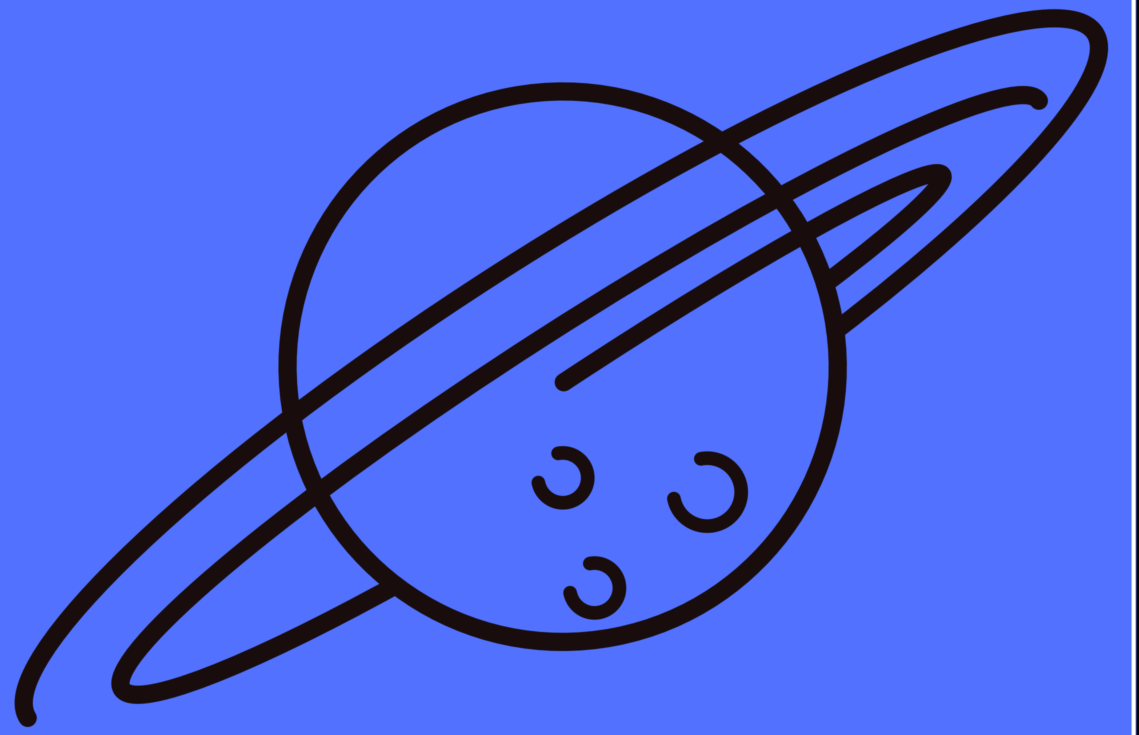
ASTROBIOLOGY MISSION ARCHITECTURE PROJECT

ERA: ENCELADUS RECONNAISSANCE FOR ASTROBIOLOGY

OVERVIEW



- INTRODUCTION
- MISSION GOAL
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- INSTRUMENTATION
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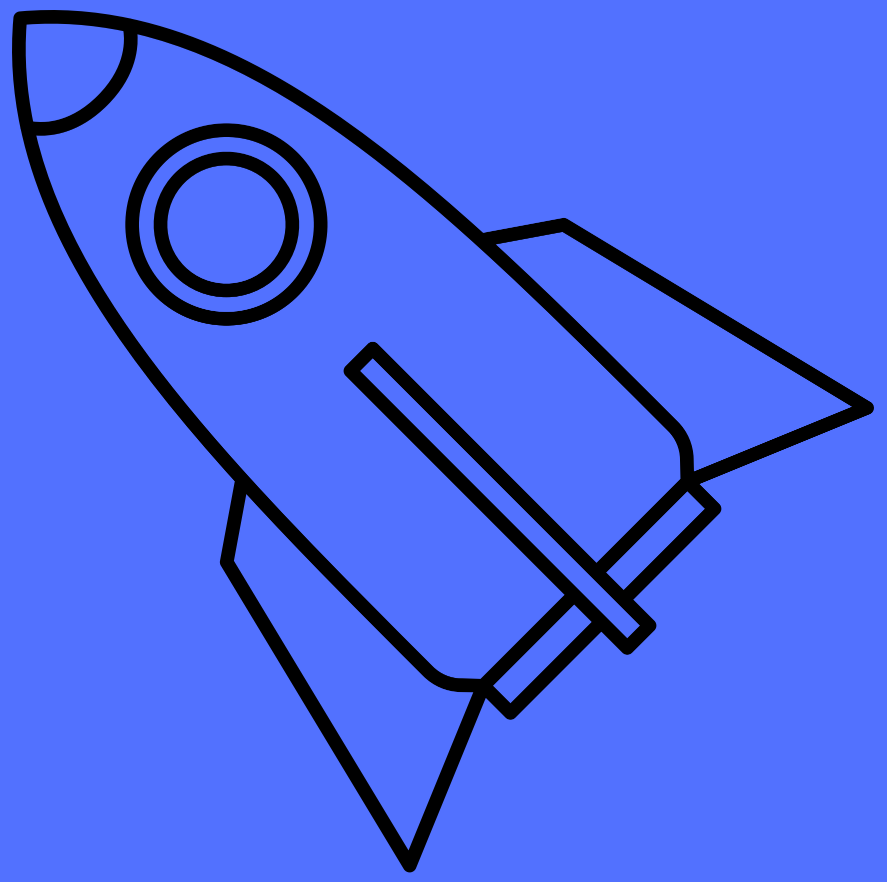


INTRODUCTION TO ENCELADUS

Enceladus is an icy moon that orbits Saturn. It is located 1,272E9 km away from Earth and has a diameter of 500 km which makes it 25x smaller than Earth.

Important characteristics of this moon include:

- A rocky core
- A big ocean of salty water beneath an icy crust
- Big fissures in the icy crust
- A south pole with hydrothermal vents (plumes)
- Is the source of material for Saturn's E-Ring

