SCIENCE OBJECTIVES FOR A MISSION CONCEPT TO ENCELADUS: THE ASTROBIOLOGY EXPLORATION AT ENCELADUS (AXE).

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Introduction: The Cassini-Huygens mission provided unprecedented information regarding Enceladus' surface and interior, including the discovery of a subsurface ocean and strong evidence for water-rock interactions, which could provide the physical and chemical conditions conducive to habitability as we know it [1]. Cassini identified tectonic fractures at Enceladus' south pole from which a cryovolcanic plume is sourced, which very likely contains material from the subsurface ocean [2]. Access to this subsurface ocean via the analysis of plume material presents a unique and exciting opportunity to examine the interior chemistry of an icy moon, including any potential biosignatures, without the cost and risk associated with landed mission architectures. Astrobiology eXploration at Enceladus (AXE; Fig. 1) is a New Frontiers (NF) class mission (based on the NF-4 AO) designed to examine the surface and interior of Enceladus in an effort to examine its potential for past or present life. Here, we present the science objectives of the AXE mission, their rationale, and the necessary measurements required for their science closure.

Science Objectives: The primary goal of the AXE mission is twofold: (1) to search for biosignatures within the plume of Enceladus, and (2) to contextualize potential biosignatures through an assessment of Enceladus's habitability in space and time. These goals are expressed through four science objectives (Fig. 2), described in detail below, which are achieved using an instrument payload consisting of a high-resolution telescopic camera and a mass spectrometer, with gravity science conducted using a high gain antenna. For more detail regarding the science mission profile, mission architecture, and spacecraft trajectory, please see the adjacent mission implementation abstract [3].

1. Determine whether the molecular and isotopic distributions in the Enceladus plume are a result of biological activity or abiotic processes. Analysis of the Enceladus plume and dust from Saturn's E-ring by Cassini revealed both an abundance of small organics and evidence for larger, more complex organics as well [4]. These organics are very likely sourced directly from the ocean of Enceladus, providing a means to probe the chemical inventory of the subsurface *in situ*. With this in mind, AXE would examine the organic chemical distributions and relative isotopic abundances at Enceladus by direct plume sampling with mass spectrometry in search of any complex abiotic chemical processing and/or potential biological activity ongoing within the icy moon.

Fig. 1. *AXE mission logo.*

2. Determine whether Enceladus is in thermal equilibrium and therefore capable of sustaining a long-lived subsurface ocean. Cassini observations of Enceladus' gravity field and libration strongly suggest the presence of a subsurface ocean [5-6], but it is uncertain if it is permanent or transient. AXE would estimate Enceladus' thermal budget through a comparison of the tidal heat generated by Enceladus to the heat conducted through its ice shell. The former would be calculated from Enceladus' orbital migration rate since Cassini [e.g., 7-8], while the latter is intimately linked to ice shell thickness that AXE would infer from degree-10 gravity field measurements [9]. A disagreement between the values would be indicative of rapid melting or freezing of the ice shell/ocean.

3. Determine whether plume material is delivered to the surface via open crevasse 'boiling' or explosive, cryovolcanic eruptions. While Cassini characterized eruption rates and duration of the observed plumes [2], the actual structure of the conduits that connect the ocean to the surface through the ice shell remains a critical unknown. Two endmember models of eruption dynamics, and the ice shell plumbing structures that support them, currently persist: a) an open-crevasse model [11] and b) a cryovolcanic, eruptive model [12]. As vent morphology and behavior

