Testimony of

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on

Unlocking the Secrets of the Universe: Gravitational Waves

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Chairman Lamar Smith, Ranking Member Eddie Bernice Johnson, and Members of the Committee thank you for holding this very important hearing, and inviting me to participate today. I thank the Committee for its interest in Gravitational Waves and LIGO, and the amazing discovery we have made.

INTRODUCTION

My name is David Reitze and I am the Executive Director of the Laser Interferometer Gravitational-wave Observatory (LIGO) based at Caltech in Pasadena, CA. On February 11, 2016, my colleagues and I announced to the world the first direct detection of gravitational waves. These waves came from the collision of two black holes occurring 1.3 billion light years from earth. This is a stunning discovery, which occurred on September 14, 2015, and comes almost one hundred years after Einstein published his General Theory of Relativity that predicted gravitational waves. It was made possible after a dedicated forty-year scientific quest funded by the National Science Foundation (NSF) with Congressional support to design and build LIGO.

LIGO is the most precise scientific instrument ever developed. Using ultrastable laser interferometry (which I explain below), we are able to measure changes in distance to a tiny fraction of the width of a nucleus of an atom. This is a feat comparable to measuring the distance between our Sun and the nearest star to better then the width of human hair. And it has allowed us for the first time to detect, in the form of simple gravitational waves, a completely new astrophysical object from the ‘dark side’ of the universe.

LIGO BACKGROUND

Like many great scientific discoveries, LIGO had humble beginnings. In the 1960s, Joseph Weber at the University of Maryland pioneered the effort to search for gravitational waves, using large cylinders of aluminum that vibrate in response to a passing wave. His experiments were ultimately unsuccessful, but led to efforts in the late 1960s and early 1970s by Rainer Weiss of MIT and Ron Drever and James Hough of the University of Glasgow to propose and investigate interferometry as a gravitational wave detector. Around the same time, Kip Thorne created a research group at Caltech working on the theory of gravitational waves and their astrophysical sources.

In 1980, the National Science Foundation funded the construction of a 40-meter long prototype interferometer at Caltech led by Ron Drever and Stan Whitcomb, and a smaller 1.5 meter long prototype at MIT directed by Rai Weiss. NSF also funded Weiss to design and lead a technical and cost study for a large scale, several-kilometer-long interferometer. In 1984 Caltech and MIT signed an agreement for the joint design and construction of LIGO, with administrative headquarters at Caltech, and with joint leadership by Drever, Weiss and Thorne.

When LIGO was first proposed as a large-scale project in the mid-1980s, it was met with great resistance and skepticism. Some in the astronomical community deemed the project too risky and too expensive, and felt that gravitational waves would never be detected. The chance of failure was perceived to be too high, and the scientific payoff too low relative to more established types of astronomy to justify the expenditure. Nonetheless, NSF and in particular Richard Isaacson and Marcel Bardon recognized both the huge scientific potential in gravitational wave physics and astronomy and the cutting edge technology that could result from designing and building a gravitational wave detector.

In 1990 the National Science Board approved LIGO construction, and in 1991 Congress appropriated LIGO's first year of funding. In 1992 Hanford, Washington and Livingston, Louisiana were chosen as the sites for LIGO's interferometers, and a cooperative agreement for the management of LIGO was signed between NSF and Caltech. In 1994 Caltech's Barry Barish was appointed LIGO Director and oversaw LIGO's construction phase as well as the installation and commissioning of LIGO's initial interferometers (1999-2002) and its first few gravitational wave searches (2002-2005). In 1997, the LIGO Scientific Collaboration was created to organize and coordinate LIGO's technical and scientific research and data analysis, and for expanding LIGO to include scientists elsewhere, beyond Caltech and MIT.

THE SCIENCE BEHIND LIGO

Let me now turn to the science of LIGO. This is what excites us the most! General relativity tells us that space-time is warped, that gravity is geometric, and that black holes exist. These are complex concepts, deriving from a mathematically intricate but elegant theory. It also predicts the existence of gravitational waves. Gravitational waves are ripples in space-time emitted by objects undergoing accelerations. A simple analogy to understand gravitational waves is this – drop a stone in a pond. Imagine the stone is the object and the surface of the pond is space (but in two, not three dimensions). When the stone hits the surface of the pond, it rapidly decelerates and slows down, losing energy as it produces outward ripples on the pond.

