Testimony of

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On

Unlocking the Secrets of the Universe: Gravitational Waves

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Mr. Chairman, Ranking Member Johnson, and Members of the Committee, I sincerely thank you for holding this hearing and for the opportunity to discuss the historic observation of gravitational waves by the National Science Foundation's (NSF) Laser Interferometer Gravitational-Wave Observatory (LIGO). We are all excited by the remarkable science, but I want to focus my remarks on LIGO's history with NSF, the vision and support of so many, including this Committee and Congress to see it through, and what this discovery means for the future of science. Before I begin, however, I note the quotes on the back of the Committee's hearing room wall. They could not be more appropriate for this celebration of science because it truly is about having vision.

The Beginning....

In 1916, Albert Einstein published a paper using general relativity to predict gravitational waves — ripples in the fabric of space-time resulting from the most violent phenomena in our distant universe. This prediction has stimulated scientists around the world, who have sought to detect gravitational waves directly and have relentlessly pushed the technology to do so. NSF's funding of laser interferometer research and construction of a prototype began in the 1970s. In the 1980s, NSF committed about $300 million to a group led by Kip Thorne and Ron Dreyer of Caltech and Rainer Weiss of MIT to move these prototype studies into a full-blown gravitational wave observatory. My colleagues will tell you more about the early work that led to this point, but this effort — driven by brilliance, vision, enthusiasm, commitment, experimental prowess, and deep theoretical insights — persuaded NSF, its National Science Board, and Congress to take a risk. Even though NSF had never funded anything on such a scale before and the discovery of gravitational waves might not occur for decades, the potential for transformative science was worth the cost and the risk.

In the mid-1970s, Marcel Bardon, the NSF Director of the Physics Division, began the Gravitational Physics Program to support science that set the stage for LIGO. The Program funded the development of LIGO, and NSF Program Directors oversaw the construction projects that built Initial LIGO and ultimately Advanced LIGO. (I use these terms to distinguish the two separate projects that brought us to today's observatory.) The NSF Physics Division has supported the operation and maintenance of LIGO and made investments, determined through NSF's merit review process, which produced the remarkable technological advances at the heart of Advanced LIGO. The Foundation devoted almost $480 million to constructing LIGO and a total of approximately $1.1 billion to all aspects of the project (including research support for scientists and students) over the past 40 years.

LIGO was the first of our agency's Major Research Equipment projects (now known as Major Research Equipment and Facilities Construction (MREFC) projects). It illustrated the importance of a dedicated funding account, separate from the Research and Related Activities account, for constructing instruments of this scale and prompted fruitful discussions with Congress. In many ways, LIGO pushed our agency to realize its potential in the exceptional —and critical —role of funding the high-risk, high-reward fundamental research platforms that propel science forward and transforms our future. Few organizations can bet so boldly on that future, and NSF powerfully serves the Nation when it does so. As the government agency with the mission of supporting fundamental science broadly, we take bold steps to further the frontiers of science.

The National Science Board gave the go-ahead to fund initial construction of LIGO in 1990, and construction began in 1992, following Congressional approval and appropriations. NSF continues to provide approximately $40 million/year to support these facilities, which includes Caltech, MIT and two interferometers located in Hanford, Washington, and Livingston, Louisiana.

LIGO began its first observations in 2000, searching the universe for the gravitational waves predicted by general relativity. For the next six years, researchers gathered data and developed capabilities that have already found applications well beyond LIGO. For example, the laser frequency stabilization technique used by LIGO, the Pound-Drever-Hall technique, is widely used to achieve narrow line-width lasers for a wide variety of applications. The primary goals of this arduous research was to prove that it was possible to create an instrument with the requisite detection sensitivity, and, indeed, the answer was yes.

Thus, in 2008, NSF and Congress understood the compelling case and approved $200 million of funding for Advanced LIGO (AdvLIGO). Several of the key technologies that increased the sensitivity of LIGO came from the German-UK GEO collaboration. The AEI Hannover Atlas Cluster, the LIGO Laboratory, Syracuse University and the University of Wisconsin-Milwaukee contributed essential computer resources. In a model of efficient use of shared resources, several universities designed, built and tested key components for AdvLIGO: The Australian National University, the University of Adelaide, the University of Florida, Stanford University, Columbia University of the City of New York, and Louisiana State University. This national and international collaboration drove the science forward and leveraged precious resources.

