MISSION IMPLEMENTATION FOR A NEW FRONTIERS MISSION CONCEPT: THE ASTROBIOLOGY EXPLORATION AT ENCELADUS (AXE).

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Introduction: The Cassini-Huygens mission conducted the most in-depth characterization of Enceladus' surface and interior to date. In particular, it is now known that interactions between the subsurface ocean and rocky core could create a potentially habitable environment [1]. This provides a compelling case for a follow-up mission to dive deeper [2].

To that end, the Astrobiology eXploration at Enceladus (AXE) mission would search for biosignatures and evaluate present-day and historical habitability of Enceladus by completing 30 flybys of the moon. During this tour, AXE would (1) travel through and collect material in the active plumes on Enceladus' south pole, (2) conduct gravity measurements with radio science to determine average ice shell thickness, (3) collect high spatial resolution images of active vents from low altitudes, and (4) characterize morphologies in the global crater population to discern the history of global geologic activity. These mission requirements are driven by the science objectives of AXE, further detailed in [3]. Here, we present a mission architecture capable of accomplishing these objectives.

Mission Design and Trajectory: The spacecraft and subsystems are designed to fit into a 4-meter Intermediate-High performance class launch vehicle fairing [4] and would launch from Kennedy Space Center. Assuming a NASA New Frontiers 5 AO release by 2024, a 21-day target launch window beginning Feb. 22, 2033 has been chosen with characteristic energy $C_3 = 15.3\ \text{km}^2/\text{s}^2$. The total mission duration would last 14.1 years, 9.1 years of which would be the interplanetary cruise to Saturn (Table 1).

AXE requires a 1.0 km/s delta-V for Saturn Orbit Insertion and 0.05 km/s over the course of a year for pump-down. During pump-down, orbital eccentricity lowering and Enceladus orbit targeting is done via Titan flybys. The AXE spacecraft would maintain a minimum 1300 km distance from Titan to prevent contamination of the spectrometer.

During the tour phase of Enceladus, a minimum of 30 flybys are required with minimum altitudes ranging between 30-50 km. Each flyby would require 25 m/s delta-V for targeting and clean-up of trajectory, and would occur approximately every two weeks. Total expected delta-V is 0.75 km/s. Per the heritage from Cassini and Europa Clipper, AXE would rely on Optical Navigation for each flyby.

Flyby	Date	V_{inf} (km/s)	Altitude (km)
Venus	8/13/33	8.232	7,850
Earth	6/25/34	10.890	10,800
Earth	6/25/35	10.908	300
Earth	10/15/37	10.881	1,790
Jupiter	9/25/39	7.358	1,570,000

Table 1. *Gravity assists on cruise to Saturn with target dates. V_{inf} represents the speed of the spacecraft after each encounter, relative to the assisting planet.*

To comply with NASA's Planetary Protection guidelines, 0.2 km/s delta-V is allocated for safe disposal of AXE. This brings the total delta-V with margin of the mission to 2.0 km/s, in compliance with NF-class constraints.

Science Mission Profile: Four investigations would be conducted over the course of the science flybys, each of which would address one of our science objectives

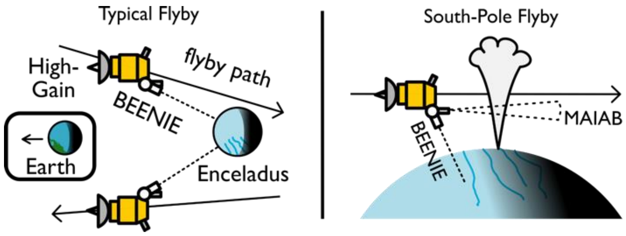

Fig. 1. *Instrument operations in a given Enceladus flyby. The right side depicts two separate flybys.*

[3]. Instrument operations during these flybys are illustrated in Fig. 1 and detailed below.

The first would be accomplished with the Molecular And Isotopic Analysis for Biomarkers (MAIAB) instrument, a mass spectrometer based on the JPL quadrupole ion trap mass spectrometer (QITMS [5] pointed in the ram direction while the spacecraft passes through the plumes. The collected plume material is then available to be analyzed by MAIAB to determine its biogenic potential.

The second investigation would address the question of whether Enceladus is in thermal equilibrium. Doppler shift in the radio signal from a high-gain antenna would be used to find deviations in Enceladus' gravity field to spherical harmonic degree 10. This would allow the ice shell thickness to be determined to within 10% and thus the total heat flux conducted through it [6]. This is compared to tidal heating (determined by how much Enceladus' orbit has migrated since Cassini [e.g., 7,8]) to answer if Enceladus is in thermal equilibrium.

The third investigation takes place during the five low-altitude flybys (< 80 km) when the Better Eyes on ENceladus IcE (BEENIE, based on LORRI [9]) camera would collect high spatial resolution images of the south polar tectonic fractures to determine vent morphology.

Finally, during at least 22 of the flybys, BEENIE would be used for surface mapping of cratered surfaces during arrival/departure to construct topographic maps. Spatial variability of crater depths and orientation of elliptical craters would inform whether Enceladus has experienced past plume activity elsewhere or undergone ice shell reorientation [e.g., 10].

Flight System: The AXE spacecraft (Fig. 2) hosts two instruments: the mass spectrometer MAIAB and imager BEENIE. Both these instruments are gimbaled such that the camera has two degrees of freedom and the spectrometer one degree of freedom. This would allow both instruments to point the required directions while the radio dish points at Earth to transmit during flybys for gravity (Fig. 1).

AXE would be powered by a Next Generation Radioisotope Thermoelectric Generator. This serves a dual purpose, providing a method of warming the spacecraft with its waste heat as well. Further, the radio dish acts as a heat shield during the Venus flyby of AXE's interplanetary cruise, as well as a shield during traversals of Enceladus' plume. Both design decisions have heritage from the Cassini-Huygens mission.

The spacecraft design is conservative, avoiding risky structures such as long composite booms or deployables, while utilizing heritage for thermal management, propulsion, and attitude control. The on-board Sphinx avionics system will soon gain flight heritage on cubesat missions [e.g.,11].

We presently consider two trades. One involves how large the radio dish must be to adequately keep the spacecraft cool at closest approach to the sun. The other considers how much image smear is reduced by movement of the BEENIE camera vs. movement of a mirror within it.

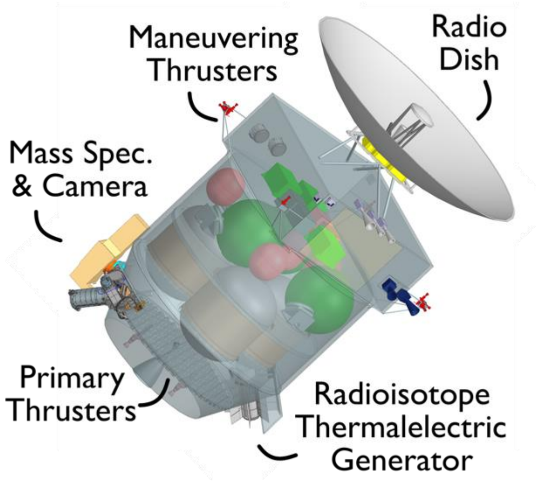

Fig. 2. *AXE with some key components labeled.*

While descoping of either MAIAB or BEENIE were investigated, we found the elimination of either would not maintain a compelling science return. Thus, our baseline and threshold missions are held equal. While this mission was designed within a New Frontiers 4 budget profile, a New Frontiers 5 budget could encompass an additional instrument. A thermal camera would bolster observations of the surface, the South Polar Terrain, and additional specific targets identified during the mission.

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