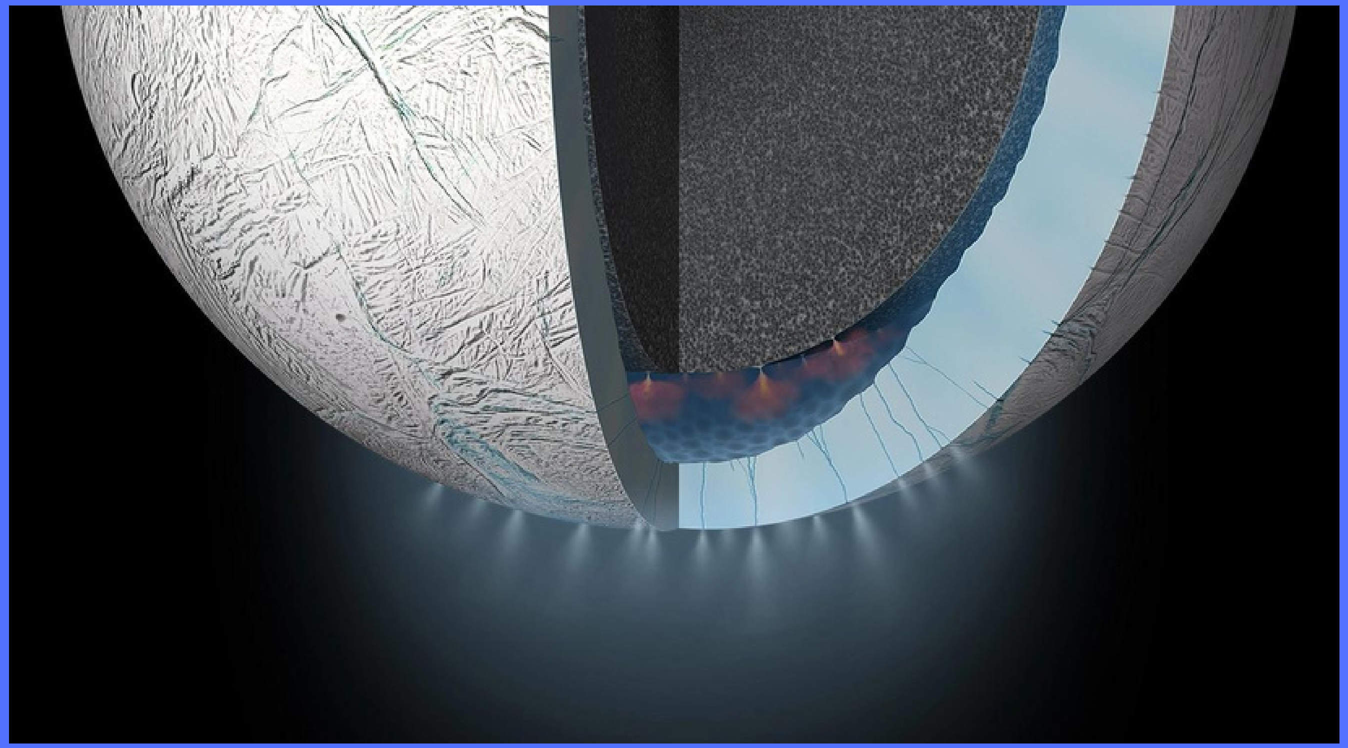
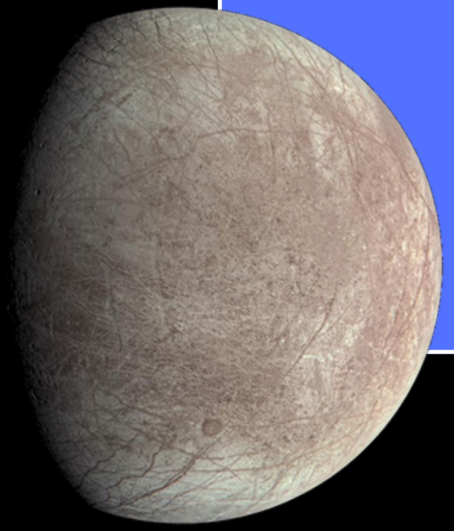
