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Statement of

Dr. Jonathan I. Lunine
David C. Duncan Professor in the Physical Sciences
Director, Cornell Center for Astrophysics and Planetary Science
Cornell University

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Chairman Culberson, Ranking Member Honda and Members of the subcommittee,

Thank you for the opportunity to present my views on ocean worlds and the search for life beyond Earth. We live in the most extraordinary of times. When I entered elementary school a half century ago, I was barely aware of the first tentative steps being taken toward exploring the planets—a time when success was measured by the mere survival of the Mariner 2 Venus flyby mission after 5 months in space, or the 21 blurry images Mariner 4 sent back during the first successful flyby of Mars. With the passing of the decades, the perseverance and ingenuity of this nation's engineering talent paid off, as the United States emerged the unparalleled leader in the robotic exploration of the solar system: Voyagers 1 and 2 have been operating in space for nearly 40 years and the US's Mars Reconnaissance Orbiter has returned close to 42,000 images of Mars as of this week.

It is difficult not to feel passionately patriotic and proud of what our nation has accomplished, by itself and together with many international partners, in the exploration of our solar system. I feel humbled to be a scientist participating in one of the greatest space odysseys ever undertaken, the Cassini mission to Saturn. This spacecraft has revealed vast hydrocarbon seas on the surface of Saturn's giant moon Titan, discovered and then penetrated deep into the icy plume of another Saturnian moon Enceladus, finding salt water and carbon-bearing molecules within. It has probed the vertical structure of Saturn's rings, solved the long-standing mystery of Iapetus' white-black dichotomy, discovered mysterious red streaks on the moon Tethys, and found a gigantic hurricane trapped within a bizarre hexagonal wind pattern at Saturn's north pole.

Engineers at NASA's Jet Propulsion Laboratory (JPL) are now preparing Cassini for multiple forays into the narrow realm of space between the innermost ring of Saturn and the planet's atmosphere, before directing it to a fiery plunge into the ringworld on September 15 of next year, after twenty successful years of complex operations in space. Cassini's extraordinary voyage of discovery, as are many other missions such as the Curiosity rover on Mars, is a testament to the extraordinary technological prowess and commitment to success of the engineers and scientists at JPL. They exemplify what makes this nation capable of doing truly extraordinary things.

Cassini, together with its antecedent at Jupiter, the Galileo orbiter, provided compelling evidence for salt water oceans underneath the icy surfaces of three moons of the outer solar system—Europa at Jupiter, Enceladus and Titan at Saturn. These are the three exemplars of an elite group of "ocean worlds" in the outer solar system. I focus on the three (Europa, Enceladus and Titan) because for them the evidence for liquid water is nearly incontrovertible and we even know something about the compositions of their oceans.

Europa has a very large salt-water ocean in contact with a rocky core, chemical energy associated with Jupiter's radiation belts, and lots of tidal heating-- but we know little else about the prospects for life here. Indeed, we do not know whether organic (carbon-hydrogen) molecules exist within the ocean—but we strongly suspect they are there. Equally important, we do not know how far beneath the moon's surface the ocean lies. Knowing that will allow a strategy to be formulated to search for life there. The Europa Multiple Flyby mission will provide the essential information needed to decide, among other things, whether ocean water is welling up through the cracks, and how to access it. It will tell us whether organic molecules are present. And, should there be plumes or fresh deposits to sample, a sub-probe or lander might access material containing signs of life. We've waited more than 15 years for this mission; it needs to be launched as soon as practicable—ideally by the early 2020's.