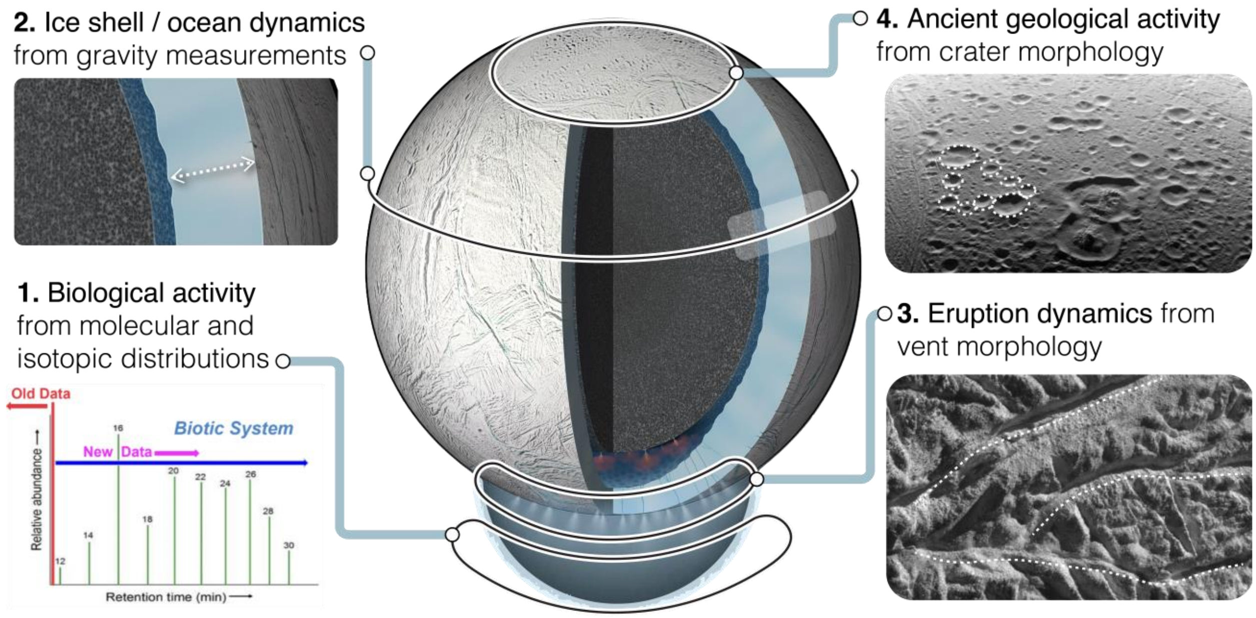

Fig. 2. *Schematic summary of four key science objectives (1-4) addressed by the Astrobiology eXploration at Enceladus mission. Enceladus interior diagram and crater/vent images obtained from NASA/JPL-Caltech.*

at the surface is a direct reflection of eruption dynamics for each of these scenarios, AXE would use its high-resolution telescope camera to accomplish this scientific objective through observations of changes in vent width and morphology at different points in Enceladus' orbit.

4. Determine if the geologic activity that produced and is modifying the South Polar Terrain (SPT) is unique to this region or has influenced other regions. Cassini images provided morphological insights into large (km-scale) crater populations, informing driving processes such as past heat flux on Enceladus [12]. However, craters that are too small to be viscously relaxed have morphologies that can instead record plume fallout deposit (using depth/diameter ratios; [13-14]), as well as elliptical major-axis orientations that may record obliquity through time [15-16]. AXE would use semi-global camera coverage to map sub-km crater populations and determine if paleoplumes existed and/or if ice shell reorientation occurred in Enceladus' geological past. Importantly, regions of high heat flux would impact availability and locations of habitable environments over time.

Conclusions: AXE is a compelling New Frontiers class mission architecture capable of utilizing a low-cost, two-instrument design to accomplish multiple critical scientific goals concerning Enceladus' habitability and potential for life, while fitting within the confines of the NF-4 AO. Here, we present four science objectives that range in focus from directly searching for biosignatures through analysis of plume material to constraining the evolution of the ice shell over geologic timescales (Fig. 2). While Enceladus was identified as a Flagship class mission destination in the 2012-2022 Decadal Survey [17], we show that a New Frontiers class mission to Enceladus can be both economically feasible and capable of offering valuable science return. Enceladus could be explored with multiple mission scales and cost caps, demonstrating flexibility in future mission designs targeting Enceladus.

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