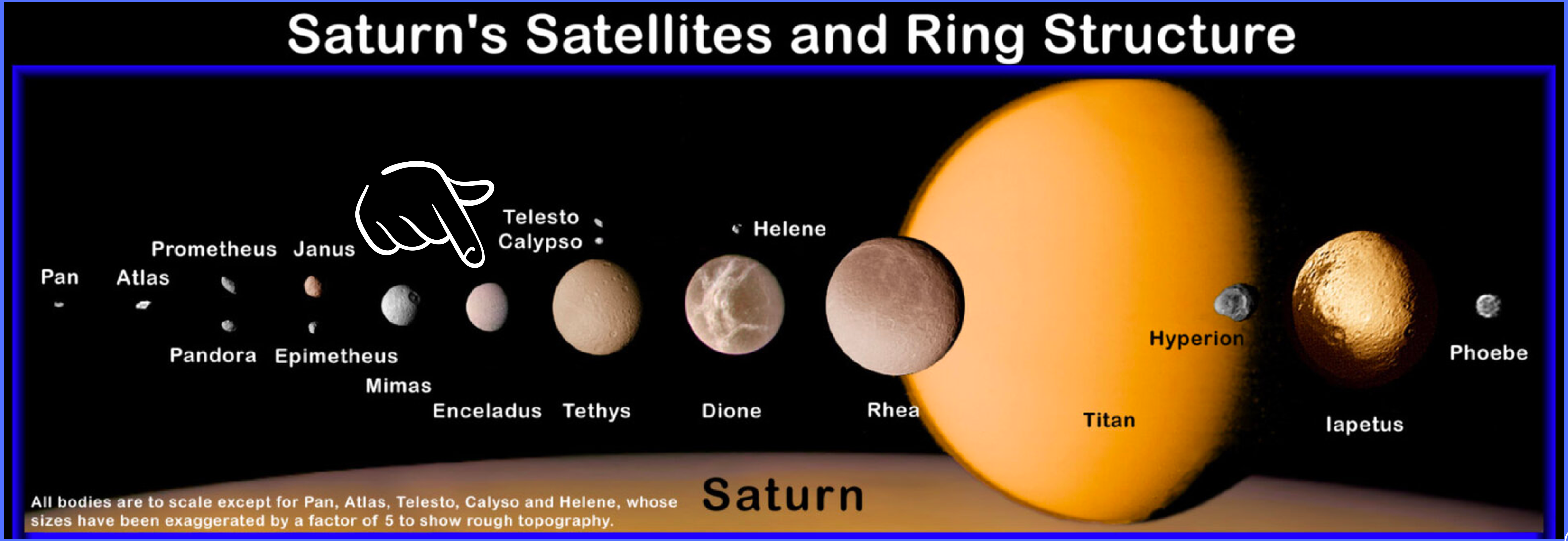


