Statement of

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before the

Committee on Science, Space, and Technology
Subcommittee on Space
And the
Subcommittee on Research
U.S. House of Representatives

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Exoplanet Discoveries; Have We Found Other Earths?

Good morning Chairman Palazzo, and Chairman Bucshon, Ranking Members Edwards and Lipinski, and members of the Subcommittees. My name is Jim Ulvestad, and I am the Division Director for Astronomy in the NSF Directorate for Mathematical and Physical Sciences. Thank you for giving NSF the opportunity to speak to you about our support of extrasolar planet, or exoplanet, research. This is one of the most exciting areas of astronomical discovery that we support today. It has been recognized by the most recent National Academy of Sciences decadal survey in astronomy and astrophysics as an area that is ripe for new discoveries over the next decade, and one whose excitement we are pleased to share with our colleagues at NASA, with the scientific community, and with the American public.

For centuries, and perhaps millennia, humans have looked up into the sky and wondered if we are alone in the universe. A first step in answering that question is to determine if there are planets orbiting other stars, a goal that remained unachievable for nearly 400 years after Galileo turned his telescope to the heavens. Technological developments beginning in the 1980s finally made it possible for astronomers to actually detect planets outside our solar system, and the first discoveries of such exoplanets were made in the 1990's by NSF-funded astronomers. Exoplanet science has progressed rapidly, to the point where 20 years after the first discoveries, there are more than 700 confirmed exoplanets, and thousands more candidates have already been identified by NASA's Kepler satellite. We are entering a scientific era in which we have the

capability to detect not only giant planets the size of Jupiter, but Earth-sized planets in the habitable zones of their solar systems, the locations where liquid water can exist.

NSF has supported this field since its infancy. The first definitive detection of an exoplanet was made in 1992 by an astronomer at NSF's Arecibo Observatory collaborating with a postdoctoral researcher at NSF's Very Large Array. Dr. Alex Wolszczan and Dr. Dale Frail used the Arecibo radio telescope in Puerto Rico to uncover the presence of two planets orbiting a pulsar, which is a dense neutron star totally unlike our Sun. This discovery was a surprise to the astronomical community, which had expected planets around "normal" stars and not around ultra-dense stellar remnants. Surprise turned out to be a hallmark of the first 20 years of research on exoplanets. Our best understanding of how solar systems form and evolve was challenged and had to be revised in light of the new discoveries made by the scientific process.

Planets orbiting Sun-like stars were detected soon after the first pulsar planets, with the surprising outcome that planets more massive than Jupiter were found in orbits very close to their parent stars. NSF has funded these transformative efforts for more than two decades, with research grants resulting directly in the first detection of multi-planet systems, the first detection of exoplanets with masses as small as that of Saturn, and the first planets detected using the technique of gravitational lensing of the radiation from background stars.

NSF-funded research on exoplanets relies on three critical elements: investigators, tools, and technology development. First, NSF funds the core scientific research of individual investigators; NSF presently has more than 40 active awards to individual investigators and small teams pursuing exoplanet research, including highly competitive awards to young scientists in the ascending stages of their careers. Second, together with our international partners, NSF provides the tools that astronomers need to make precision measurements of planetary systems; the newly inaugurated Atacama Large Millimeter/submillimeter Array (ALMA) can study planets in the act of formation, while the Gemini Observatory is poised for new exoplanet discoveries with the Gemini Planet Imager (GPI) that will be commissioned in the next year. Third, NSF supports the technology development that will enable the detection of planets as small as the Earth. In total, NSF currently invests approximately $10 million per year in exoplanet research. Roughly half of this amount is spent on individual investigator research grants, and the other half on the development and operation of advanced-technology telescopes.

As exoplanet science enters its third decade, we are growing beyond the mere counting of planets and beginning to investigate and understand their physical characteristics. At NSF, we are funding research into the observational characterization of planetary properties, measurements and models of exoplanet atmospheres, and the theory of the formation and evolution of planetary systems. With our international partners, we are poised to take the next step with the $25 million GPI mentioned earlier. This instrument will combine advanced adaptive optics to correct for the blurring effects of Earth's atmosphere, a coronagraph to block the glare of the parent star, and advanced spectral capabilities to image exoplanets and study their chemical compositions. Starting in 2014 a US-led team will begin a GPI survey of up to 600 nearby stars, which will provide family portraits of dozens, if not hundreds of other planetary systems.

