ASSESSING THE HABITABILITY OF AN ACTIVE OCEAN WORLD: THE ETNA MISSION CONCEPT TO EXPLORE ENCELADUS' TIGER STRIPES. Chandrakanth Venigalla[1], Ariel N. Deutsch[2], Paolo Panicucci[3,4,5], Graciela González Peytaví[6], Jennifer Pouplin[7], Laura Tenelanda-Osorio[8], Andrea Guarriello[9,10], Emiliano Castillo Specia[11], Yun-Hang Cho[12], Victoria Da-Poian[3], Onalli Gunasekara[13], Lewis Jones[14], Mariya Krasteva[15], Thasshwin Mathanlal[16], Nicole Villanueva[17], Sam Zaref[18], [1]University of Colorado, USA (Chandrakanth.Venigalla@colorado.edu), [2]Brown University, USA, [3]ISAE-SUPAERO, France, [4]Centre National d'Etudes Spatiales, France, [5]Airbus Defence & Space, France, [6]Universität der Bundeswehr, Germany, [7]Purdue University, USA, [8]Universidad Eafit, Colombia, [9]Heriot-Watt University, UK, [10]Institut d'Électronique et de Télécommunications de Rennes, France, [11]Tecnologico de Monterrey, Mexico, [12]University of Sheffield, UK, [13]University of Illinois Urbana-Champaign, USA, [14]California Institute of Technology, USA, [15]Concordia University, Canada, [16]Luleå University of Technology, Sweden, [17]Pontificia Universidad Católica del Perú, Perú, [18]Rhode Island School of Design, USA.

Introduction: The presence of contemporary habitats elsewhere in the Solar System with the ingredients necessary to sustain life [1] is one of the strongest drivers of exploration. Do such habitats exist, and do organisms live there now? One of the most promising targets to explore these questions is Enceladus – an icy world where a liquid water ocean exists between a dynamic icy shell and a potentially active silicate interior [2–6].

Enceladus, one of Saturn's moons, became a compelling target when Voyager [7] revealed it to be our Solar System's most reflective body, suggesting that the surface is composed of fresh snow or ice [3, 8–9]. The Cassini spacecraft subsequently imaged active plumes erupting material sourced from beneath the moon's south polar crust and expelling it tens of kilometers into the atmosphere [5], revealing Enceladus as an active world, likely to be driven by subsurface geothermal activity [6]. The Cassini mass spectrometer detected four important biogenic elements coincident with the building blocks of terrestrial life: H, C, O and N [4]. However, the limited resolution of the Cassini instrument [10] prevented the detection of P and S: the two additional key biomarkers of Earth-based life that are critical in assessing astrobiological potential. Thus, questions remain related to the habitability of Enceladus.

The coincident presence of an energy source, a catalyst for life, and the building blocks of Earth-like life promotes Enceladus as a paramount target for studying the origin and evolution of habitable conditions and life throughout our Solar System. Among all of the other ocean worlds in our Solar System, Enceladus is the only active body that provides direct access to its ocean through the expulsion of subsurface material.

Etna is a mission concept designed and proposed during the 5th Caltech Space Challenge 2019 (spacechallenge.caltech.edu) in order to "assess whether Enceladus provides the conditions necessary (or sufficient) to sustain biotic or pre-biotic chemistry." In Greek mythology, Enceladus was struck down during an epic battle for control of the cosmos and buried under Mount Etna, where the Giant is trapped today.

Science goals: The Etna mission is designed to address two overarching science goals, responding to two of the three identified cross-cutting science themes of the Decadal Survey: *Planetary habitats* and *Building new worlds*. The first science goal of Etna is to understand how Enceladus provides habitable conditions. To accomplish this goal, Etna will (1) constrain the dynamics of the energy sources that drive surface and sub-surface interactions, (2) assess the chemistry and bulk composition of the subsurface, and (3) analyze the periodicity and lifetime of habitable conditions. This goal addresses primary questions in the Decadal Survey regarding the primordial sources of organic matter, possible locations of ongoing organic synthesis, and locations of contemporary habitable environments [1]. Understanding the moon accretion model for Enceladus is relevant to addressing the habitable conditions of the moon in order to constrain the origin and evolution of volatiles and organics in the Enceladus system, such as whether these interior materials are primordial, derived from accretion or produced via chemical reactions such as serpentinization or Fischer-Tropsch reactions [11].

The second science goal of Etna is to characterize the biotic and abiotic signatures of Enceladus. Etna will (1) characterize the composition, structure, and ratio of subsurface molecules, (2) determine the presence of visual biomarkers in the Tiger Stripes ejecta, and (3) determine how H, C, O, and N are produced. This goal directly addresses the Decadal Survey's priority of determining whether any extra-terrestrial habitats are or ever have been occupied by organisms [1]. This science goal also directly addresses one of the four Science Questions identified by NASA's Science Mission Directorate as the motivation for Solar System exploration: "How did life begin and evolve on Earth, and has it evolved elsewhere in the Solar System?"

