University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Etna

1 Approvals

	Name	Affiliation	Approved	Date
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Course Coordinator		CU/AES		

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2.1. Project Customers

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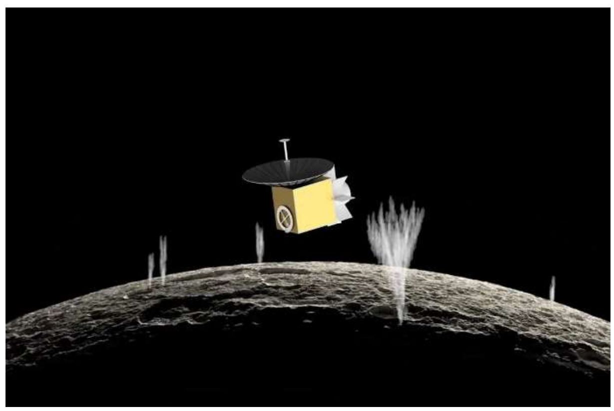
3 Problem and Need

The ASTROBi Foundation is working toward advancing the field of astrobiology. The company's Encelascope mission will be searching Enceladus, one of Saturn's moons, for signs of extant life. Enceladus is an icy moon with water geysers that erupt from the surface, sending plumes of water droplets and ice grains over 100 km above the surface of the moon. The Cassini mission to Saturn deemed the moon potentially habitable, mostly due to the water found on the moon. Cassini performed spectroscopy on the plumes and scientists were able to find water, salt, silica, methane, complex organics, and nitrogen. The salt concentration seems to be similar to that found in Earth's oceans, which is compatible with life. The silica from the samples is similar to silica that is found at hydrothermal vents on Earth, and the abundance of methane could be an indicator of biogenic sources. These samples are very encouraging for scientists, and for the ASTROBi Foundation. In addition, the radiation on Enceladus is less intense than the radiation on other moons or planets holding potential for life, providing more leniency in the electronics and design of the Encelascope mission.

The Etna Team will be working with the ASTROBi Foundation to build a compact digital holographic microscope for imaging plume material. This microscope is intended to be the baseline for the mission, as it shall be a flight-like payload integration that must meet a strict set of requirements. The microscope is expected to be able to characterize any microbial life that may be present in Enceladus's plumes. The image below is an artistic rendering of the spacecraft orbiting Enceladus during the science phase of the mission (1).



It was said that during Gigantomachy, a battle for control of the cosmos, the giant Enceladus was struck down and buried under Mount Etna - her volcanic plume believed to be his breath. The Encelascope mission aims to send instruments to Saturn's brightest moon in hopes of finding evidence of extant life. This team will begin the development of a microscope meant to conduct the first observations of life beyond Earth. It will do so by venturing into the moon's icy plumes - the breaths of Enceladus. Hence this project will hold the title of "Etna."

4 Previous Work

The ASTROBi Foundation's Encelascope mission isn't a direct continuation of a prior project. However, it can be said that it is an indirect continuation of the Cassini mission which flew through the ice plumes of Enceladus and discovered that the ocean underneath was similar to ours on Earth. The mission also has similarities to other space missions that gather samples and runs experiments on them, to further our understanding of our solar system. Two good examples are the Mars rovers gathering samples on mars and the OSIRIS-REx mission that retrieved samples from an asteroid. Both these missions show previous projects that pushed the boundaries and laid the groundwork for future missions such as the Encelascope.

With a rough foundation built from previous missions the Encelascope will likely become a heritage mission. This mission is one of the few if not only space missions that currently plans to fly with a holographic microscope to try to find life on Enceladus. This is a unique mission because it presents a relatively low cost and small scale mission with the intent to fly to outer solar system moons and detect life. This is recognized as a trade off since the detection algorithm for life is quite simple. The mission's outcomes would either be a definitive 'yes there is life' or a 'we didn't detect life but it is still possible.' Regardless, this instrument is the first use of a holographic microscope to try to find life beyond Earth by looking in the salty water plumes of Enceladus where life is the most likely to exist (3). If this mission is successful it could lower the barrier to entry for outer solar system missions. To our knowledge the farthest small scale missions have gone is Mars.