Meanwhile, NASA's Kepler satellite has opened wonderful opportunities over the past four years, and we are all very grateful to NASA and the Kepler team for the advances they have enabled in exoplanet research. NSF-funded scientists have taken full advantage of the Kepler data; in recent months, Earth-sized planets have been confirmed in the habitable zone of the Kepler-62 stellar system. This exciting discovery was made using a technique developed by Dr. Eric Agol of the University of Washington, with funding he received from an NSF early-career award made in 2006. An NSF Graduate Research Fellow at the University of California, Mr. Erik Petigura, leading another recent study using Kepler data, has concluded that approximately 15 percent of Sun-like stars have Earth-sized planets in close-in orbits. This implies that many such stars also will be found to have Earth-sized planets in their habitable zones.

We stand at the threshold of many exciting discoveries over the next decade, as the worlds of science fiction become part of scientific reality. In 2013, the number of proposals for exoplanet research received by the NSF increased to more than 100, from a number of 20-25 proposals per year just eight years ago. NSF is able to fund only a small fraction of those proposals, but we expect them to give rise to more exciting discoveries. For example, while still in its scientific checkout phase, scientists using ALMA have found evidence for Earth-mass planets around nearby stars; as it nears its full complement of 66 antennas, ALMA will deduce the presence of many more exoplanets and study the chemical composition of the planetary nurseries. Over the next 3 to 5 years, studies like the ones done with ALMA will be complementary to the expected frequent releases of exoplanet images and spectra from Gemini as the GPI instrument comes on line. As with all of NSF's major facilities, the data acquired with these instruments will be freely available to all researchers after an initial proprietary period.

Where will we be 20 years from now? We will have dozens, probably hundreds of Earth–sized worlds detected and imaged in our region of the Galaxy. We will have an accurate knowledge of the fraction of nearby stars with planets of all sorts, and of those with Earth-sized planets. We will have images of solar systems like our own, including other Earth-like planets. We will have information about the chemical compositions of many of these planets and we will be searching the data for biosignatures, or evidence of life. These discoveries will continue to change our understanding of how planetary systems like our own form and evolve, and of humanity's place in the universe.

Summary

One of the key goals of NSF's strategic plan is to "Transform the Frontiers" of science and engineering. Since the very first discoveries of exoplanets 20 years ago, NSF-funded research has transformed the frontiers of exoplanet research, enabling us to address a fundamental question: "Are there other places out there where life could exist, and what kind of life is there?" Because the people of the United States value knowledge and discovery, we continue to understand more and more about the possibilities of life elsewhere, and can only await the fabulous new discoveries of the next 20 years.

Mr. Chairman this concludes my remarks. I would be happy to answer any questions you may have.