Figure 1: Enceladus south pole plumes showing internal hydrothermal activity



(1)

INTRODUCTION TO ENCELADUS



(3)

Figure 2: Enceladus location concerning the saturninan system

MISSION GOAL

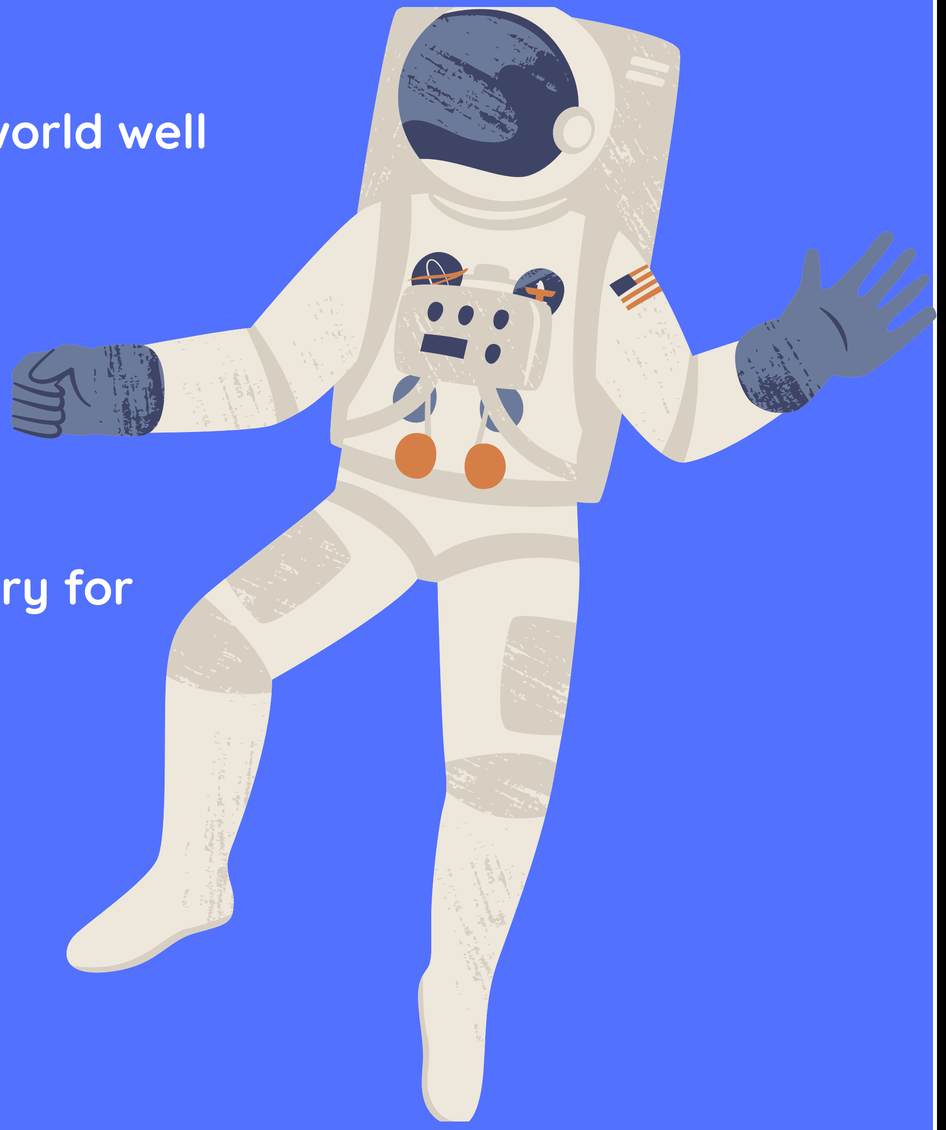
WHY IS IT IMPORTANT TO GO HERE?

