



**Testimony of**

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**Hearing**

**On**

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Chairman Babin and Ranking Member Edwards, Chairwoman Comstock and Ranking Member Lipinski, and Members of the Subcommittees. I sincerely thank you for holding this hearing and for the opportunity for the National Science Foundation (NSF) and its partners to discuss the exciting recent progress in astronomy and astrophysics, and the outlook for the future. We are all excited by the remarkable science in exoplanets, studies of dark energy, and the evolution of the universe. But I also would like to step back and highlight the historical context, namely that the remarkable progress we see in astrophysics is the product of multiple National Academies' decadal surveys, and the sustained long-term effort of the basic research community.

**The Context: A Special Moment**

We have come to a special moment in viewing the universe. Theoretical, experimental, and technological advances have opened new windows on the cosmos. For millennia, humans viewed light from the sky to learn about the universe. Four hundred years ago, Galileo brought new technology to bear, and the opportunities have exploded. Today we observe across the electromagnetic spectrum from radio waves to gamma rays, and now we are ready to look in fundamentally different ways with a powerful collection of

approaches. Just as electromagnetic radiation gives us one view, particles such as neutrinos and cosmic rays provide a different view, and gravitational waves give yet another. In this new era of multi-messenger astrophysics, NSF has a leadership role.

### **The Impact of Decadal Surveys**

In the 1950s, the same decade when NSF was formed, NSF established national observatories for the benefit of the entire U.S. astronomical community. The philosophy behind the formation of these national observatories was the same as that of NSF—their telescopes were open to use by all scientists, without regard to their home institution, purely on the basis of the quality of their scientific proposals. The national telescopes were built and operated not for the sake of having large facilities, but to enable scientific research requiring tools that only the federal government can deliver.

Within a few years, the U.S. astronomy community carried out a priority-setting exercise, the first of what became a series of surveys of the field carried out approximately every 10 years. The sixth of these studies, now known as decadal surveys, was delivered in 2010 by the National Academies. The decadal surveys include both the space-based astronomy supported by NASA and the ground-based astronomy enabled by NSF; in 2010, the Department of Energy (DOE) participated as well. Most young astronomers today have used data from both space- and ground-based telescopes, either to observe fundamental phenomena or to construct theoretical predictions that may be testable by those observations. Hence, the cooperation of agencies in sponsorship of the decadal surveys is critically important to delivering the best science return for our taxpayer dollars.

What is a decadal survey? An enduring purpose of decadal surveys is to survey the state of astrophysics, identify the most important science goals for the upcoming decade, and recommend a program to the federal agencies that best addresses those science goals. These surveys are carried out by the community of scientists, not by the federal agencies. Thus the decadal survey recommendations are truly the outcome of broad-based merit review. Their impact reaches beyond the federal government; university and foundation investments also are driven by the same community-derived science questions.

For 50 years, the decadal surveys have driven the evolution of federal observatories. The 1970 decadal survey recommended the Very Large Array radio telescope, while the 1990 decadal survey recommended the large optical/infrared telescopes that became the International Gemini Observatory. The 1990 survey also recommended the Millimeter Array, completed within budget in 2013 as the international Atacama Large Millimeter/submillimeter Array (ALMA). Thus NSF's frontier astronomical observatories have grown and evolved based primarily on the recommendations of the community-based surveys.

Fundamentally, the decadal surveys recommend the most important science, and the observatories that they recommend have reached expanding across multiple decades. Although the large observatories may be the most visible components of decadal surveys,

the true driving force is the science that is carried out by thousands of researchers at hundreds of U.S. institutions, from senior faculty to undergraduate and even high school students. Recent decadal surveys have paid close attention to the balance between the funding of the spectacular scientific tools and the support of the individual researchers who use the tools to deliver frontier science. These researchers often achieve results that could not be guaranteed when the tools were first envisioned. For example, the scientific reach of the Laser Interferometer Gravitational-wave Observatory, LIGO, was greatly extended by the development of computer simulations funded by dozens of individual investigator awards over the last thirty years. Hence the first detections of gravitational waves were not just detections, but were accompanied by an understanding of the masses and even the spins of merging black holes more than a billion light years away.

### **New Worlds, New Horizons in Astronomy and Astrophysics: the 2010 Decadal Survey**

This historical tour now brings us to the most recent decadal survey, delivered to the federal agencies in August 2010. That survey identified three principal science areas of focus for the present decade. They are:

- (1) Cosmic Dawn: Searching for the First Stars, Galaxies, and Black Holes;
- (2) New Worlds: Seeking Nearby Habitable Planets; and
- (3) Physics of the Universe: Understanding Scientific Principles.

Not surprisingly, these scientific areas are not newly identified for this decade, but represent enduring human quests. Spectacular advances are being made using new observational tools recommended in previous decades, as well as those to be built in the future.

