

Mission Concept and Geophysical Analysis with SNOW-E:

Seismic iNvestigations of Ocean Worlds at Enceladus. J. Noel^{1,2}, C. Derosett³, K. Gansler⁴, C. Mitchell⁵, D. Santiago Rodriguez⁶, S. Nguyen⁷, S. Gnesin⁸, A. Straziuso⁹, C. Deaver²

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Summary: After searching for life on Mars, the planetary science community is now expanding its pursuit to the ice worlds of the outer Solar System. Europa Clipper is set to launch in 2024 [1] followed by Dragonfly to Titan in 2027 [2]. Absent from approved and scheduled missions, however, is one to Saturn's small but unexpectedly active moon, Enceladus.

Seismic iNvestigations of Ocean Worlds at Enceladus (SNOW-E) is designed to be a secondary payload lander of a primary orbiter in the Saturnian system. Developed with strict budgetary, mass, and size constraints, this desk-sized lander would gather geophysical data from Enceladus's surface and core to determine the geologic cause of organic material detected by Cassini's Cosmic Dust Analyzer (CDA) in 2015 [3]. SNOW-E would study seismic activity and measure deformation and gravitational response to tidal loading in an effort to constrain the moon's physical structure, core composition, and subsurface ocean depth. This analysis would span the moon's entire 33-hour orbital period around Saturn. By characterizing seismic activity in Enceladus's ice shell and potentially in the rocky interior, SNOW-E would contribute to our understanding of fracturing, faulting, and volcanism [4,5]. SNOW-E would collect laser altimetry, vector gravimetry, three-component seismometry of the south polar region (SPR) and color images of its landing site in the Tiger Stripe area. This data would enhance the planetary science community's understanding of small but geologically active worlds as a part of NASA's continued search for extraterrestrial life.

Introduction: With a radius of 252.1 km [6], Enceladus was presumed to be a cold, frozen, inactive world before Voyager's visit in 1980. Surprisingly, Voyager's images showed a relatively young surface that indicated recent geologic activity, which was later confirmed by Cassini's images of active plumes erupting from the SPR. As Cassini flew through the plume's hydrous contents, the CDA measured salt compositions suggestive of prolonged contact between salt-rich water and rocky material [3]. Such environments may host energy sources for possible chemosynthetic biota, indicative of extraterrestrial life [7]. Physical observations would constrain the nature of suspected interactions between a siliceous core and a saltwater ocean within Enceladus, furthering our exploration of conditions for life beyond Earth.

Objective: SNOW-E's mission is to gather geophysical data of Enceladus's interior, supplementing Cassini's flyby observations. SNOW-E would help find

the geologic source of Cassini's discovery of organic material and create preliminary maps of Enceladus's internal structure. SNOW-E would collect:

- Topographic data of the active SPR to complement geophysical measurements and aid descent surface distance detection and navigation
- Gravimetric and seismic data to measure tidal energy output to learn about the internal structure of Enceladus
- Visual images to characterize the surface and confirm successful spacecraft touchdown

Topographic data would be captured during descent using laser altimetry. A series of 8 to 30 images would be taken when SNOW-E lands. SNOW-E's primary focus would be vector gravimetry and seismology during its 33-hour lifetime on the surface. This mission duration ensures that the stresses experienced by Enceladus can be determined over the course of an entire orbit around Saturn. The seismometers would detect signals related to plume vents opening and closing as well as seismic signals from ice shearing. These observations should provide information about periodic changes to the tidal stresses Enceladus experiences.

Payload Overview: SNOW-E was developed under design and budget limitations from NASA's L'SPACE Academy's Mission Concept Academy [8]. The assigned specifications were:

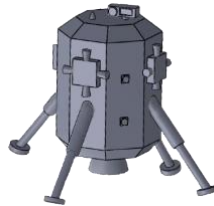
- Secondary mission released from primary Enceladus orbiter on a polar trajectory
- Maximum budget of \$400 million
- Maximum payload mass of 77 kg
- Maximum stowed volume of 51×51×76 cm

With a limited budget, SNOW-E would exclusively contain instrument designs made for prior missions. This would decrease the instrument development period and provide significant savings.