Titan is larger than the planet Mercury and is the only moon to host a dense atmosphere of nitrogen and methane. Cassini and the European Space Agency lander Huygens carried by Cassini have revealed a "methane hydrologic cycle" with clouds, rain, river valleys and seas in an unimaginably frigid environment. The surface seas –concentrated in Titan's arctic-- are so vast that they hold hundreds of times more hydrocarbons than do the known oil and gas reserves on planet Earth. And so we cannot avoid asking whether a form of life might have arisen in this exotic environment. Titan's surface has all the formal requirements for life—abundant organics, liquids, and sources of energy. And yet, that liquid is not water—it is methane and ethane. Should we include the seas of Titan in our search for life? As a 2007 National Research Council study[1] noted: "Titan['s seas are] a test for the universality of life as an outcome of cosmic evolution." Beneath the nightmarish landscape of organic rivers and seas, and under perhaps 60 miles of ice crust, is a liquid water ocean. Detected in two different ways by Huygens and Cassini, the ocean must be charged with salts, suggesting that it may have access to an underlying rocky core. This too is a surprise, since models of Titan suggested that any ocean would be perched between two layers of ice, unlike the oceans of Europa and Enceladus. The solar system is, as always, full of surprises.

Because Titan's interior water ocean is so deep, it is probably inaccessible to us. Any future search for life will be difficult. The easiest approach is to drop a floating capsule—a boat--onto one of the vast surface hydrocarbon seas. It would be the first maritime exploration of

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[1] The Limits of Organic Life in Planetary Systems, National Research Council, National Academies Press, Washington DC, 2007, p. 74.

an alien sea. Here the complication is that we don't know what kind of biochemistry we are looking for, but a generalized search for patterns in molecular structures and abundances that indicate deviation from the randomness of abiotic chemistry is a good first step.

Enceladus has not surprised scientists—it has shocked us. It's a small moon and yet it sports a plume of material emanating from a series of fractures in its south polar region. Cassini discovered this plume of icy grains and vapor and has flown into it seven times. Thanks to the prodigious capabilities of its chemical sniffers—mass spectrometers—and other instruments, Cassini has found organic molecules, frozen drops of salty water, and tiny grains of silica—all indicators that inside Enceladus is a hydrothermal system in which water, organics and minerals are heated together in the sort of chemical stew from which life on Earth might have begun. And yes, there really is a subsurface ocean: Cassini has detected its presence in two completely different ways. Make a list of the requirements for terrestrial-type life—liquid water, organics, minerals, energy and chemical gradients—and you find that Enceladus has it all. Conveniently, the evidence is not hidden beneath the surface—it's coming out into space in the plume.

Therefore Enceladus provides us potentially with the most straightforward way to look for life signs, given the compelling evidence that much of the gas and the grains are being expelled from the ocean itself. *To sample the plume of Enceladus is to sample its ocean.* Merely flying through the plume as Cassini has done multiple times, with instrumentation more modern than Cassini's and hence capable of detecting the molecular signposts of life, is sufficient to search for signs of life. It is fair to assume that the basic biochemical building blocks are like those on Earth, since every indication we have from Cassini is that the subsurface ocean would support terrestrial microbes. This can be done for well below the cost of a Flagship mission and it can be done with instruments available for flight today.

The ocean worlds have captured the imagination, not just of planetary scientists and astrobiologists, but of oceanographers, explorers and the general public. Thanks to our nation's investment in the space program—an investment made through the hard-earned wages of every working American—all of humanity can now gaze at Jupiter and Saturn in the night sky and ponder the real possibility that within some of their moons are organisms whose origin was completely separate from life on Earth. What would they be like? Before we can answer this question, we must go back and search these ocean worlds to see if life really does exist in any or all of them.

Discovering life on or within the ocean worlds of our own solar system may provide unexpected and as yet hard to predict practical benefits, as Carl Sagan pointed out many decades ago.[2] But more profoundly, it will inevitably direct our attention to the Milky Way Galaxy beyond the confines of our own planetary system. If life can begin two or three or four times in our own solar system, the number of planets in the Galaxy as a whole harboring life must be very great indeed. And how could we then resist taking the leap beyond our solar system to explore the vast spaces between the stars?

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[2] Sagan, C. The Cosmic Connection: An Extraterrestrial Perspective. Doubleday, New York 1973, p. 57.