THEO Mission Concept: Testing the Habitability of Enceladus's Ocean

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Introduction: Saturn's moon Enceladus affords an excellent opportunity in the search for life and habitable environments beyond Earth. Representing a key theme of the 2013 Decadal Survey [1], the study of Enceladus would further our understanding of life and habitability in our solar system by addressing (i) the limits of life under colder, fainter sun conditions, (ii) the importance of hydrothermal alteration in the origin of life, and (iii) the distribution of molecules in the solar system that may have served as the precursors for life.

Plumes of predominately water vapor and ice spew from the south pole of Enceladus [2,3,4]. Cassini's data suggest these plumes are sourced by a liquid reservoir beneath an icy crust that contains organics, salts, and water-rock interaction derivatives [5]. Thus, the ingredients for life as we know it— liquid water, hydrocarbons, and energy sources— are all available in Enceladus's subsurface ocean. We only have to sample the plumes to dramatically enhance our understanding of this hidden ocean environment.

Objectives: The feasibility study, Testing the Habitability of Enceladus's Ocean (THEO), would primarily focus on gaining inference into whether Enceladus is habitable. Further, we would aim to investigate the following questions. (1) How are the plumes connected to the subsurface ocean? (2) Is there evidence of biological processes? (3) Are the abiotic conditions habitable? (4) What mechanisms maintain the liquid state of the ocean?

Instruments: The spacecraft would consist of five science instruments: mass spectrometer, sub-mm radiometer-spectrometer, visible spectrum camera, magnetometer suite, and doppler tracking (Table 1).

Observing Schedule: Enceladus data would be collected from three orbital attitudes (high, medium and low) with each representing a separate mission phase (Fig. 1). Examining the plumes during the high phase would be mission critical. Therefore, the schedule would include a limited number of orbits from 12am to 12pm before transitioning to a 6am to 6pm orientation for the duration of the mission (Table 2). During in-situ sampling and imaging of the plumes, the instruments would point in the direction of the spacecraft's trajectory.

Table 1: Instrument Suite

Acronym/ Instrument	Name	Data(Gb)/ Mass(kg)/ Power(W)/ Heritage
SWAMP Mass spectrometer	Spacebourne Water Analysis by Molecule Pulverization	12/50/15.3/ MASPEX
WAVES Sub-mm	WAter Vapor Emissions Sub-mm	6/22.9/59/ MIRO
DRIPS Camera	Dynamic Resolution Imaging of Plumes Surface	186/1.53/12/ Malin
OSMOSIS Magnetometer Suite	Ocean Sensing Magnetometer Orbital Salinity Induction Science	1/6.12/3/ Cassini
GEISER Doppler Tracking	Gravity Engaging Investigation Sensing Enceladus with Radio	

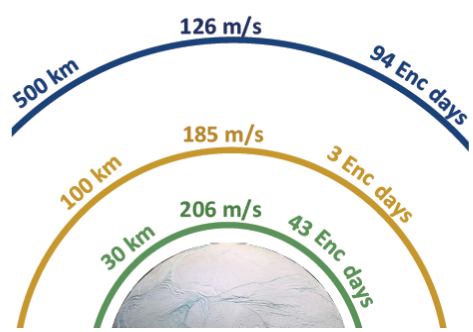
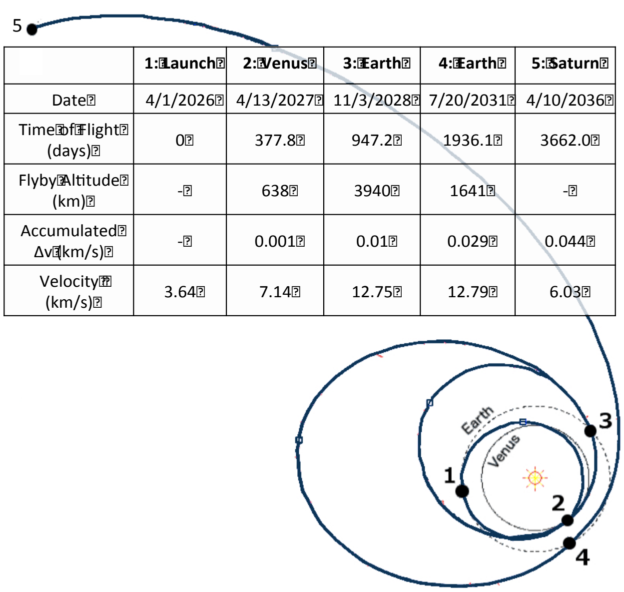


