years ago, the 1,000-scientist-strong LIGO Scientific Collaboration was able to both identify the candidate event within minutes and perform the detailed analysis that convincingly demonstrated that gravitational waves exist."

An Idea That Began Decades Ago

Einstein predicted in 1916 that gravitational waves would exist, but thought them too weak to ever be detected. By the 1960s, technological advances such as the laser and new insights into possible astrophysics sources made it conceivable that Einstein was wrong and that gravitational waves might actually be detectable.

The first person to build a gravitational-wave detector was Joseph Weber of the University of Maryland. Weber's detectors, built in the 1960s, used large aluminum cylinders, or bars, that would be driven to vibrate by passing gravitational waves. Other researchers elsewhere, including the late Ronald W. P. Drever at the University of Glasgow in Scotland—later a professor of physics at Caltech—soon followed Weber's lead.

When those experiments proved unsuccessful, the focus of the field began shifting to a different type of detector called a gravitational-wave interferometer, invented independently by Weiss at MIT and, in rudimentary form, by several others. In this instrument, gravitational waves stretch and squeeze space by an infinitesimal amount while widely separated mirrors hanging by wires "ride" the oscillations, moving apart and together ever so slightly. This mirror motion is measured with laser light using a technique called interferometry.

In the late 1960s, Weiss began laying conceptual foundations for these interferometers. In parallel, Thorne, along with his students and postdocs at Caltech, worked to improve the theory of gravitational waves, and estimated the details, strengths, and frequencies of the waves that would be produced by objects in our universe such as black holes, neutron stars, and supernovas.

In 1972, Thorne, with his student Bill Press (MS '71, PhD '73), published the first of many articles that would appear over the next three decades, summarizing what was known about the gravitational-wave sources and formulating a vision for gravitational-wave astronomy.

"LIGO would not exist without Kip's vision for the scientific potential of gravitational waves and his amazing gift for sharing that vision with other scientists," says Stan Whitcomb (BS '73), the chief scientist for the LIGO Laboratory at Caltech, who began working on the project in 1980.

Also in 1972, Weiss published a detailed analysis of his interferometers. He identified all of the major obstacles that could prevent the instruments from detecting gravitational waves, such as vibrations of the earth and of the mirrors, and he invented techniques to deal with each obstacle. At this stage, it became evident that large interferometers, several kilometers or more in size, might possibly prove successful—as, indeed, they ultimately did with LIGO and its 4-kilometer-long arms. Also evident was the fact that perfecting the interferometers would be exceedingly difficult: a passing gravitational wave would induce mirror motions 1,000 times smaller than a proton, and these infinitesimal changes would have to be measured. That's 100 million times smaller than an atom, and a trillion times smaller than the wavelength of the light being used in the measurement.

Triggered by Weiss's work, Drever's research group in Glasgow switched from bars to interferometers, as did a research group in Garching, Germany, led by Heinz Billing. By 1975, there were three prototype interferometers under development at MIT, Glasgow, and Garching.

A Fateful Hotel Room Discussion

At first Thorne was skeptical of Weiss's interferometer idea. "I even wrote, in a textbook, that it was not very promising," he says. But that changed when Thorne studied, in depth, Weiss's 1972 analysis. Thorne came to call it a "tour de force" and a "blueprint for the future."

In 1975, Weiss invited Thorne to speak at a NASA committee meeting in

Washington, D.C., about cosmology and gravitation experiments in space. Hotel rooms that summer were fully booked, so the two shared a room, where they stayed up all night talking. Thorne came away so excited by the experimental prospects that he went home and proposed creating an experimental gravity group at Caltech to work on interferometers in parallel with MIT, Glasgow, and Garching. Caltech then brought Drever on board in 1979 to lead the new experimental effort, because, as Thorne says, they knew his inventiveness would prove crucial to LIGO's success. Soon thereafter, in 1980, Caltech hired a young Chicago astrophysicist, Whitcomb, to assist in the leadership.

"What a pleasure it was to have this brilliant, budding experimental group working alongside my theory group at Caltech," says Thorne. "Those were heady days."

Together, Drever and Whitcomb led the design and construction of a 40-meter interferometer at Caltech—a prototype to test and perfect the ideas of Weiss, Drever, and others, including the teams at Glasgow and Garching.

Meanwhile, Thorne and his theory students—in collaboration with the late Vladimir Braginsky of Moscow State University, a regular Caltech visitor over three decades—were analyzing various sources of noise that the big interferometers would face, especially "quantum noise," or random fluctuations of the mirrors' positions predicted by quantum theory. They were coming up with ways to deal with those fluctuations.

In 1984, all of this parallel work came together. Caltech and MIT, with encouragement from the NSF, formed a collaboration to design and build LIGO. Rochus E. (Robbie) Vogt, Caltech's R. Stanton Avery Distinguished Service Professor and Professor of Physics, Emeritus, was recruited in 1987 as LIGO's first director. Vogt led the merging of the Caltech and MIT experimental groups; the early planning for LIGO; the writing of a proposal to NSF to fund the project; and the education of Congress about this high-risk project with a potentially exceedingly high payoff. In 1992, Congress allocated the first major funding. "NSF and Congress have backed LIGO unwaveringly ever since," says Thorne.