5 Specific Objectives

Success Level	Functional Objectives
1	Etna shall be able to cycle unlimited sample volumes of liquid water Etna shall weigh no more than 2.0 kilograms The microscope of Etna shall draw less than 10 watts The processor of Etna shall draw less than 10 watts Etna shall survive vibration testing Etna shall withstand -50C to +100C during survival and -15C to +40C during operation Etna shall be designed to support a 15 year mission life Etna shall be contained in a maximum 1U payload housing
2	Etna shall weigh less than 2.0 kilograms The microscope of Etna shall draw less than 5 watts The processor of Etna shall draw less than 5 watts Etna shall Survive vibration and TVAC testing Etna shall be contained in a less than 1U payload housing

Success Level	Sampling Objectives
1	Etna shall be able to capture images of microbe sized objects Etna shall capture images at a rate necessary to detect the movement of microbes Etna shall use a inline holographic microscope design Etna shall have a liquid water interface for receiving and expelling samples under expected operating conditions Etna shall capture images at a resolution of 0.8 micrometers in the X-Y direction Etna shall capture images at a resolution of 2 micrometers in the Z direction Etna shall have an instantaneous imaging volume greater than 2 microliters Etna shall have a configurable exposure length from 0.1 milliseconds to 1 second
2	Etna shall capture images at a resolution less than 0.8 micrometers in the X-Y direction Etna shall capture images at a resolution less than 2 micrometers in the Z direction

Success Level	Processing Objectives
1	Etna shall be able to output raw and compressed data of the captured images Etna shall be able to reconstruct the images collected into stacks of the 2D slices Etna shall be controllable from a functional ground control system Etna shall produce digital data Etna shall process data in a timely manner to keep up with the data collection process The heat from the processor shall not interfere with Etna's performance Etna shall be able to detect objects of no interest Etna shall transmit data under a 1 kbps downlink constraint
2	Etna shall use an optimized algorithm to reconstruct the collected images

Level 1 requirements are the most essential requirements and must be met to consider the project successful. Level 2 requirements reflect high level expectations that provide additional value to the customer. The final product will be a 1U payload, Etna, containing a holographic microscope. The payload will accept a sample of liquid water to be observed and recorded. In addition to meeting all the size and operational requirements, Etna will process the data into a stack of 2D slices. Both this and the raw data will be passed to a mock ground station.

To test the resolution of Etna's microscope a control sample will be used to verify the imaged captured is the correct resolution. A bench test will be conducted to verify exposure length and frame rate. The power consumption will be tested with the electrical tools available to ensure the voltages and amperage through the circuit match our calculated and anticipated values. Thermal regulation will be modeled with thermal analysis software. Survivability of idle and operational temperatures will be verified through component research. To help verify flight readiness of the microscope we will use a vibration table to simulate launch. Thermo-vac testing of components shall occur under the limitation of budget and time constraints. The design will use hardware that is made to last for 15 years or longer. Etna's ability to cycle samples will be tested using a control fluid. The data transmission and collection processes will be analyzed using a test sample and by inspecting the images and data transmission rates to ensure the microscope is working as designed and in a reasonable amount of time. To test the detection of objects of no interest a control sample will be used.

6 High-Level Functional Requirements

Label	Word	Description
T	Test	Use of specific test equipment to acquire physical data
A	Analysis	Use of modeling and system knowledge
M	Measure	Measure a basic physical characteristic

Table 1: **Verification Key**

No.	Functional Requirement	Rationale	Verify
1	Etna shall remain functional for 15 years	The travel to Enceladus will take roughly 13 years	A
2	Etna shall be able to transfer the liquid samples to the microscope and expel them after imaging	To process a valuable number of samples, Etna must be able to cycle samples in and out of the sampling chamber	T
3	Etna shall be able to detect particles in the collected plume samples	The microscope must be capable of imaging particles to detect life	T
4	Enta shall be able to detect particle movement in the collected plume samples	The microscope must be able to detect life if present within the samples and life is detected through movement	T
5	Etna shall be able to keep the samples viable in a temperature range of $-15°C$ to $0°C$	The samples, while never exposed to the outside environment after collection, will be thermally sensitive and it is required to maintain their temperature in a liquid state between $-15°C$ and $0°C$	T

Table 2: **Mission Requirements**

No.	Functional Requirement	Rationale	Verify
6	Etna shall be able to withstand the G's experienced throughout the flight (Lateral -2g to +2g, Axial -2g to 6g)	The microscope must be capable of withstanding the G's it is exposed to during takeoff and travel without damage to the hardware or components	T
7	Etna shall be able to survive the vibration experienced during take off (Vibration 20 - 2000Hz)	Etna must be able to survive the vibration environment seen during the launch of ABL RS-1	A/T
8	Etna shall be able to survive a temperature range of $-50°C$ to $100°C$	The payload will be exposed to a temperature range of $-50°C$ to $100°C$ during the duration of travel to Enceladus, including takeoff	A/T

