STATEMENT OF DR. DAVID SHOEMAKER, DIRECTOR, MIT LIGO LABORATORY AND DIRECTOR, ADVANCED LIGO PROJECT, ON "UNLOCKING THE SECRETS OF THE UNIVERSE: GRAVITATIONAL WAVES," AT THE FEBRUARY 24, 2016 HEARING OF THE HOUSE COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY,

Chairman Smith, Ranking Member Johnson, and Members of the Committee:

Thank you for holding this hearing, and inviting me to participate today. I too would like to thank the Committee for its interest in Gravitational Waves and LIGO, and hope our testimony helps the work of the Committee.

My name is David Shoemaker, from the Massachusetts Institute of Technology in Cambridge Massachusetts. I had the honor and pleasure to lead the Advanced LIGO Project, the NSF-supported Major Research Equipment and Facilities endeavor to upgrade the detectors in the LIGO infrastructure. I note with pride that the LIGO Laboratory completed the upgrade on time and on budget. I would like to provide some broad sense of the importance of the discovery, and discuss the future of LIGO and the field.

As Dr. David Reitze stated, we succeeded in our first goal: The direct detection of gravitational waves. But it is just the beginning of the opportunity to use this new view on the universe to learn about otherwise inaccessible phenomena in the Universe. With gravitational waves, we can "see" events – like the inspiral and coalescence of two black holes – that produce signals that cannot be seen any other way. It also will allow us to work with other observatories using established technologies, such as radio, optical, and x-ray telescopes and satellites, to combine data from gravitational waves and traditional instruments. In this way we can test theories about fundamental components of the cosmos, such as neutron star matter and supernovae. We certainly also expect many surprises will be discovered and explained as we develop this new branch of astronomy.

One important consequence is that the value of the existing observatories on the ground and in space will be increased and leveraged by adding this new view on the universe. When a gravitational-wave trigger seen by LIGO indicates an astronomical event that is expected to have an optical signature, such as the coalesence of neutron stars, NASA x-ray satellites and NSF radio telescopes can now aim at the appropriate point in the sky earlier. They will obtain a more complete picture of the event, allowing us to understand much more about, for example, the neutron star composition and behavior, especially when combined with gravitational wave data.

I want to emphasize another point from Dr. Reitze's testimony: that LIGO's past, and future, development has many more earthly payoffs. Fundamental science at the cutting edge often requires significant technology advances at the cutting edge, and this is the case for LIGO. Our development in very powerful, stable lasers finds applications in high-end communications, time-keeping, and navigation; our seismic isolation systems are being used for next-generation semiconductor fabrication and in seismometer design; low-loss optics have seen applications in NIST time-keeping references; and our work in signal identification in noise has found applications in defense related fields. Many of our precision measurement innovations are also used in other scientific research.

Echoing Dr. Gonzalez's testimony, we also note the large number of students who learn from working on LIGO then often follow careers in other academic or commercial fields, and in that way give back to society from this seemingly esoteric field. LIGO is training a new talent base on the leading edge of science and of technology. Some of them are continuing as gravitational wave researchers. Others are working for SpaceX, or Google, or for the defense industry at Lincoln Labs, bringing specific technical expertise with them but also an ability to develop innovative solutions to hard problems.

Gravitational wave science is just starting. In the very near term, the LIGO Laboratory and the LIGO Scientific Collaboration will complete its analysis of the first science observing run, which ended in mid-January 2016 – we can hope that we will find other events in those data. In Fall 2016, we will start another observing run, having made some improvements in the performance of the detector, which is already the best in the world by far but is only at about one-third of its design sensitivity. We hope to find that the French-Italian Virgo detector in Italy is ready to join us then. Combining their data with ours would give much better information on the position of gravitational-wave sources and allow us to read additional information from the combined 'signatures' of the sources.

Continued "commissioning" – the tuning of the detectors to reach the full sensitivity for which they were designed – will take place over the next few years, interleaved with more observations. Improvements in the optical alignment, in the systems which control the position of the optics, in baffling to control stray light, and in the sensors which convert the light to electrical signals, will all be pursued to bring the Advanced LIGO detectors to their full design sensitivity. Our data analysis teams will also be able to fine-tune their techniques as their understanding of gravitational wave sources and of our instrument deepens.

By 2019, we believe we will have a generous collection of observations of variety of sources of gravitational wave signals, such as:

Black holes: This is the system we have now see in our first detection: two black holes, orbiting around each other, losing energy through production of gravitational waves, and ultimately coalescing into a single black hole. Remember that black holes are called "black" because gravity is so strong that light can't get out. That includes everything from radio waves to gamma rays, so we've already seen something no traditional astronomical techniques could ever observe directly. Additional gravitational wave detections will tell us more about the very basic physics of black holes, for instance how their 'spin' (like a gyroscope) affects their behavior, and will allow us to look more closely at the final black hole as it wobbles right after the coalescence. This will allow ever more stringent tests of general relativity and the models for the improbable nature of space when it is infinitely distorted.

Neutron star binaries: These are pairs of incredibly dense compact objects, where a teaspoon of neutron star matter would weigh 10 million tons on earth. By observing their coalescence, we can understand better this matter – how stiff it is, how the object wobbles when excited, and the transformation from two neutron stars into one black hole at the final coalescence. As they collapse, we believe they give off a very strong burst of energetic photons – gamma rays – which we can observe using satellites like the NASA Fermi satellite now in operation. Seeing both gravitational waves and gamma rays from the same object would be incredibly informative on the makeup of this strange matter.