I think all of us realized that detecting gravitational waves promised to open a singular new window on our universe, allowing us to see phenomena to which we were previously blind. Congress and the NSF saw that promise as worth the investment.

The Present....

At this point in our NSF story, I think most of us know what happened, and I do not want to dwell on the discovery here. I leave it to my colleagues to discuss the events of September 14, 2015, a mere four days after the start-up of AdvLIGO. That date marks the first direct detection of a gravitational wave, resulting, remarkably, from the collision and merger of two black holes approximately 1.3 billion years ago. It has taken that long for the signal to propagate to the detectors in Livingston, Louisiana and Hanford, Washington and produce the "chirp", a 100 millisecond transient signal that opened a new window on the universe.

The LIGO Scientific Collaboration (LSC), which carries out this work, is a group of more than 1,000 scientists at universities around the United States and in 14 countries. Post-doctoral researchers, graduate students, and undergraduates are all active participants in this work. The LSC network includes the LIGO interferometers and the GEO600 interferometer, a project located near Hannover, Germany, designed and operated by scientists from the Max Planck Institute for Gravitational Physics, along with partners in the United Kingdom funded by the Science and Technology Facilities Council (STFC). This is an open collaboration in which anyone can participate, provided they contribute substantively to the work of the group. Everyone is working toward the same goal, but in different ways.

The LSC works jointly with the Virgo Collaboration — which designed and constructed the Virgo interferometer, which has 3-km-long arms and is located in Cascina, Italy. The Collaboration is enhancing the original facility to create Advanced Virgo, which should begin operation later in 2016 in concert with the next LIGO science observations.

International partners have contributed equipment, labor, and expertise to LIGO, including the UK's STFC supplying the suspension assembly and mirror optics; the Max Planck Society of Germany providing the high-power, high-stability laser; and an Australian Consortium of universities supported by the Australian Research Council contributing systems for initially positioning and measuring in place the mirror curvatures to better than nanometer precision.

The Future.....

The discovery in September is a beginning, not an end. In much the same way as when Galileo first turned his telescope towards the night skies or when radio astronomy transformed our view of the universe, we now have a tool to probe the most violent phenomena in the furthest reaches of the cosmos.

And here's the really good news: AdvLIGO has reached only about one third of its design sensitivity. The observatory is in the midst of further optimization and improvements that will allow it to begin six months of observations with increased sensitivity later this summer or fall.

The United States has led this international collaboration, showing the pioneering, trail-blazing spirit upon which the country was founded. However, continued close cooperation with our international partners is key to taking the science to the next level. With two detectors, it is only possible to localize the source of the signal to a large portion of the sky. With the advent of Advanced Virgo later this year, it will be possible to "triangulate" the source of gravitational waves and make other, more detailed observations. We look forward to even greater capabilities when the new Japanese detector, KAGRA, begins operations in a few years, and we hope that additional international partners will join the effort.

The majesty of discovering our universe motivates such ambitious experiments, but as with all fundamental science, LIGO offers other important benefits. This science will advance education, inspiring students and developing the workforce our society requires. It has, and will continue, to lead to collaborations in engineering, computer science and other fields. This project has already led to other unpredictable advances, enabling technology spin-offs ranging from vibration isolation to mirror coatings to vacuum technology, that make the Nation more competitive. Significantly, industrial manufacturers were crucial partners in an effort driven by the goal of making an unprecedented measurement.