Scaling up LIGO

Building LIGO was a tremendous challenge—logistically and technically. To meet this challenge, Caltech and MIT later recruited, as LIGO's second director, Barry Barish, who at that time had been the leader of several very large high-energy physics projects. Barish developed the first high-energy neutrino beam experiment at Fermilab near Chicago and was one of the leaders of a large international collaboration that performed a search for magnetic monopoles—magnetic analogs of single electric charges that, if found, would help confirm the Grand Unified Theory that seeks to unify the electromagnetic, weak, and strong forces. The experiment, called MACRO (Monopole, Astrophysics and Cosmic Ray Observatory), did not find magnetic monopoles but set the most stringent limits on their existence. Barish then led the design of one of the two detectors planned for another big science project, the Superconducting Super Collider—a particle accelerator to be built in Waxahachie, Texas. The accelerator was canceled during construction in 1993, after which Barish took on the challenge of LIGO, becoming its principal investigator in 1994, and then its director in 1997.

"I always wanted to be an experimental physicist and was attracted to the idea of using continuing advances in technology to carry out fundamental science experiments that could not be done otherwise," says Barish. "LIGO is a prime example of what couldn't be done before. Although it was a very large-scale project, the challenges were very different from the way we build a bridge or carry out other large engineering projects. For LIGO, the challenge was and is how to develop and design advanced instrumentation on a large scale, even as the project evolves."

"Barish, in my opinion, is the most brilliant leader of large science projects that physics has ever seen," says Thorne.

Barish ushered LIGO through its final design stages and secured funding through NSF's National Science Board. He oversaw construction of the two LIGO facilities from 1994 to 1999, and then the installation and commissioning of the initial LIGO interferometers from 1999 to 2005. The scaling up from Caltech's 40-meter prototype to LIGO's 4-kilometer interferometers was such a huge undertaking that it was carried out in two steps. First, the team built initial interferometers, which operated from 2002 to 2010, at a sensitivity that Barish characterized as being at a level where detections were "possible." This first step demonstrated the observatory's basic concepts and solved many technical obstacles. The development and approval of the next phase of LIGO, called Advanced LIGO, was also led by Barish and then-LIGO Laboratory deputy director Gary Sanders, and was designed to be sensitive to a level at which detections were "probable." Advanced LIGO was commissioned and built between 2010 and 2015. Though Barish left LIGO in 2006 to become director of the Global Design Effort for the International Linear Collider, he would rejoin the LIGO team in 2012, in time for the project's historic discovery in 2015. After Barish left, LIGO was led by Jay Marx of Caltech, followed by current executive director, Caltech's David H. Reitze.

"LIGO had to make the change from tabletop science to a real science facility," says Whitcomb. "Barry understood what was needed, and he guided that transformation without ever losing sight of the scientific goals."

Under Barish's leadership, several key technologies were developed that ultimately led to the detection of gravitational waves. For the first phase of LIGO, now referred to as Initial LIGO, he chose to use solid-state lasers rather than the gas lasers that were more commonly in use at that time. These solid-state lasers were the basis of more powerful versions developed for Advanced LIGO. He also oversaw the development of technologies for reducing unwanted movements in LIGO's mirrors, caused by earthquakes, passing trucks, and other ground vibrations.

"In the initial phase of LIGO, in order to isolate the detectors from the earth's motion, we used a suspension system that consisted of test-mass mirrors hung by piano wire and used a multiple-stage set of passive shock absorbers, similar to those in your car. We knew this probably would not be good enough to detect gravitational waves, so we, in the LIGO Laboratory, developed an ambitious program for Advanced LIGO that incorporated a new suspension system to stabilize the mirrors and an active seismic isolation system to sense and correct for ground motions," says Barish.

The active seismic isolation system developed for Advanced LIGO works in a similar fashion to noise-canceling headphones, except it can measure and cancel out ground vibrations coming from many directions. In conjunction with this system, a new "quieter" way to suspend LIGO's mirrors was developed with the help of the Glasgow group, which involved hanging the mirrors with a four-stage pendulum. The combination of these two advances gave LIGO a huge improvement in sensitivity to lower frequencies of gravitational waves, which was ultimately what was needed to detect the crashing of two black holes.

Barish also created the LIGO of today: a collaboration of approximately 1,200 scientists and engineers at about 100 institutions in 19 nations called the LIGO Scientific Collaboration (LSC).

"In addition to picking the right technologies and developing them, and securing funding, we needed to build a collaboration of the absolute best people possible for this almost impossible project," says Barish. "Forming an international collaboration, the LSC, enabled this. We attracted the best people from other universities and countries, creating an 'equal opportunity' collaboration, where there was no advantage to being at Caltech or MIT." The LSC conducted the scientific searches and analysis that led to the LIGO discovery.

