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Statement of

Dr. Ellen Stofan
Chief Scientist
National Aeronautics and Space Administration

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Committee on Science, Space and Technology
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Chairman Smith, Ranking Member Johnson and Members of the Committee,
I am pleased to have the opportunity to appear before you to discuss astrobiology and the search for life beyond Earth.

NASA's robotic spacecraft and telescopes are providing strong evidence of possible habitable environments beyond Earth. With future technology and instruments currently under development, we will explore the solar system and beyond, and could indeed -- perhaps in as little as 10-20 years -- discover some form of life, past or present.

Our search is making amazing progress. When I was a PhD student, scientists certainly suspected that planets must be commonplace in the Universe, but we had not found evidence of a single one. Twenty years ago, we found evidence of the first such planet. Today, thanks to NASA's Kepler, Hubble, and Spitzer space missions and several ground-based telescopes, we have identified nearly 5,000 planets orbiting other stars – and we now believe that that the vast majority of stars in the Universe have planets. In July, the Kepler mission confirmed the first near-Earth-size planet in the "habitable zone" around a sun-like star. Kepler-452b is the smallest planet to date discovered orbiting in the habitable zone of a star like our sun.

On Mars, a series of NASA missions culminating in the *Curiosity* rover, which touched down in Gale Crater nearly three years ago, have allowed us to make amazing discoveries. We now know that Mars was once a water world much like Earth, with clouds and a water cycle. For hundreds of millions of years, about half of the northern hemisphere of Mars had an ocean, possibly a mile deep in some places. *Curiosity* is now at the edge of where that ocean was and *Curiosity* has determined that the Martian soil is currently about 2 percent water, by weight.

Indeed, we now know that we live in a soggy solar system, and undoubtedly, in a soggy universe. We continue to find vast amounts of liquid water in unlikely places. For instance, Jupiter lies outside the habitable zone and we would expect water in Jupiter's vicinity to be frozen. Yet we now have evidence of liquid oceans on three of the four moons of Jupiter, sloshing around tantalizingly under the icy crusts of those worlds. Using the Hubble and Spitzer space telescopes, we have found signs of water in the atmospheres of planets around other stars.

So what lies ahead in the next decade of exploration? I would like to describe just some of the highlights.

Life - as we know it - requires water, specifically liquid water, that has been stable on the surface of a planet for a very long time. That's why Mars is our primary destination in the search for life in our solar system, because our robotic spacecraft have shown us strong evidence that water was stable on Mars for a very long time.

In July 2014, NASA selected the instruments for the Mars 2020 rover mission, which will study Martian rocks and soils to understand past habitable conditions on Mars and to seek signs of ancient microbial life. Mars 2020 will also test our ability to extract oxygen from the Red Planet's carbon-dioxide atmosphere to prepare for future human exploration.

If we do find evidence of life on Mars, it will likely be fossilized microorganisms preserved in the rock layers. The Mars 2020 rover will begin the search, but as a field geologist, I can tell you it may be hard to find. That's why I believe it will take human explorers - geologists and astrobiologists - who can move quickly and make intuitive decisions on their feet - to identify it.

Over the next decade, our journey to Mars involves the development of a commercial crew capability for low earth orbit, the development of the Space Launch System (SLS) and *Orion* to go beyond low earth orbit, and the proving ground of an asteroid redirect mission. We are well on our journey, with a very successful first flight test of *Orion* this past December and hardware for the first SLS well underway.

Beyond Mars, we are planning to look at another intriguing world in our solar system. The President's Fiscal Year (FY) 2016 budget request supports the formulation and development of a mission to the Jovian moon Europa. We estimate that Europa has twice as much water as the Earth's oceans and that there is an interchange of materials between Europa's icy crust and its water oceans. *Hubble* has observed plumes at one of Europa's poles. A Europa mission could potentially, among other things, analyze Europa's water plumes to determine the composition of those oceans.

Of course, beyond our solar system, there are countless other worlds that could harbor life. As I mentioned above, space- and ground-based telescopes have found nearly 5,000 exoplanets to date. The majority of these exoplanets are giant gas planets close to their home stars, because such planets are more easily detected. However, extrapolating from the available data, we calculate that the majority of the planets in the Universe are smaller rocky planets, which are more likely to support life. In 2017, NASA will be launching the Transiting Exoplanet Survey Satellite, (TESS), which will look for rocky planets near the habitable zones of the closest stars. With TESS' planets in hand, we will use the James Webb Space Telescope to analyze the kinds of molecules that such planets' atmospheres contain, such as water, oxygen, carbon dioxide and methane. The President's FY 2016 budget request supports the pre-formulation of a Wide Field Infrared Survey Telescope with the capability of directly imaging planets around the nearest stars and analyzing their atmospheres. These will be the prime targets for our search for life.

Since Earth remains – for now – the only known instance of an inhabited planet, the search for life in the cosmos also requires that we further develop our understanding of life on Earth. Through our research on Earth, we have learned that life is tough, tenacious, metabolically diverse and highly adaptable to local environmental conditions. Astrobiologists have discovered life in numerous extreme environments on Earth such as volcanic lakes, glaciers, sulfur springs and the top of the stratosphere. We have also found life in extraordinary forms, ranging from bacteria that consume chemicals that would be toxic to most other life, to microbes that live under high levels of gamma or ultraviolet radiation.

In 2012, astrobiologists found that microbes from Earth can survive and grow in the low pressure, freezing temperatures and oxygen-starved conditions seen on Mars. Their research found that microbes from permafrost soil collected in northeastern Siberia could grow at 7 millibars of an atmospheric pressure, equivalent to that of Mars, which is less than one percent of Earth's average pressure. In a companion study, these same scientists investigated 26 strains of bacteria commonly found on spacecraft. Incubating them under Mars-like conditions, they found that one particular bacterium could survive and even reproduce under these extreme conditions.

Perhaps even more interesting is the possibility that life could exist in the absence of liquid water. That's why scientists are interested in exploring some of the more unusual places in our solar system and beyond, such as Saturn's moon Titan, where it rains liquid methane and ethane. Could such an environment harbor life? We don't know yet.

Ultimately, of course, the search for life is a crosscutting theme in all of NASA's space science endeavors, bringing together research in astrophysics, Earth science, heliophysics and planetary science. Astrobiology is guided by a community-constructed roadmap generated about every five years, most recently in 2008, with the next roadmap slated for release this year. The ongoing development of astrobiology roadmaps embodies the contributions of diverse scientists and technologists from government, universities and private institutions. These roadmaps outline multiple pathways for research and exploration and indicate how they might be prioritized and coordinated.

In addition, in April NASA announced the formation of an initiative dedicated to the search for life on planets outside our solar system. The Nexus for Exoplanet System Science is an interdisciplinary effort that connects top research teams and provides a synthesized approach in the search for planets with the greatest potential for signs of life. All of the research teams participating in this network are funded by grants from the four research divisions of NASA's Science Mission Directorate. Those grants were awarded through NASA's standard competitive solicitation, peer review and selection process. This new network will help scientists communicate and coordinate their research, training and educational activities across disciplinary, organizational, divisional and geographic boundaries. It will also foster new collaborations, including international partnerships, address interdisciplinary topics, and help break down barriers between stove-piped research activities.

From research, to our knowledge of where to go and what to look for, to the capabilities of finding it both within our solar system and beyond, we are making great discoveries.

Again, thank you for the opportunity to testify today. I look forward to responding to any questions you may have.