Spinning neutron stars: Neutron stars are usually magnetized and when they spin they act like electric generators, sending off very strong radio signals, which can be observed with NSF's radio telescopes. If we can find the gravitational waves given off by these same objects, we can learn what sorts of mountains and other defects can exist on their surfaces, and how the magnetization and the material interact.

Supernovae: Supernovae close enough to the earth to be detected by LIGO are rare, roughly one per 100 years. There was one in 1987, but we did not yet have detectors of LIGO's exquisite sensitivity to observe it. We will continuously monitor for a supernova, as seeing it – with other observations in optical, radio, X-ray, and neutrino detectors (like NSF's IceCube detector) – may help us unravel the mechanism behind the explosion of a star. Remarkably, the very best models for stars do not yet predict how supernovae happen, and gravitational waves could well be the key to move beyond that challenge.

Surprises: As has always been seen with other new windows on the universe, we expect surprises, and those surprises may shed light on some of the profound mysteries of dark energy and dark matter. The first observations by Galileo with his telescope revealed things beyond the imagination of the time. Radio telescopes similarly showed that the universe is rich with sources, including the remaining heat from the Big Bang. We can't predict the surprises, but certainly we will look for them.

We can take the sensitivity of the Advanced LIGO detectors even further. Using our improved understanding of quantum effects of light, we can 'squeeze' some uncertainty out of our measurement of gravitational waves and improve the sensitivity by enough to double the rate of our signals by 2020 and with some additional refinement perhaps a factor of 10 by 2025 through the adoption of better optics and better mechanical systems closest to the most critical optics. By then we expect to be observing and fully sharing data with instruments in Japan and India. That should allow gravitational waves to really deliver on the promise of transforming our understanding of the most violent and inaccessible events in the cosmos.

I am proud to see that the United States is a leader in this field. At the same time, we will continue to work with researchers from other countries. International partners made significant contributions to Advanced LIGO, both in R&D and as in-kind contributions (from Germany, Australia, and the UK), which helped in reaching our current sensitivity and will certainly help in the future as well. Because our detectors can give even more value when combined with other detectors, the LIGO Collaboration looks forward to aiding other countries as they bring their detectors on line. As the field matures, and as the community of scientists in the US and elsewhere grows, we will want to continue to lead in the development of better detectors through small-scale university R&D as well as in providing engineering and scientific management of the large-scale projects like LIGO that will be needed.

There are several longer-term visions that will help to complete our ability to 'see' or 'hear' all of the gravitational-wave sources in the Universe; here are two examples:

Studies of the Cosmic Microwave Background: There have already been efforts to find the traces of gravitational waves in the residual heat from the Big Bang, but the signals are (like LIGO's) very small and elusive. With continued development of these instruments, though, these very first signals can be recovered, helping our story of the first moments in the Universe's history.

Pulsar timing: The spinning neutron stars described above – also called 'Pulsars' – serve as wonderful clocks, spread throughout space. By comparing the signals from many such pulsars, small shifts in time earlier or later can be perceived, and can be interpreted as due to gravitational waves from galaxies with their central black holes coalescing over tens, hundreds, or thousands of years. Radio telescopes are used for this measurement, and may be sensitive enough quite soon to succeed in this approach.

I've also been asked to look at the really long-term horizon, and I thought I would leave you with a picture of where gravitational wave research might eventually go now that we have detectors that are starting to uncover fascinating data. There two "big ideas" I should note – "Ultimate LIGO" and "space-base detectors." But let me emphasize that these projects are for discussion in future years, not now – we are racing at this time to understand the amazing developments that our just-proven tools can tell us about.

Ultimate LIGO: There are concepts even now for how to get the very most out of our terrestrial gravitational-wave detectors, ones which can reach back to the time of the Big Bang – the beginning of the Universe - and fill in missing parts of the story that lead to the Universe we now know. We can help explain the growth of large-scale structures like galaxies and their interactions, and detect *every* sun-sized black hole coalescence in the universe. This would require new observatories with arms tens of miles long, to enable additional discoveries after LIGO's lifetime is completed and its mission fulfilled. These new instruments would require additional technology advances and would be championed by the greater astrophysics and astronomy community once gravitational waves are adopted as a universal tool for discovery in those fields.

Space-based detectors: The longer the arms of a gravitational-wave detector, the greater the sensitivity. Only in space is it possible to conceive of instruments with arms hundreds of thousands of miles in length, and only with these instruments can one make direct time-trace measurements of the ripples in space-time from galaxies coalescing and search for deviations from general relativity with a precision of one part in a thousand. LISA – Laser Interferometer Space Antenna – is a project that has been studied by both NASA and by ESA in Europe, and we hope that the confirmation of gravitational waves by LIGO can help bring this transformational detector to realization, and speed its path to launch. It is, in addition to a unique tool for astrophysics, a fantastic opportunity to develop and test technology in space – lasers, formation flying of satellites, data transmission and control over great distances, and precision measurement in space.

In summary, I wish to repeat for the entire LIGO Team and the LIGO Scientific Collaboration our appreciation for the support form the NSF, from this committee, and from Congress. LIGO is a wonderful example of what can be accomplished by a science funding agency with vision and commitment, with consistent funding to allow the best use of taxpayer's money to be made, and with a dedicated science team working in collaboration and resonance with the overseeing agency.

The window to this new world of gravitational waves has just been cracked open. As we open it wider and more and more people look out on the landscape, we will be rewarded with discoveries that will, time and time again, give us all – scientists, leaders, and laypersons – a thrill of understanding of things much bigger than ourselves.

Thank you again for your time, your interest in our science, and your continuing support for a broad spectrum of innovations in science and technology in the United States. We hope this glimpse of our field has allowed you to share in the sense of accomplishment you have enabled.