While this experimental work was taking place, theorists outside Caltech, MIT, and the LIGO project were developing computer codes to simulate the massive collisions of black holes and other sources of gravitational waves that LIGO might detect. These simulations are essential to LIGO; by comparing the shapes of the waves that LIGO observes with the simulations' predicted wave shapes, LIGO scientists can figure out what produces the observed waves. In the early 2000s, Thorne became alarmed at the slow progress on simulations and so with then-Caltech physicist Lee Lindblom, he created a research group at Caltech in collaboration with a group at Cornell University led by his former student Saul Teukolsky (PhD '74), who is now jointly the Robinson Professor of Theoretical Astrophysics at Caltech and Hans A. Bethe Professor of Physics and Astrophysics at Cornell University. By 2015, this SXS (Simulating eXtreme Spacetimes) project was simulating the collisions of black holes with ease, as were several other research groups.

On September 14, 2015, just after the Advanced LIGO interferometers began their first search for gravitational waves, they captured a strong signal. Comparison with the SXS simulations revealed that the signal was from the collision of two hefty black holes 29 and 36 times more massive than the sun and located 1.3 billion light-years from Earth. The waves carried away as much energy as would be produced by annihilating three suns. After intense scrutiny of the results, the LIGO scientists announced this discovery to the world on February 11, 2016.

"I'm positively delighted that the Nobel Committee has recognized the LIGO discovery and its profound impact on the way we view the cosmos," says Reitze. "This prize rewards not just Kip, Barry, and Rai but also the large number of very smart and dedicated scientists and engineers who worked tirelessly over the past decades to make LIGO a reality."

"LIGO was a huge technical and scientific gamble," says Fiona Harrison, the Benjamin M. Rosen Professor of Physics and the Kent and Joyce Kresa Leadership Chair in Caltech's Division of Physics, Mathematics and Astronomy. "But it paid off in spades with one of the most dramatic discoveries in decades. The entire LIGO team should be celebrating today."

The 2017 Nobel Prize in Physics represents the 37th and 38th Nobel Prizes awarded to Caltech faculty and alumni. Current Caltech faculty with Nobel Prizes include: Robert Grubbs, winner of the 2005 Nobel Prize in Chemistry with Yves Chauvin and Richard R. Schrock; David Politzer, recipient of the 2004 Nobel Prize in Physics with David J. Gross and Frank Wilczek; Rudy Marcus, sole winner of the 1992 Nobel Prize in Chemistry; and David Baltimore, winner of the 1975 Nobel Prize in

Physiology or Medicine, with Renato Dulbecco and Howard M. Temin.

In 2016, Drever, Thorne, and Weiss won the Kavli Prize in Astrophysics, the Shaw Prize in Astronomy, the Gruber Foundation Cosmology Prize, and the Special Breakthrough Prize in Fundamental Physics. In 2017, Barish, Thorne, and Weiss won the Princess of Asturias Award for Technical and Scientific Research and the European Physical Society's Giuseppe and Vanna Cocconi Prize.

Barish was born on January 27, 1936, in Omaha, Nebraska, and spent his childhood in Los Angeles. He received his BA in physics in 1957 and his PhD in experimental particle physics in 1962, both from UC Berkeley. In 1963, he joined Caltech as a research fellow. He became an assistant professor in 1966, an associate professor in 1969, and a professor of physics in 1972. He was named the Ronald and Maxine Linde Professor of Physics in 1991 and Linde Professor, Emeritus, in 2005. He is a member of the National Academy of Sciences, and a fellow of the American Academy of Arts and Sciences, the American Association for the Advancement of Science, and the American Physical Society, the latter of which he served as president. In 2002, he received the Klopsteg Memorial Lecture Award from the American Association of Physics Teachers and, in 2016, he received the Enrico Fermi Prize from the Italian Physical Society. He won the Henry Draper Medal in 2017 with Whitcomb. For a full biography, click here.

Thorne was born on June 1, 1940, in Logan, Utah. He received a bachelor's degree in physics from Caltech in 1962 and a PhD in physics from Princeton University in 1965. He joined Caltech as a research fellow in 1966, and joined the faculty in 1967 as an associate professor of theoretical physics. In 1970, he became a professor of theoretical physics. In 1991, he was named the Richard P. Feynman Professor of Theoretical Physics. He retired in 2009. Thorne has coauthored or authored several books, including *Black Holes and Time Warps: Einstein's Outrageous Legacy*, published in 1994. He served as an executive producer and science adviser for the 2014 film *Interstellar*. He is a member of the National Academy of Sciences, the American Physical Society, the American Academy of Arts and Sciences, and the American Philosophical Society. On October 11, 2017, Thorne will publish the textbook *Modern Classical Physics,* coauthored with Roger Blandford. For a full biography, click here.

More information about LIGO's many partners is online here.

To date, 37 Caltech alumni and faculty have won a total of 38 Nobel Prizes.

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