Table 3: **Flight-Like Requirements**

No.	Functional Requirement	Rationale	Verify
9	Etna's microscope shall be equipped with a resolution in the X-Y directions of less than $0.8\mu m$	To be able to accurately see any particle within its field of view with enough resolution to detect detail and movement	T
10	Etna's microscope shall be equipped with a resolution in the Z direction of less than $2\mu m$	To be able to see any particle within the depth of the sample volume with proper detail	T
11	Etna shall have an instantaneous imagining volume of greater than 2 uL	The microscope is expected to capture a three dimensional image with enough volume to efficiently collect data	A/T
12	Etna shall be able to capture images at a rate of 30 to 100 frames per second	The images must be taken within this rate in order to capture the movement of particles within a given sample	T
13	Etna shall have a system for reconstructing the images of the liquid samples	To analyze the particles from the captured samples, reconstruction of the particles in all three dimensions is necessary	A/T

Table 4: **High-Resolution Imaging Requirements**

No.	Functional Requirement	Rationale	Verify
14	Etna shall have a mass less than 2kg	This mass requirement is necessary for the microscope to be implemented as part of the satellite payload	M
15	Etna shall have a volume and size of 1U	This volume requirement is necessary for the microscope to be implemented as part of the satellite payload	M

Table 5: **Weight, Size, and Volume Requirements**

No.	Functional Requirement	Rationale	Verify
16	The microscope shall be able to operate at a peak power of less than 10 W (active)	This power requirement needs to be met to ensure the usability of the microscope during operation	A/T
17	The microscope shall be able to survive with an average power of less than 0.5 W (inactive)	This power requirement needs to be met to ensure the long-term survival of the microscope during the journey to Enceladus	A/T
18	The active processor power shall be less than 10 W	The power requirement needs to be met to ensure processor usability during operation	A/T
19	The inactive processor power shall be less than 0.5 W	The power requirement needs to be met to ensure processor survival during the journey to Enceladus	A/T

Table 6: **Power Requirements**

No.	Functional Requirement	Rationale	Verify
20	The microscope's behavior shall be controllable via commands from ground control	Communication between the microscope and the ground station is necessary to ensure proper functioning of the microscope	T
21	The microscope shall output its digital data via the orbiter's science data downlink	This requirement ensures that the data retrieval process is successful	A/T