The LIDAR laser altimeter, initially designed for the Hayabusa2 mission [9], would provide data to create altitude maps of the Tiger Stripe region in higher resolution than Cassini data could. The LIDAR data would initially be used for guidance, navigation and control procedures during landing. LIDAR topographic data, used in combination with gravimetry to determine elastic thickness variations, is critical to understanding the icy crust's properties. The VEGA gravimeter, designed for small-scale planetary missions [10], would periodically measure Enceladus's absolute gravity vector. Properties of the moon's suspected

differentiated interior can be inferred using gravimetry data to calculate tidal response. From the Rosetta mission's Philae lander, four CASSE seismometers would complement the gravimetric measurements in mapping Enceladus's interior. Seismic data would reveal activity intensity and indicate the direction where activity occurs [11]. One seismometer would be placed on each foot forming a mini-array. SNOW-E's Mastcam-Z system, from the Perseverance Mars rover [12], would take color images of Enceladus's surface. Images would aid in understanding the surface features of Enceladus and confirming SNOW-E's safe landing.

Figure 1: Initial concept design for Seismic iNvestigations of Ocean Worlds at Enceladus (SNOW-E) lander



BAE Systems' RAD5545 SpaceVPX single board computer would support SNOW-E's instrumentation [13]. It would control SNOW-E's thermal and power subsystems, direct instrumentation, and store data collected while the orbiter is out of range. Communication with the main mission element would be provided by L3Harris's CXS-1000 satellite transponder [14] and AS-48915 conical spiral antenna [15]. The main mission element would serve as a relay, sending data back to earth. The lander would be powered by ten EaglePicher Lithium/CFx-MnO2 Hybrid Batteries [16].

Risk Mitigation: Enceladus's environment is extremely harsh compared to that on Mars and Earth's Moon. Gas planets like Saturn have strong magnetic fields which would bombard SNOW-E with ionizing radiation [17]. Radiation hardening of all electronics [18] and a whipple shield would protect SNOW-E's sensitive electronics in flight. The shield would also protect the spacecraft from micrometeoroids and debris during the seven years of travel time to Enceladus [19]. The most significant environmental risk for SNOW-E is the cold. Enceladus's surface temperatures are between 50 and 75 K [20]; much lower than those experienced by any Mars landers. An external bi-layer insulation system [21] and Minco insulated thermal patch heating system [22,23] would keep SNOW-E's interior at an operating temperature of 293K. For power, batteries were chosen over solar panels due to the short mission duration, design constraints, and limited solar flux at Saturn's orbit. Liquid water from the plumes requires SNOW-E to be waterproofed with an exterior polyurethane coat [24] to protect its payload. Planetary protection is essential for a lander on an ocean world. In addition to clean room processes and procedures, dry heat microbial reduction would be used on SNOW-E to prevent terrestrial contamination [25].

Concept of Operations: After release from its primary mission, SNOW-E would take 1.5 hours for a Hohman descent orbit insertion with one Aerojet Rocketdyne MR-106L 22 Newton engine [26] mounted on a 2-axis gimbal assembly [27]. Two Hyperion ST200 star trackers [28] would assist orientation and navigation and 16 1N monopropellant hydrazine thrusters [29] would provide attitude control. SNOW-E's descent would pause twice for detailed LIDAR imaging: at 7 km for 10 minutes and 5 km for 7 minutes. LIDAR would cease operations and Mastcam-Z would capture 8 to 30 long-exposure images upon surface contact. Once landed, the VEGA gravimeter would perform gravitational field strength measurements every 15 minutes during the mission, each measurement lasting 5 minutes. Thus, the average absolute gravity vector for each 5 minute measurement period would be calculated to return a magnitude of that vector and an angle. CASSE seismometers would be activated at landing and operate for the mission duration.

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