Gravitational waves are somewhat similar, although their effect on space is mind-bogglingly tiny. To make gravitational waves that can be detected by LIGO, it takes massive cosmic objects such as black holes or neutron stars colliding with one another or supernovae. Even then, the size of the emitted wave is incredibly tiny, requiring instruments that can accurately detect changes to better than *one one-billionth of one one-billionth* of a meter. The gravitational waves that LIGO detected on September 14 produce a change in distance in our detectors less than 5/1000 the diameter of a proton.

It is worth pointing out that even though Einstein derived the existence of gravitational waves as a natural consequence of general relativity in 1916, he himself doubted they would ever be detected because the waves are so incredibly small. It has taken new technologies and the ingenuity and dedication of over 1000 scientists and engineers to make this detection a reality.

To detect gravitational waves, LIGO uses two interferometers, each having 4 km long arms configured in an L-shape. In this simplified representation, an infrared laser beam from the world's most stable lasers is sent toward a partially reflecting mirror and split. When the gravitational wave passes, the space between the beamsplitter and the end mirrors stretches along one arm and compresses along the other arm, producing a signal.

The two beams are split equally and travel in a vacuum system over a 4 km distance to end mirrors and return to interfere again. When no gravitational waves are present, the light waves combine in such a way that no light is sent to the detector. When a gravitational wave passes, the light experiences constructive interference at the beamsplitter to produce a signal at the detector. The signal we measured is in the audio frequency range – humans can hear this signal!

Because LIGO's interferometers are so incredibly sensitive, they are susceptible to other forces and events that can produce signals that can mimic gravitational waves. This demands that we use two independent interferometers separated by almost 2000 miles to detect gravitational waves.

THE SIGNIFICANCE OF THE DISCOVERY

The detection of gravitational waves by LIGO is in and of itself an incredible scientific and engineering accomplishment, proving that they can be directly measured and that general relativity has once again triumphed as *the* theory of gravity. However, this detection is much more than that. The signal that LIGO detected (we call it a chirp) captured the end stage of two stellar mass black holes locked in orbit and spiraling in toward each other until they collided and united to form a new larger black hole and producing, as my colleague Kip Thorne calls, it ‘a storm in space time’. Up until this point, humanity has never observed this storm before. Indeed, until now we had not even confirmed that black holes could exist in pairs.

In essence, LIGO is a new kind of astronomical receiver, similar to a radio telescope, which can directly "hear" the vibrations in space-time produced by colliding black holes and other cosmic cataclysms. The gravitational-wave window opened by LIGO differs dramatically from all previous windows. The previous windows - optical, radio, and X-ray, all used radiation made from oscillating electric and magnetic fields. LIGO, by contrast, uses an entirely new kind of radiation: gravitational waves.

LIGO should be able to detect not only the two black holes of September 14, each tens of times more massive than our Sun, colliding with each other at nearly the speed of light, but also many other phenomena. We expect to discover black holes that rip apart neutron stars, and two neutron stars that spiral together, collide, merge, and then implode to form a black hole - and that generate short bursts of gamma rays. We are also searching for waves from massive stars exploding in our galaxies -- central engines of supernova explosions, as well as waves produced by cosmic strings that stretch across the universe - gigantic strings thought to have been created in the big bang by the inflation of fundamental strings, the building blocks of all matter.

IMPACT ON U.S. SCIENTIFIC ENTERPRISE

While the discovery of gravitational waves is a triumph of science and engineering, it is natural to ask ‘so what?’ or perhaps more specifically ‘what are the past returns for the $1.1 billion United States investment in LIGO? What will we get going forward?’ Setting aside the excitement that comes from exploring our cosmos, the deep sense of satisfaction in learning how it works, and the awe it inspires, there are near term benefits, both tangible and intangible, that have come from these efforts.

First, LIGO leads the world in this new form of astronomy. In addition to the two LIGO detectors, large-scale interferometers are currently under construction in Italy and Japan, which will join in the search for gravitational waves in the coming years. India has just announced that it will partner with the LIGO Laboratory to construct a third LIGO Observatory in India, expected to be operational early in the next decade. The world is following the US into this new scientific frontier.

