Hearing of the House Appropriations Committee
Sub-Committee on Commerce, Justice and Science

Ocean Worlds Hearing

Testimony submitted by
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Chairman Culberson, Acting Ranking Member Honda, and distinguished members of the Subcommittee, thank you for the opportunity to come before you to discuss the exciting science and mission opportunities for exploring the Ocean Worlds of our solar system.

The search for life beyond Earth is one of humanity's oldest, most profound, and yet unanswered questions. Long before Einstein conceived of gravity waves, long before Higgs conceived of the Higgs boson, long before Watson and Crick discovered DNA, our ancestors were looking up at the night sky wondering if life exists beyond Earth.

We do not yet know whether we are alone in the universe, or if our universe is teeming with life. For the first time in human history, however, we now have the tools and technology needed to answer this age old question. Let me emphasize this point again – **for the first time in human history we have the tools and technology needed to search for, and potentially find life beyond Earth**. We can build the spacecraft and instruments needed to search for life in our solar system and beyond.

In addition, we know exactly where to look: along with the planet Mars, we now know of several moons in the outer solar system that likely harbor liquid water oceans and which could support life as we know it. NASA's search for life beyond Earth has long been guided by the mantra of 'follow the water'. We now know that vast quantities of liquid water reside within many moons of the outer solar system. These moons, these worlds – these **Ocean Worlds**, if you will - are quite likely the best places within our Solar System to find life that is alive today – life that we could someday directly observe: living, thriving, possibly even swimming in these distant oceans.

A critical achievement of NASA's program for the robotic exploration of the solar system is that we now have strong evidence for these oceans of liquid water trapped beneath the icy shells of moons in the outer solar system. These Ocean Worlds are Jupiter's moons, Europa, Ganymede, and Callisto; and Saturn's moons Enceladus and Titan. It may even be that Neptune's curious moon Triton harbors a liquid water and ammonia-rich ocean beneath its icy shell. As we continue our exploration we may find that the giant asteroid Ceres, and the dwarf planet Pluto may also join the list of potential ocean worlds. Taken all together the volume of liquid water in these oceans could be well **over 20 times** the total volume of liquid water found on Earth.

Today I will highlight just three of these moons: Jupiter's moon Europa, and Saturn's moons Enceladus, and Titan. But before I detail those worlds, I should provide some context for what we think it takes for a world to be habitable. That context is best provided by our own planet, our own ocean world, Earth.

Importantly, our study of life on Earth has served as a guide for where to look for habitable environments beyond Earth. Over the course of the past 54 years of NASA's exploration of our solar system we have also learned much about life on Earth and what it takes for life to survive. Microbial life on Earth can survive and grow throughout an incredible range of conditions – from the hottest springs in Yellowstone National Park, to the deepest depths of our ocean, to the driest, coldest valleys of Antarctica – microbial life finds a way.

Life on Earth finds a way - we have learned – in just about any location on our planet where liquid water, the elements for building life, and some form of energy from the Sun, or chemistry from the rocks, comes together. In other words, **the keystones for life are water, elements, and energy**. Wherever we find these keystones together on Earth, we generally find life. We predict that, if these keystones are brought together on distant worlds, we may also find life.

Let me give you one beautiful example of how this works on Earth. In the spring of 1977 my colleague oceanographer Bob Ballard was part of the team that discovered hot springs in the deep dark depths of our ocean. Around those hot springs – which are often referred to as hydrothermal vents – Bob and the team discovered a thriving ecosystem of bizarre red tube worms, eel-like fish, bright white crabs, and an assortment of microbial communities. How could such an ecosystem exist? The Sun does not shine down to those depths. What makes life possible in such an extreme environment? As scientists began to study these vents the answer became clear. The microbes that serve as the base of the food chain are eating the compounds erupting out of the vents – they are doing what we call chemosynthesis, using the chemical energy of materials coming out of the vents. The fish and tubeworms and larger creatures then eat the microbes. The hydrothermal vents bring together the water, elements, and energy needed for life to exist – the energy comes from the rich chemistry of the vents. This is much different from the base of the food chain that we experience around us – where photosynthesis rules the day and the energy to power life comes from our Sun.

The discovery of life around hydrothermal vents at the bottom of our own ocean provides a key bridge to the potential habitability of ocean worlds beyond Earth, which brings us back to the ocean worlds of the outer solar system. Let me begin with Europa.