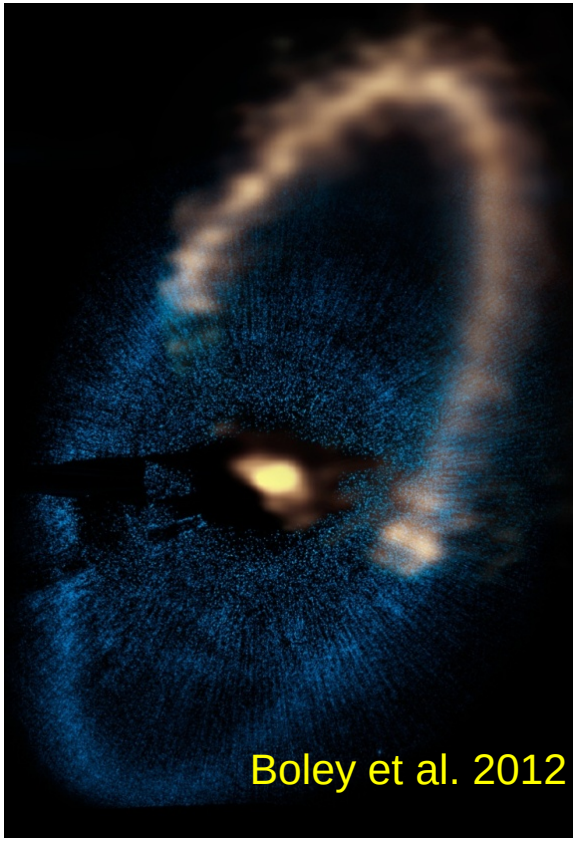
Biography – Dr. James S. Ulvestad

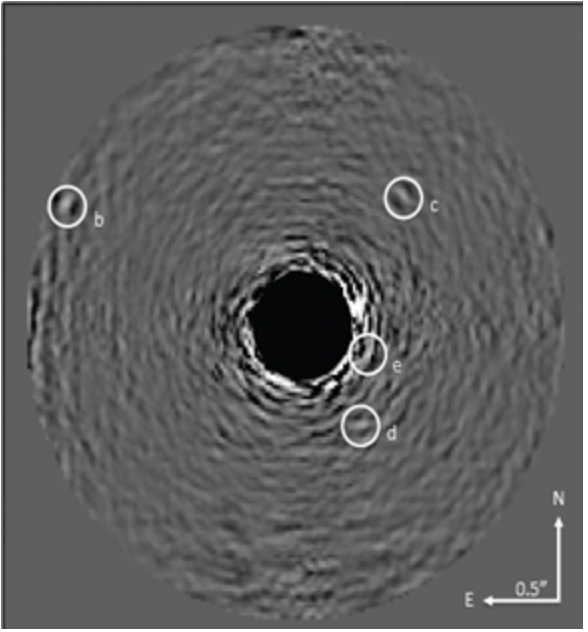
Dr. James S. Ulvestad is the Division Director of the Division of Astronomical Sciences at the National Science Foundation, a position he has held since 2010. Previously, he was an Assistant Director of the National Radio Astronomy Observatory (NRAO), where he was in charge of the Very Large Array and 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 Academy of Sciences 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. Dr. Ulvestad is an author or co-author of more than 80 refereed papers in the scientific literature, as well as numerous technical reports.

ALMA

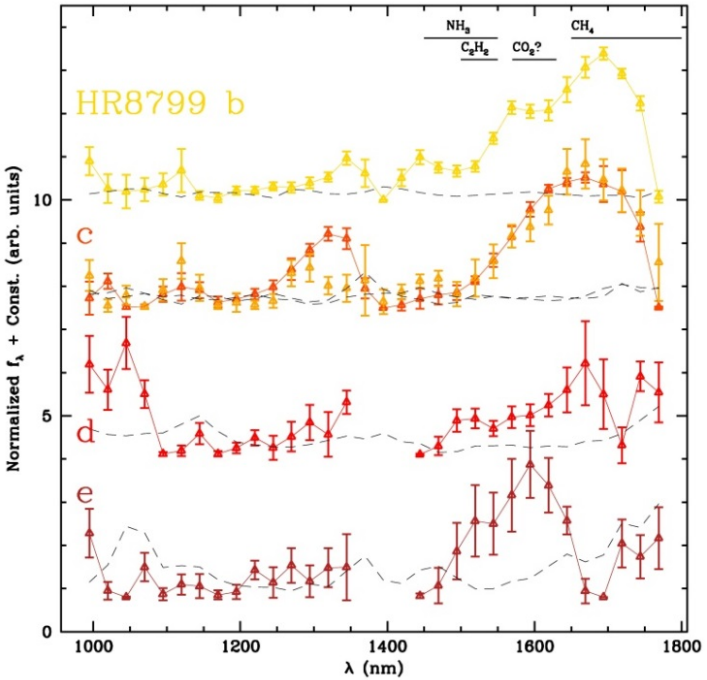
- ALMA was inaugurated March 13, 2013

- Early ALMA image of debris disk around Fomalhaut shows narrow dust ring, modeled to be shepherded by two Earth-mass planets





Monitoring Cloudy Skies on Extrasolar Planets



- Spectra of four exoplanets observed simultaneously for the first time: HR 8799 (Oppenheimer et al. 2013, AST-0908484).
- Data show methane and ammonia molecules present at levels consistent with dynamical changes in the clouds (→weather?)
- Atmospheric changes can now be tracked over time on extrasolar planets.