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STRATEGIC MAP FOR EXPLORING THE OCEAN-WORLD ENCELADUS
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Introduction: Cassini's discovery of jets emitting salty water from the Saturn's small moon Enceladus is one of its most astounding results. Measurement of salts and organic species in the resulting plume, finding that tidal stretching at apocrone valves the jet activity, modeled lifetime of E-ring particles, and gravitational inference of a long-lived, large water reservoir in contact with the rock core all indicate that Enceladus meets textbook conditions for habitability: liquid water, biologically available elements, energy source, and longevity of conducive conditions. Enceladus is among the best places in our solar system to search for direct evidence of biomarkers.

Exploring an ocean world: Enceladus also proffers the simplest access by a flight mission to telltale molecules, ions, isotopes, and potential cytofragments, since its plume continuously expresses material from the ocean directly into space. In situ mass spectroscopy of the plume, plume sample return, in situ investigation of plume snow on the surface, direct sulcus and vent exploration, and eventually submarine exploration can all be envisioned.

However, the strategic urgency and feasibility of planning and funding elaborate in situ exploration of this ocean world will hinge on new data revealing promising results. The very first steps of the roadmap are pivotal.

Two straightforward mission concepts, one Discovery-class and one New Frontiers-class, are: flythrough plume analysis using gas and particle mass spectrometers, upgrading the Cassini INMS and CDA measurements but with modern, high-resolution instruments; and collection of plume ice particles, dust, and gas upon Stardust-like flythrough, followed by sample retrieval for comprehensive analysis in terrestrial laboratories.

Building a strategic map: The mission waypoints on an integrated strategic map each require unique capabilities, address focused science questions, and yield results important for setting priorities and making subsequent in-vestments. However, overlaid on this logical sequence are important, mutually competing programmatic constraints: astrobiology pursuits at other ocean worlds and Mars, and exoplanet spectroscopy; cadence of realistic opportunities for mission selections and formal science-community planning cycles via Decadal Surveys; programmatic and even popular impatience to await interim results before vectoring investments in enabling capabilities; and alignment of US exploration strategies with international partner goals. As with Mars for many years, anticipation of interesting eventual results may be a key driver of strategic intent, able to withstand absence of validation for many years. And as for major exploration pursuits like Cassini-Huygens and the International Space Station, synergy among international partners may prove key for establishing and sustaining programmatic intent and momentum.

Key enabling elements for long-term exploration of the ocean-world Enceladus include: coherent sequence of science questions addressable by various type of mission; technologies that mature at the right time to enable both mission performance and approval (e.g., planetary protection); integrated concepts whose cost estimates survive review; lessons learned from analog exploration (e.g., terrestrial oceanography and extremophile research), and community momentum and international partnerships.

Decision levers and opportunities for action: Analysis of these elements of the strategic map yields a short list of decision pressure points for the next two decades. Using these opportunities the community may systematically prosecute the grand objective of finding and exploring an alien ecosystem within the working lifetime of today's graduate students. If missed, however, progress toward an age of comparative ocean exploration will be episodic, haphazard, and slow. Windows for making significant advances are sparse, and much remains to be done to prepare to take advantage of them.

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