* The plume venting from its south pole,the hydrocarbons in the plume; a global, salty ocean and hydrothermal vents on the seafloor,all point to the possibility of a habitable ocean world well beyond Earth’s habitable zone.

* Cassini's instruments found that the plume contained a surprising mix of volatile gases, water vapour, CO2, CO as well as other organic materials like ammonia.

* Carbon, Oxygen, Hydrogen, Nitrogen, Sulfur and Phosphorus are the six elements considered necessary for life.Over the years, scientists have found evidence for all of them on Enceladus.

OUR GOALS
* To search for the evidence of life
* To study the plume ejecting from the south pole
* Flybys of the E-ring for analyzing the transition of the plume to forming the E-ring
* To explore how the water-rock interactions may have relationship with biosignatures
* To identify the concentration of organics specifically aldehydes for amino acid formation



MISSION TIMELINE

2027

Spacecraft lauch from Kennedy Space Center F1

2038

Flybys of the E-ring

Locking with the Orbit of Enceladus

2039

Arrival at the surface of Enceladus

Landing site : South Pole near the Geysers

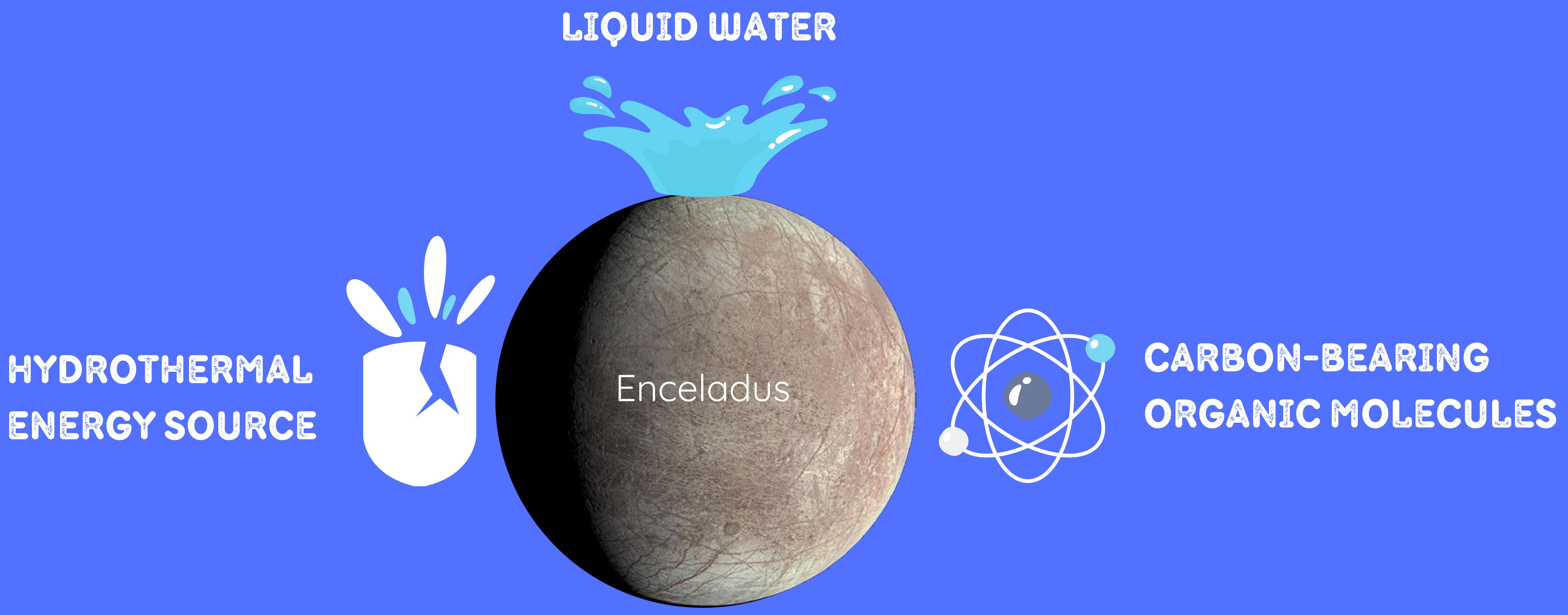
Early 2040s

Atmospheric and Plume analysis

Exploration of water-rock interactions

HABITABILITY EVIDENCE

THE 3 REQUIREMENTS FOR AN HABITABLE ENVIRONMENT



HABITABILITY EVIDENCE

CASSINI-HUYGENS

The cryo-volcanic plumes contain

- Water vapor (H_2O)
- gaseous carbon dioxide (CO_2)
- simple hydrocarbons such as methane (CH_4) , propane (C_3H_8), and acetylene (C_2H_2)
- molecular hydrogen (H_2)
- Salt-rich ice grains containing sodium (Na) and potassium (K)