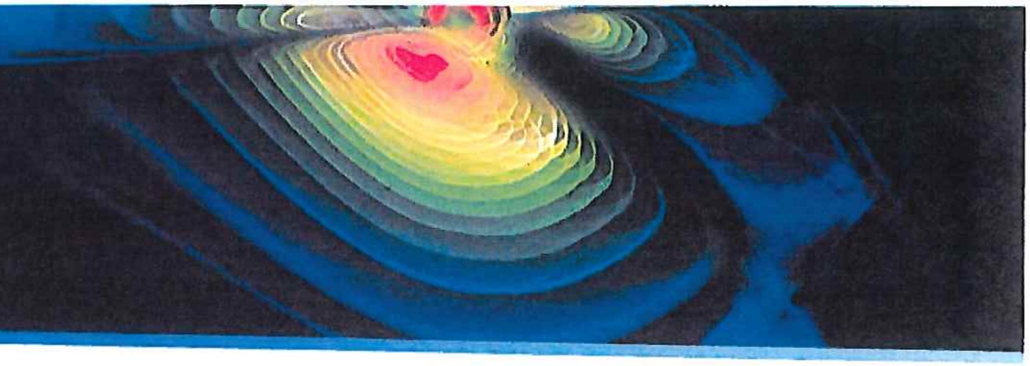
In Summary....

Mr. Chairman, this historic detection of gravitational waves by LIGO illustrates the importance and singular role of NSF. This project exemplifies the vision of NSF: Advancing discovery, innovation, and education beyond the frontiers of current knowledge, and empowering future generations in science and engineering. NSF supports basic research that drives innovation and innovators that transform our future. The fruits of NSF-supported research drive our economy, enhance our security, and ensure our global competitiveness.

Basic research is uncertain and risky, but it is also revolutionary. LIGO is a perfect example but not the only one. Fundamental science has transformed our world and will continue to change it in ways we have not yet imagined. All the contributors to LIGO: scientists, NSF, the National Science Board, and Members of Congress, should take enormous pride in our collective accomplishment. With this discovery we can move forward with the science of understanding our universe —pushing the boundaries of discovery and innovation still further.

This concludes my testimony and I will be pleased to answer any questions.

LIGO Timeline



1970s

Early work on gravitational-wave detection by laser interferometers, including a 1972 MIT study describing a kilometer-scale interferometer and estimates of its noise sources.

1979

The National Science Foundation (NSF) funds a new group at Caltech for laser interferometer research and a prototype interferometer. It funds MIT to complete its prototype and design and lead industry study of technology, costs and sites for a kilometer-scale interferometer.

1983

MIT and Caltech jointly present results of the kilometer-scale interferometer study to NSF. Receive NSF committee endorsement on new large programs in physics.

1984

LIGO founded as a Caltech/MIT project. National Science Board approves LIGO development plan.

1986

Physics Decadal Survey and special NSF Panel on Gravitational Wave Interferometers endorse LIGO.

1990

The National Science Board (NSB) approves LIGO construction proposal, which envisions initial interferometers followed by advanced interferometers.

1992

NSF selects LIGO sites in Hanford, Washington, and Livingston, Louisiana. NSF and Caltech sign LIGO Cooperative Agreement.

1994-95

Site construction begins at Hanford and Livingston locations.

Caltech

LSC LIGO Scientific Collaboration

1997

The LIGO Scientific Collaboration (LSC) is established and expands LIGO beyond Caltech and MIT, including the British/German GEO collaboration, which operates the GEO600 interferometer in Hannover, Germany.

2002

First coincident operation of initial LIGO interferometers with GEO600 interferometer.

2004

NSB approves Advanced LIGO.

2006

Initial LIGO design sensitivity achieved. First gravitational wave search at design sensitivity.

2007

Joint data analysis agreement ratified between LIGO and the Virgo Collaboration, which operates the Virgo interferometer in Cascina, Italy. Joint observations with enhanced initial LIGO interferometer and Virgo.

2008

Start of Advanced LIGO construction.

2010

Initial LIGO operations conclude; Advanced LIGO installation begins.

2011-14

Advanced LIGO installation and testing.

2014

Advanced LIGO installation complete.

2014-15

Advanced LIGO sensitivity surpasses initial LIGO.

9/2015

During an engineering test a few days before the first official search begins, Advanced LIGO detects strong gravitational waves from collision of two black holes.

Image credit: Werner Benger/ Max Planck Institute for Gravitational Physics