In addition, to make LIGO work, we had to develop the world’s most stable lasers, the world’s best mirrors, some of the world’s largest vacuum systems, as well as push the frontiers of quantum science and high performance computing. LIGO advances the state-of-the-art in every technology it uses, and it uses lots of technology. We have partnered with many commercial technology firms in the US and abroad to produce the incredible technology that LIGO uses.

In addition, the LIGO detectors produce almost 1 petabyte (one million gigbytes) of data per year – it is a Big Data generator. To search through that data, LIGO scientists develop and employ sophisticated state of the art computer algorithms and high throughput computing to search through the data and reveal these miniscule signals. Numerical solutions of the equations of general relativity to model binary black hole mergers and supernovae require high performance supercomputers as provided by NSF's XSEDE and Blue Waters program.

However, I believe that the largest impact from LIGO has been in scientific workforce development --- the education of scientists and engineers over the past forty years. Funding from the NSF has produced over 100 Ph. D.s in Physics from Caltech and MIT alone, along with many more from leading US research universities in the LIGO Scientific Collaboration. Many scientists have chosen to stay with LIGO and pursued academic careers driven by their passion for fundamental research. Others have moved on to distinguished, productive careers at NASA and national laboratories such Lawrence Livermore National Laboratory. Silicon Valley giants and start ups, defense and aerospace industries, biotechnology and telecommunications, and even investment banks all have employed Ph. D.s trained at LIGO. Still others have become K-12 educators. Nearly 500 undergraduate students have worked with LIGO scientists through summer research programs over the past 15 years, allowing them to explore careers in research.

And every year, LIGO's educational programs based at our Observatories host over 20,000 students, teachers, and members of the general public, inspiring them to become better teachers and learners. One teacher put it like this after completing a LIGO professional development program and applying what he learned in his elementary school classroom "My students frequently ask, "Are we going to do science today?" When they hear, "Yes" they cheer."

CLOSING REMARKS

LIGO is a testament to the vision and tenacity of scientists like Rainer Weiss, Kip Thorne, Ron Drever, and others who began research programs to develop interferometers for gravitational wave detection, and, equally, to the National Science Foundation, whose bold vision and steadfast stewardship has enabled this discovery. It is also with great appreciation that I thank the U.S. Congress for recognizing the importance of scientific discovery and funding the NSF so it can support groundbreaking research.

LIGO's first observation opens a completely new window onto the universe – the window of gravitational-wave astronomy. 400 years ago, Galileo turned the first telescope to the sky and began the era of modern astronomy. Much of what we understand about the universe today comes from light – electromagnetic waves spanning the electromagnetic spectrum ranging from gamma rays to radio waves. The gravitational wave universe is completely uncharted territory. With this detection, we've accomplished the gravitational wave equivalent of Galileo – we've entered the era of GW astronomy and have just begun to explore the darker and more violent side of the universe.

This discovery is the first time we've been able to hear the cosmos communicating to us using gravitational waves. I am quite confident that that it won't be the last time. Even more exciting, we will see, or rather hear, something completely unexpected from the universe that will revolutionize our understanding of the universe. We cannot wait to get there.

Thank you.

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Biography - David Reitze is the Executive Director of the LIGO (Laser Interferometer Gravitational-wave Observatory) Laboratory at the California Institute of Technology and a Professor of Physics at the University of Florida. He received a Ph. D. in Physics from the University of Texas at Austin in ultrafast laser spectroscopy in 1990 and has worked extensively in the area of experimental gravitation-wave detection since the mid-1990s. He has authored or co-authored over 250 peer-reviewed publications. He is a Fellow of the American Physical Society and the Optical Society. He has served on numerous scientific advisory and program committees and within the physics and optics communities, including the Science and Engineering Council of the Optical Society of America, the Division of Laser Science of the APS, the Gravitational-wave International Committee, and the National Research Council Committee on Atomic, Molecular, and Optical Physics. From 2007-2011, he served as the Spokesperson (leader) of the LIGO Scientific Collaboration, a group of almost 1000 scientists who conduct the science of LIGO.