Modeling suggests availability of phosphorus in the form of orthophosphates

Building blocks of life

essential for
planetary habitability

PLUME AND VAPOR FOCUS

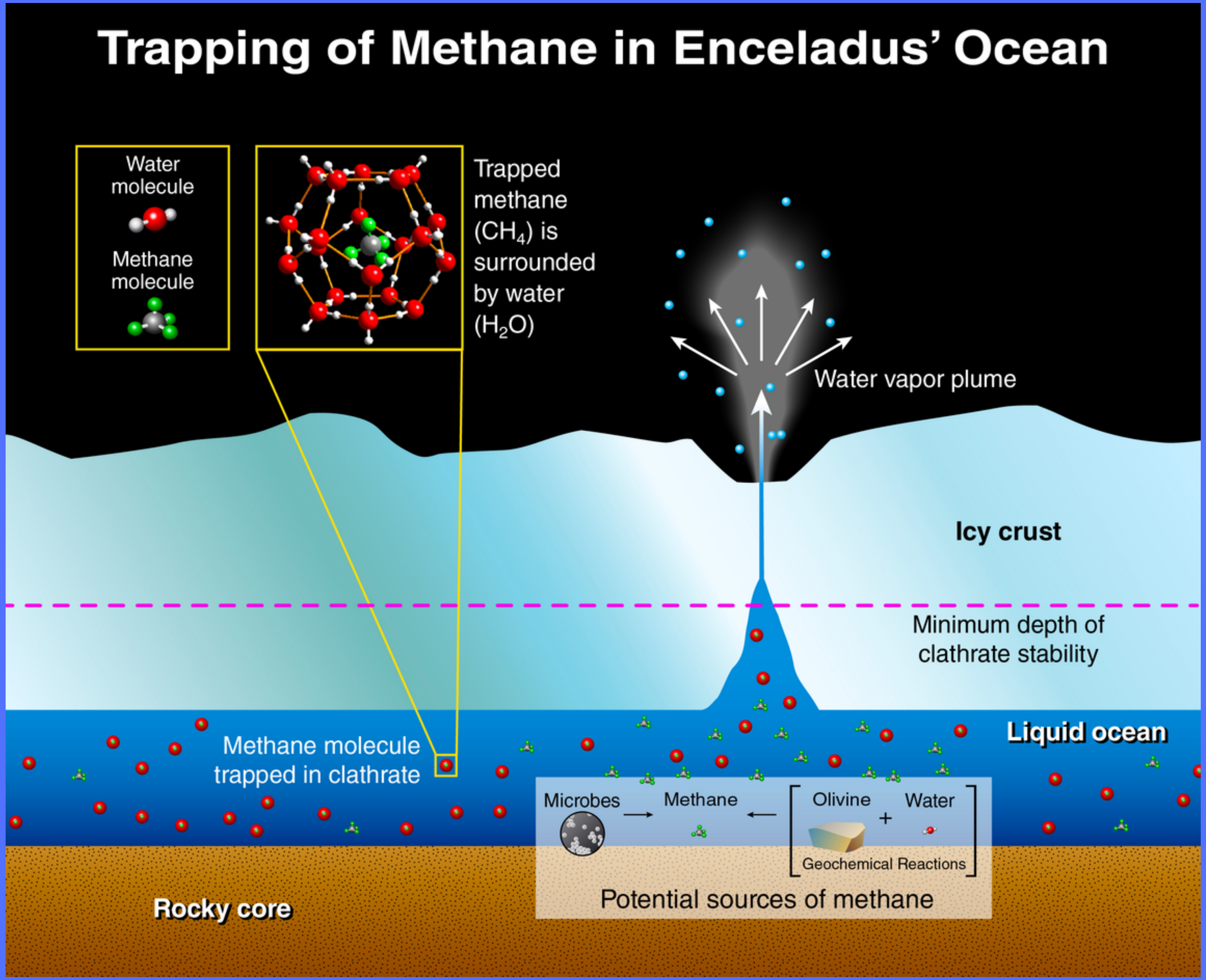
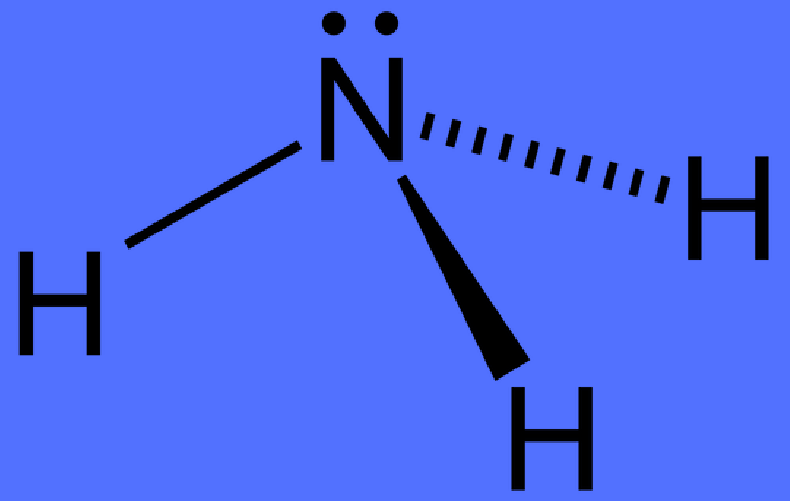
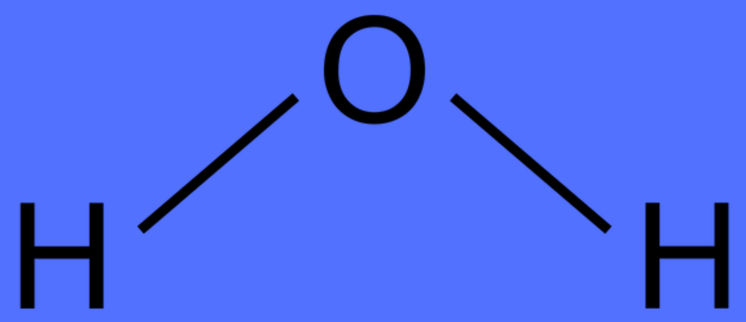


Figure 3: Image Courtesy of Southwest Research Institute *Illustration depicts the potential origins of methane found in the plumes of the Saturn moon, Enceladus.*