Europa, the second of Jupiter's four large moons, is about the size of our Moon, but it orbits Jupiter, which is some 318 times as massive as the Earth. The tidal tug-and-pull that Europa experiences as it orbits Jupiter creates the energy needed to maintain liquid water beneath Europa's icy shell. To the best of our knowledge, Europa's ocean is global and it is approximately 60 miles deep; that is **roughly ten times as deep as the Mariana Trench**, the deepest point in our own ocean. The total volume of liquid water within Europa's ocean is **two to three times the volume of all the liquid water in Earth's oceans**.

To reach that ocean – to someday explore that distant sea with highly capable and instrumented robots that can send back images and data – we need to develop a well-defined and systematic approach for exploring the Ocean Worlds.

We will make progress toward this goal with the Europa mission currently in formulation, which will fly past Europa approximately 45 times as it orbits Jupiter. The instrument payload for the Europa mission is already selected and the spacecraft is under development for a launch in the 2020s. With each flyby of Europa, the spacecraft will collect images and return data about Europa's surface composition, structure and thickness of the ice shell. This mission also has the capability to do the type of reconnaissance necessary for finding landing sites for a potential future lander.

Recently, we at JPL have completed initial studies for landers that would go down to Europa's surface and directly sample and analyze material on Europa's surface. We presented these architectures to NASA Headquarters in February, and are in the process of conducting additional studies to refine the requirements for a potential lander over the next several months, and assess implications for cost, schedule, risk, and complexity.

Of course, having a mission on the launch pad is a lot different than having it at the destination. The rocket that is used to send spacecraft to their destinations is a key part of the process. Future large rockets, such as the Space Launch System (SLS) or, though not in same class as the SLS, the commercial Falcon Heavy, now in development, and existing Delta IV Heavy could help to carry a large payload or reduce the time it takes to reach the outer planets; however costs of the new rockets are not known at this time.

Right now the *Cassini* spacecraft is orbiting Saturn, flying by Saturn's moons and returning data that is revolutionizing our understanding of the Saturnian system. A key discovery of the *Cassini* mission is that Saturn's curious little moon Enceladus – which is only 300 miles across – has an ocean beneath its icy shell. That ocean is jetting out through cracks in the ice shell, creating plumes of water that the *Cassini* spacecraft has flown through and sampled with its instruments conceived in the early 90s but not designed to chemically characterize such an environment. Within those plumes of water we have also found salts, organic compounds, and silica – all of which point toward a salty subsurface ocean that has an active seafloor, with hydrothermal vents that could possibly support life.

The case for Saturn's moon Titan is similar. Titan is a world full of organic molecules, which are of course key building blocks for life. Clouds in Titan's atmosphere rain out liquid methane and ethane, which then collects into lakes that dot Titan's earthlike landscape. Some of these lakes are comparable in size to the Great Lakes that define much of our border to the north with Canada. On Earth, however, our lakes are carved into rock, whereas on Titan the lakes of methane and ethane are carved into a shell of water ice. Beneath Titan's icy shell may reside a global liquid water ocean. Could life have arisen on such a world? For many in the planetary science community Titan is heralded as the place to go to look for 'weird life' – life unlike life as we know it; life that may have originated in liquid methane instead of liquid water. Titan is a totally new frontier for organic chemistry.

Because of these discoveries and great potential for new ones, NASA has added Enceladus and Titan as potential targets for the upcoming call for New Frontiers missions.

An ocean worlds program provides the necessary framework for the systematic exploration of these worlds that may harbor life beyond Earth. Importantly, there is a win-win for exploring, mapping, and making discoveries within our own ocean here on Earth. The tools and technologies for exploring oceans beyond Earth will first be tested and utilized in our own ocean, making scientific discoveries along the way. The physics, chemistry, and biology of our own ocean is the bridge to understanding and exploring oceans elsewhere.

I would like to finish by simply stating that the exploration program I have just outlined – the exploration of Ocean Worlds – will not be easy. There will be failures and successes as we march down this path of discovery. But here is where I find inspiration in the words of that visionary leader, President Teddy Roosevelt. Each day when I walk into my office I see his words displayed in the entryway of my building. The words are simply 'Dare Mighty Things'. In a speech in 1899, Teddy Roosevelt proclaimed that it is "far better to dare mighty things, to win glorious triumphs even though checkered by failure, than to rank with those timid spirits…" This sentiment, "To Dare Mighty Things," has become a clarion call for what we do at JPL and NASA. We want to dare mighty things, and we want to lead this country on the next grand voyage. We are a nation of explorers and innovators and the exploration of Ocean Worlds – on Earth and beyond – is a new great frontier.