FOLLOW THE (OUTER SOLAR SYSTEM) WATER: PROGRAM OPTIONS TO EXPLORE OCEAN WORLDS. B. Sherwood[1], J. Lunine[2], C. Sotin[1], T. Cwik[1], F. Naderi[3], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, (brent.sherwood@jpl.nasa.gov). [2]Cornell University, Ithaca NY. [3]Consultant, Los Angeles CA.

Motivation and summary: Based on emergent findings from the past two decades of planetary exploration missions, the US Congress now requires NASA to implement a virtual Ocean Worlds Exploration Program (OWEP) using a mix of flagship, New Frontiers, and Discovery class missions [1].

Discovery-class (roughly half-$B) missions have not been found feasible: in 2010 and 2014, respectively, Discovery proposals to explore Titan and Enceladus were rejected for too-high cost risk. NASA is currently developing a moderate-cost flagship mission to assess the habitability of Europa; this may be accompanied by an essentially simultaneous flagship mission that would land on Europa to search for biosignatures. In 2016, NASA took three steps responsive to the Congressional direction: added an ocean-worlds theme to the New Frontiers-4 opportunity currently open [2]; solicited COLDTech proposals to mature relevant technologies [3]; and chartered the Roadmap for Ocean Worlds (ROW) team to catalogue potential ocean worlds and articulate key science questions for them [4]. New Frontiers (roughly $1B) is NASA's intermediate cost class for planetary missions, and multiple proposals are in preparation. The next planetary Decadal Survey will be chartered by 1QFY20, and its results reported out to NASA in 2QFY22 [5]; its deliberations will be informed by the outcome of all these initiatives.

Despite the current activities, opportunities, and interest, lack of a formal program structure precludes rapid progress for an OWEP. Nothing akin to what has been delivered by the Mars Exploration Program (MEP) over the past 15 years can occur with the current model. The strategy analysis presented here treats the governing programmatic constraints, technical uncertainties, and policy gaps that cause this to be so. Then it lays out technical constraints for results-based OWEP decision making, and multiple options for making progress in this environment. It derives and presents candidate technology investments and policy decisions that would have high leverage over the viability and velocity of an OWEP.

Not like MEP: The MEP has been able to make rapid progress just since the early 2000s because: 1) Mars-distance missions are technically moderate; 2) the 26-month synodic cadence of half-year transfers to Mars allows mission formulation to be responsive to emergent findings; 3) NASA controls project new-starts within a single Congressionally funded program budget line; 4) NASA is thus able to direct New Frontiers-class missions that implement key steps of a progressive investigation; and the multi-mission program accommodates both 5) program-dedicated technology investments and 6) operational infrastructure that simplifies individual missions. Not one of these six key conditions exists for the virtual OWEP envisioned by Congress.

The technical challenges for an integrated OWEP are formidable. Missions to the Jovian and Saturnian ocean worlds are intrinsically power-challenged: sunlight at Saturn is only 1% as strong as at Earth. When limited to the type of expendable launch vehicles standard for NASA planetary exploration, missions require half-decade (to Jupiter) or decade-long (to Saturn), transfers with multiple gravity assists: a single one-way mission to explore Enceladus or Titan would take as long as has the entire MEP to date. Key pieces of the overall scientific puzzle of ocean-world phenomenology are found at multiple moons distributed across interplanetary distances, rendering shared in-space operational infrastructure (e.g., MEP's telecommunication relays and observational assets) moot. And the oceans themselves are inside the moons, beneath kilometers of cryogenic ice.

In addition to these endemic physical challenges, a "virtual program" imposes severe handicaps to progress: development of OWEP-enabling technologies must compete for priority with other solar system objectives; and every mission requires individual new-start approval. The selection process for PI-led, competed missions (New Frontiers and Discovery) is semi-stochastic: selection depends on what is proposed, and how the proposals fare under independent evaluation by SOMA (the NASA Science Office of Missions Assessment). Ocean-worlds missions compete directly against other science objectives identified by the current Decadal, and NASA cannot directly "put its thumb on the scale" to assure selection of ocean-worlds investigations. Thus New Frontiers and Discovery can never be useful for strategic planning: the "program" could end up comprising only the Europa mission and concept currently in work. NASA's Planetary Science Division has no class of mission opportunity comparable to the MEP backbone (MGS, Odyssey, MER, MRO, and the potential NeMO, all of which are directed medium-class missions). Without a genuinely strategic program plan, the great promise of an OWEP is highly likely to remain unfulfilled.

Strategic options: The solar system serves up almost a dozen diverse ocean worlds [6]. By various counts there are 2-3 relict ocean worlds, including Mars, Ceres, and possibly even Venus. At least five Jovian and Saturnian moons have global subsurface salt-water oceans; three of these are already known to be in contact with silicate rock, a key to chemical habitability. A few implausibly tiny moons (e.g., Dione and Mimas) show tantalizing signs of interior liquid; and even the three Kuiper Belt Objects visited so far (Triton, Pluto, and Charon) evince dynamic geology caused by eutectic mixtures of water and ammonia. By systematically exploring this large set of targets, humanity can learn the limits of life's ability to appear, evolve, and survive.

The provisional assessment that Enceladus may be habitable is based on hard evidence – multiple lines of evidence more diverse and quantitative than we have so far for any other extraterrestrial ocean world. Some of the most compelling findings have been published even since the current Decadal Survey was issued, energizing this dynamic field. Although Enceladus' unique geophysics makes it the most accessible place for a direct search for biosignatures, a stepwise roadmap to find and then characterize life in this ocean world [7] can in some ways serve as a template for other ocean worlds as well.

OWEP progress would be accelerated if NASA could adapt a few key characteristics that have made the MEP so successful: 1) cross-cutting investments in enabling technologies not tied to or funded by individual mission projects; 2) directed, New Frontiers-class missions to conduct strategically pivotal investigations on a roadmap; and 3) common, multi-mission technical infrastructure. In the case of missions to distributed moons of Jupiter and Saturn, a primary example of such infrastructure could be the use of SLS (the Space Launch System) for launch onto direct-transfer trajectories into the outer solar system, which would halve trip time.

By comparing the default constraints with various options for a multi-decade, multi-world program, we frame high-leverage choices that NASA and its stakeholders could consider.

References:

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[4] A. McEwen, Roadmaps to Ocean Worlds, www.lpi.usra.edu/opag/meetings/.../day.../08-Roadmap-Ocean-Worlds-McEwen.pdf.

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[6] J. Lunine (2017) Ocean Worlds Exploration, Acta Astronautica 131 pp.123–130.

[7] B. Sherwood (2015) Strategic map for exploring the ocean world Enceladus, Acta Astronautica 126 pp.52–58.

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