Figure 1: Three orbital phases of Enceladus observation

Table 2: Instrument Altitude, Orbits and Tasks

Altitude (km)	# of orbits	SWAMP	WAVES	DRIPS	OSMOSIS	GEISER	Science task
500	200	-	ram	ram	-	-	Ice/vapor relative abundance
	100	ram	-	-	-	-	Vapor sampling
100	10 (entry) 20 (exit)	ram	nadir	-	-	on	Vapor sampling, thermal mapping
30	300	ram	nadir	-	on	on	Vapor sampling, SPT thermal mapping, ion flux, gravity field
	300	-	-	nadir	on	on	Geological mapping, , ion flux, gravity field

Mission Design: The trajectory of THEO (Fig. 2) would obtain the needed kinetic energy with one Venus and two Earth gravity assists. Upon arrival at Saturn, THEO would reduce its delta-v by making fly-bys of Titan, Rhea, Dione, Tethys, and Enceladus before the Enceladus orbit insertion. To meet requirements set by planetary protection, THEO would depart its Enceladus orbit after its nominal six month mission on an impact trajectory to Tethys.



	1: Launch	2: Venus	3: Earth	4: Earth	5: Saturn
Date	4/1/2026	4/13/2027	11/3/2028	7/20/2031	4/10/2036
Time of Flight (days)	0	377.8	947.2	1936.1	3662.0
Flyby Altitude (km)	-	638	3940	1641	-
Accumulated Δv (km/s)	-	0.001	0.01	0.029	0.044
Velocity (km/s)	3.64	7.14	12.75	12.79	6.03

Figure 2: Interplanetary trajectory and proposed schedule

Spacecraft Design: The proposed spacecraft is an orbiter with a main cylindrical body that is 4.5m in height and 1.5m in diameter (Fig. 3). A 3m gimbaled high-gain antenna would be mounted on the top of the main body. Four roll-out solar arrays (ROSA) would deploy from the main body providing 72 m^2 of area with an estimated power production of 594 W.

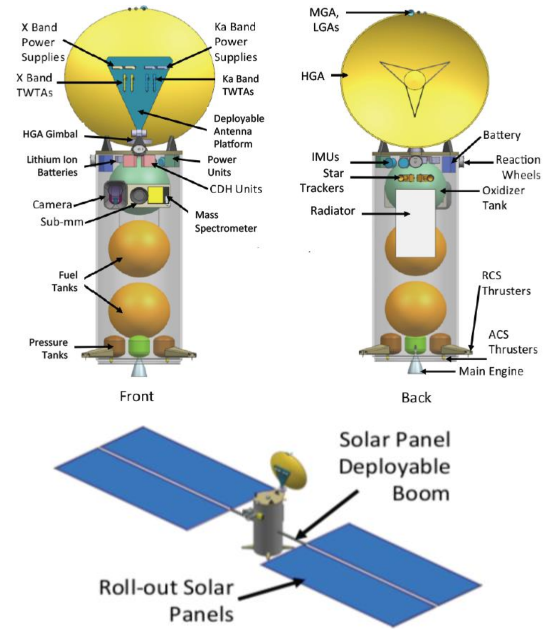


Figure 3: THEO Spacecraft Configuration

Discussion: This feasibility study aims to provide a viable mission concept to study the habitability of Enceladus. We made the following considerations during the development of this mission concept. Orbiter architecture was selected over flyby because of the minimum delta V difference, increased flight time, increased thermal costs from propellant, and slower orbital velocities. Solar power was selected over nuclear to avoid regulation compliance costs and restrictions, as well as the mass cost associated with thermal generators. The science mission would be specifically enabled within the cost cap by using solar panels. Based on the science goals of the Decadal Survey, this mission concept would meet a multitude of the Enceladus goals as a New Frontiers class mission. Specifically, it would take advantage of the direct sampling opportunities of a subsurface ocean.

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