Instrumentation: The mission payload consists of six scientific instruments (Table 1), split between an orbiter and a lander, selected to fulfill the scientific goals of the mission. All of the instruments have high TRL with the exception of the geophones, which were explored as a component of our design challenge.

Instrument	Goal 1	Goal 2	Phase
Ultra-Violet Imaging Spectrograph	X		O
Optical Camera	X		O
Radio Science	X		O
Ion Microscope + Mass Spectrometer	X	X	F, L
Temperature Sensors	X		F, L
Geophone Surface Probes	X		L

Table 1. Science payload. The mission phase is denoted by O for orbital, F for plume fly-through, and L for landed.

Mission architecture: The Etna spacecraft (Fig. 1) consists of a single orbiter, a single lander, and three geophone surface probes (Fig. 2) that form a network of distributed landers.

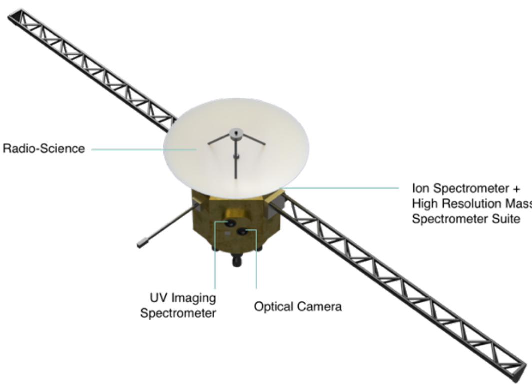

Fig. 1. The orbiter, housing the lander and surface probes.

The Orbiter. The orbiter (Fig. 1) will be placed in the Saturn-Enceladus system to conduct remote science, finalize the precise landing location, and relay data from the landed assets back to Earth. It will also conduct fly-throughs of the active plumes. The orbiter incorporates a variety of subsystems with high TRL components, a Juno-heritage propulsion system, and RTG-provided power. The lander stays attached to the orbiter for early science operations, then is released from the orbiter for surface science operations.

The Lander. Etna includes a robust soft lander that is radiation tolerant. Design drivers for the lander include the need for a soft and upright landing, the ability to use the same instrument package (Ion Microscope + Mass Spectrograph) both in-orbit and on the surface, and the need to deploy the geophone probes during descent to the surface.

The Surface Probes. An important component of our driving science is related to the dynamics, periodicity, and lifetime of habitable conditions. We developed geophone surface probes with the purpose of characterizing the dynamics of the icy crust and constraining dominant stress directions, magnitudes, and timescales in the South Polar Terrain.

The geophone probes (Fig. 2) are spun up along axis and released from the orbiter during descent. Shock absorbers, designed for impacting a hard surface, mitigate the landing impact. In the case of snow-covered ground, the probes extend their Storable Tubular Extendible Member (STEM) into the surface until contact is made with a hard surface. This allows the seismic vibrations (otherwise damped out by the snow) to be observed by the probe. From the top end of the probe, the Telescopic Tubular Mast (TTM) is deployed. This 1.5-m antenna will clear the surface to allow communication with the orbiter, even during precipitation events. Temperature control of the instruments is managed by an insulating layer of aerogel and an internal resistive heater. Two LP 33330 6Ah batteries are used as power sources and provide sufficient power for the threshold of one week operational life of the probes.

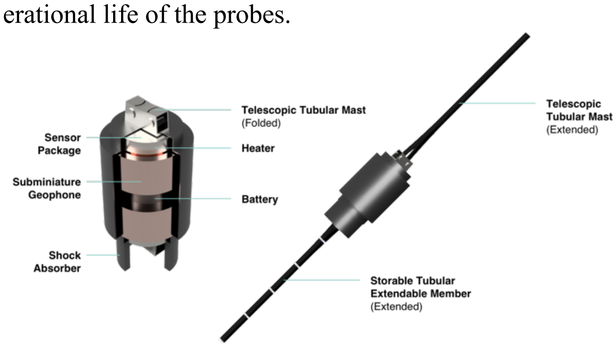

Fig. 2. Diagram of an Etna geophone surface probe.

Conclusions: Enceladus is unique Solar System target because of the coincident presence of energy catalysts and the building blocks of Earth-like life, and because active plumes provide unparalleled access to its subsurface ocean. The Etna mission concept provides a feasible architecture to explore Enceladus as a means of better understanding the origin and evolution of habitability and life.

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