Table 7: **Communication Requirements**

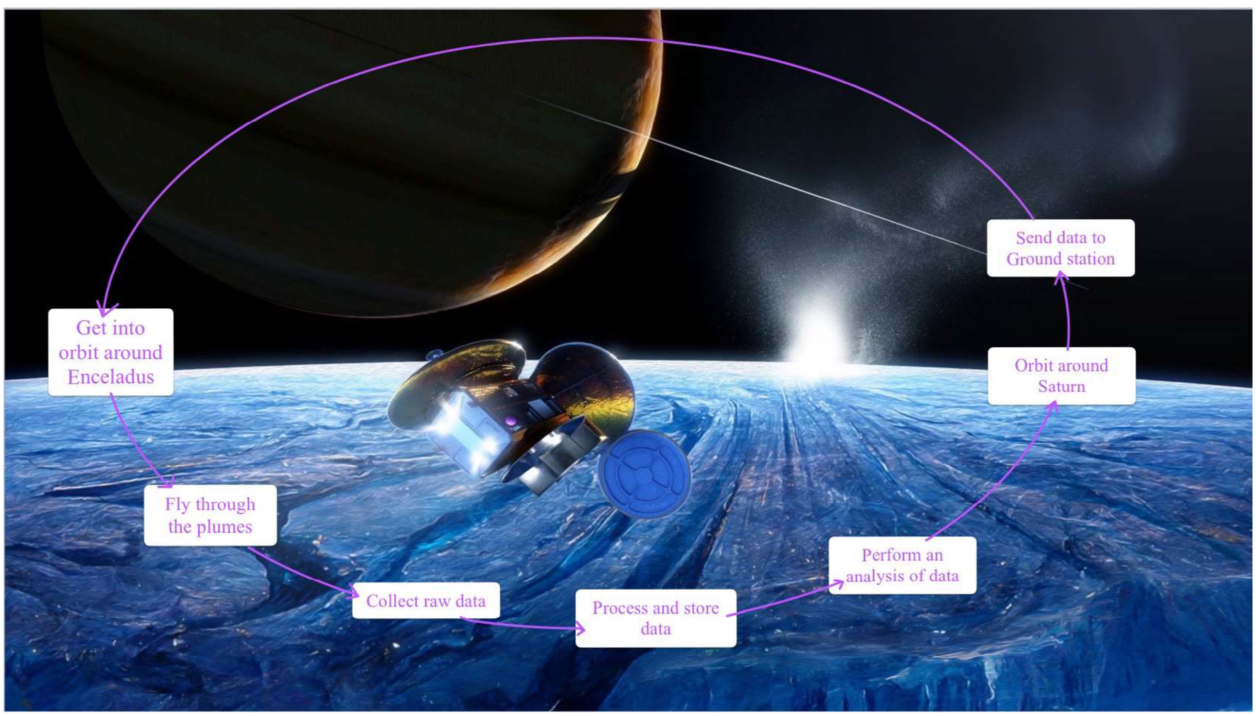


Figure 1: **Overall Mission CONOPS**

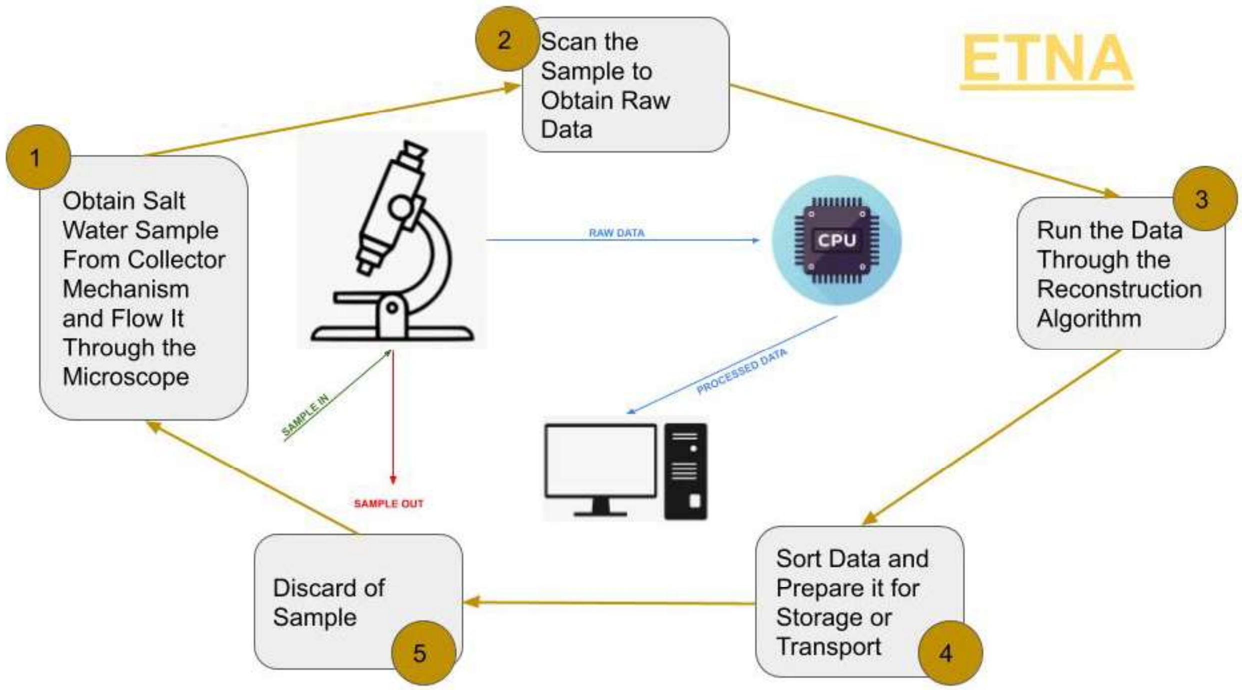
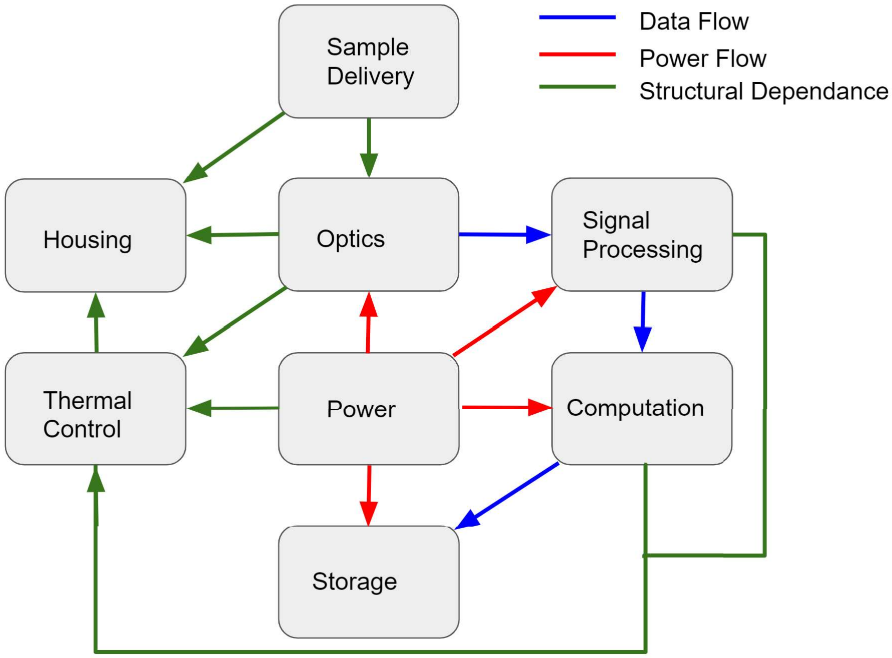