Take “New Worlds” as an example. The first half of this decade has seen amazing discoveries from both ground- and space-based observatories. ALMA has imaged the disks of dust and gas orbiting newly forming stars, including gaps that are surely swept out by newly forming planets. Both the Gemini Observatory and privately funded telescopes such as the Keck Observatory have imaged planets orbiting other stars. NASA’s Kepler Space Telescope has detected thousands of exoplanets, but it is ground-based telescopes that measure the subtle variations in stellar velocities that reveal the masses of the planets. At present, NSF and NASA are collaborating on construction and implementation of a new instrument to measure these velocities very precisely; it will be installed on the WIYN telescope that is funded and operated collaboratively by several universities and NSF’s National Optical Astronomy Observatory. These are all basic and important steps toward understanding how planetary systems form and evolve, and ultimately the likelihood that they host life.

Because decadal surveys are aspirational, their expansive visions inevitably are constrained by economic realities. But NSF takes very seriously the priorities set by the decadal surveys, and makes every effort to fund the most important recommendations provided by the community.

At present, NSF and its awardees are constructing two major astronomical observatories recommended by decadal surveys and funded by Congress through the NSF Major Research Equipment and Facilities Construction account. We are building the Daniel K. Inouye Solar Telescope (DKIST) atop Haleakala on the island of Maui. The 2000 decadal survey recommended this telescope, and it is on schedule for completion by early 2020. Its observations of magnetic phenomena and energy transport in the Sun will be critical to the understanding of the ultimate source of space weather, which has a dramatic impact on our technological society.

NSF is leading construction of the Large Synoptic Survey Telescope, LSST, the highest priority ground-based recommendation of the 2010 decadal survey. LSST is on schedule to begin its 10-year survey by late 2022. LSST construction results from a strong NSF collaboration with the DOE and private funding partners, while its operations also will include substantial international contributions. LSST will revolutionize many areas of modern astrophysics, with its defining science cases including a survey of the contents of the solar system, and a robust investigation of the nature and evolution of the mysterious “dark energy” that is accelerating the expansion of the universe. LSST will discover thousands of Near-Earth Asteroids. With its well-characterized data sets, LSST is well-positioned for contributions by citizen scientists, and part of the construction plan is the development of a public interface to the datasets. Thus citizens with a variety of backgrounds and capabilities will participate in the excitement of astronomical discovery.

Two important recommendations of the 2010 decadal survey were the initiation of a Mid-Scale Innovations Program, known as MSIP, and increases in the NSF’s individual-investigator programs. NSF initiated MSIP, which targets programs that are too large for individual investigators, but can provide discoveries on timescales much shorter than the major observatories. MSIP is an ideal, hands-on training ground for young scientists and instrument builders who will go on to participate in the great observatories of the future. For example, the first round of this program funded the Zwicky Transient Facility, expected to make important discoveries in time-domain science and set the stage for the millions of transient sources that LSST will discover each night.

### **Where Are We Going?**

Let me recap the tremendous progress in astrophysics over the past several decades. When I left graduate school in 1981, we did not know that the expansion of the universe was accelerating, nor that there were planets beyond our solar system, nor that we would be able to detect gravitational waves from merging black holes. The unpredicted discovery of the acceleration of the universe in the 1990s relied on many years of individual investigator awards, NSF and privately funded observatories, and NASA missions. Progress in understanding the early universe now relies on mid-sized experiments with crucial contributions from graduate students and postdocs. Understanding the observations is enabled by spectacular simulations and visualizations by individual investigators who take advantage of large national computational facilities. The discovery and fundamental understanding of exoplanet populations and formation

needs large observatories such as the Kepler Space Telescope and ALMA, but also needs the growing population of individual researchers who make observations, analyze the data, and interpret the surprising discoveries we are now making.

With observatories such as ALMA, LIGO, and the Ice Cube Neutrino Observatory, NSF and its community are moving rapidly into an era of multi-messenger astrophysics. We at NSF are proud to work with our federal partners at NASA and DOE, as well as our non-federal partners, and most importantly with the broad community of scientists. We are poised to continue our journey of discovery on behalf of the American public, and we thank you and all U.S. taxpayers for your support.

This concludes my testimony, and I would be happy to answer any questions.

## **James S. Ulvestad**



Dr. James S. Ulvestad is the Division Director of the Division of Astronomical Sciences in the Directorate for Mathematical and Physical Sciences at the National Science Foundation, a position he has held since 2010. He leads a staff of 25 and oversees an annual budget of \$246 million, plus major observatory construction projects with an additional budget of \$100 million in FY 2016. Dr. Ulvestad earned a Bachelor's degree in astronomy from the University of California at Los Angeles and a Ph.D. degree in astronomy from the University of Maryland. He was previously an Assistant Director of the National Radio Astronomy Observatory (NRAO), where he was in charge of the Very Large Array and Very Long Baseline Array radio telescopes, and later was the head of the NRAO New Initiatives Office. Before his time at NRAO, Dr. Ulvestad served in various capacities at the NASA Jet Propulsion Laboratory, where he played important roles in several interagency and international programs. Among his community service activities, Dr. Ulvestad chaired the Demographics Study Group of the 2010 National Academies decadal survey in astronomy and astrophysics, was an elected member of the American Astronomical Society Council, and has been a member of NASA's Structure and Evolution of the Universe Subcommittee. He is an author or co-author of more than