Figure 2: **Component Specific CONOPS**

7 Critical Project Elements

Critical Element	**Constraint Rationale**	**FR**
E1: Structural Survival	The Etna module must fit into the allocated 1U payload housing and withstand simulated structural loads associated with launch and space conditions	1, 6, 7, 14, 15
E2: Thermal Survival	Etna must survive a temperature range and maintain the samples within a viable temperature range	5, 8
E3: Sample Handling	Etna must be able to accept fluid samples from a simulated microfluidic sample collector in order to image it, and then clear its sample tray to accept infinite reloads	2, 5
E4: Optical Design	The microscope must capture images to the required resolution for the purposes of detecting desired particles/microbes with an adequate depth of field and imaging volume	9, 10
E5: Data Handling and Reconstruction	Etna must have onboard computing capability to efficiently reconstruct the image data - providing both raw data and processed imagery as outputs	3, 4, 11, 12, 13, 20, 21
E6: Data Collection	Etna must reliably capture adequately resolved exposures of samples at the desired frame rate	3, 4, 11, 12, 13
E7: Power Consumption	Etna and her components must operate below peak active power and inactive power constraints	16, 17, 18, 19

8 Sub-System Breakdown and Interdependencies



9 Team Skills and Interests

Critical Project Elements	Team Member(s) and Associated Skills/Interests
E1: Structural Survival	Ania - Interest in Mechanical Design Srija - Experience and Interest in Mechanical Design and Prototyping Anna - Experience and Interest in Mechanical Design and Testing
E2: Thermal Survival	Hayden - Experience and Interest in Thermal Analysis
E3: Sample Handling	Jacob - Interest in Non-Mechanical Delivery
E4: Optical Design	Ace - Experience and Interest in Optics Izaak - Interest in Optics
E5: Data Handling and Reconstruction	Bart, Lucas, Atkin - Interest and Experience w/ Software Development
E6: Data Collection	Max, Devin - Interest in Electronics Design
E7: Power Consumption	Max, Devin - Interest in Electronics Design

10 Resources

Critical Project Elements	Resource/Source
E1: Structural Survival	Vibration Testing and Prototyping: KatieRae Williamson
E2: Thermal Survival	Thermal Testing: Matt Rhode
E3: Sample Handling	Microfluidics: uFluidix forum
E4: Optical Design	Component Design Considerations, Building Scientific Apparatus book, and Papers provided by Sponsor.
E5: Data Handling and Reconstruction	Electronics: Trudy Schwartz, Robert Hodgkinson; Software: Papers from Sponsor
E6: Data Collection	Electronics: Trudy Schwartz, Robert Hodgkinson; Software: ACM Digital Library
E7: Power Consumption	Electronics: Trudy Schwartz, Robert Hodgkinson; Software: ACM Digital Library

11 References

1. ASTROBi Website: https://astrobi.space/missions
2. Building Scientific Apparatus: Moore, John H., et al. Building Scientific Apparatus: A Practical Guide to Design and Construction. Fourth ed., Cambridge University Press, 2009.
3. Caltech Paper: https://www.caltech.edu/about/news/holographic-imaging-could-be-used-detect-signs-life-space-78931
4. Optics: Hecht, Eugene. Optics. Fifth ed., Pearson Education, Inc., 2017.
5. uFluidix: “Microfluidic Channel- Practical Design Tips.” UFluidix, UFluidix, 10 Aug. 2021, https://www.ufluidix.com/microfluidics-technical-notes/microfluidic-channel-design-tips/.