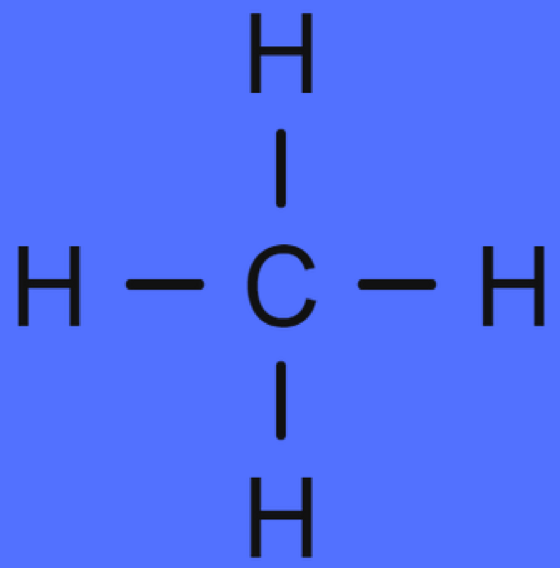
ORGANICS: DIVERSITY IN THE SYSTEM



Ammonia

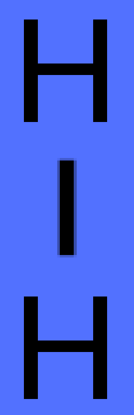


Liquid Water

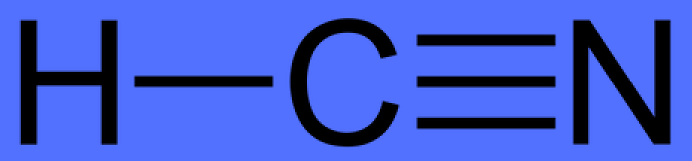


Methane

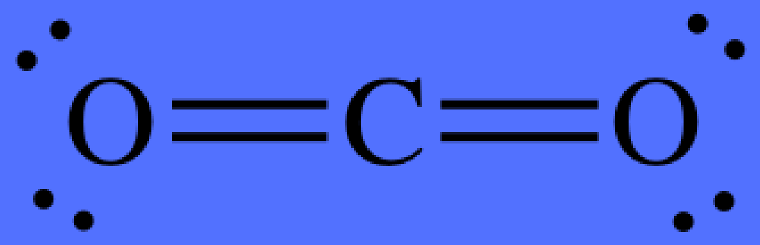
ORGANICS: DIVERSITY IN THE SYSTEM



Molecular Hydrogen



Hydrogen Cyanide



Carbon Dioxide

Aldehyde concentration

INSTRUMENTATION: PLUME REMOTE SENSING ANALYSIS

Infrared Spectroscopy:
MISE.2
Mapping Imaging
Spectrometer for
Enceladus

Surface chemicals fingerprints specifically looking for Aldehydes

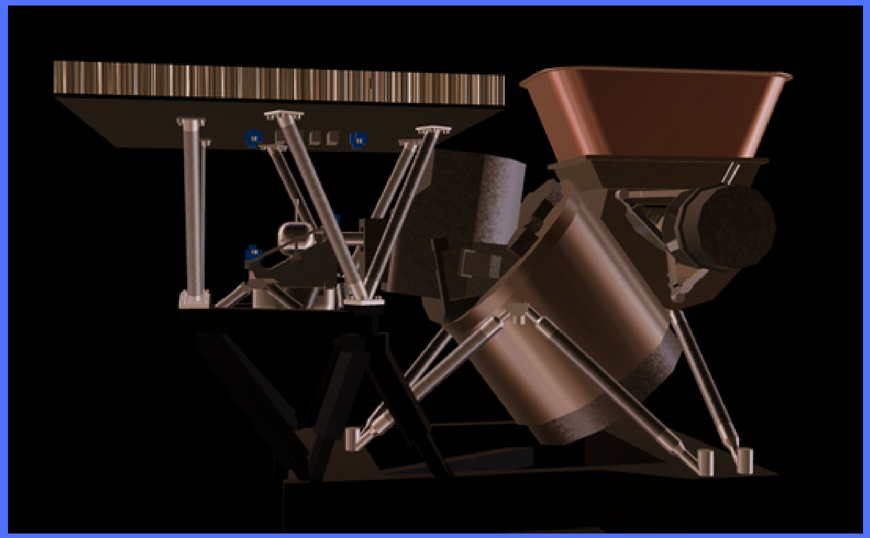


Fig 4: MISE Mapping Imaging Spectrometer for Europa inside Europa Clipper, taken from NASA JPL.

INSTRUMENTATION: PLUME REMOTE SENSING ANALYSIS

Thermal Imager: E-THEMIS.2 Enceladus Thermal Emission Imaging System

Temperature mapping for hot spot identification from Orbit

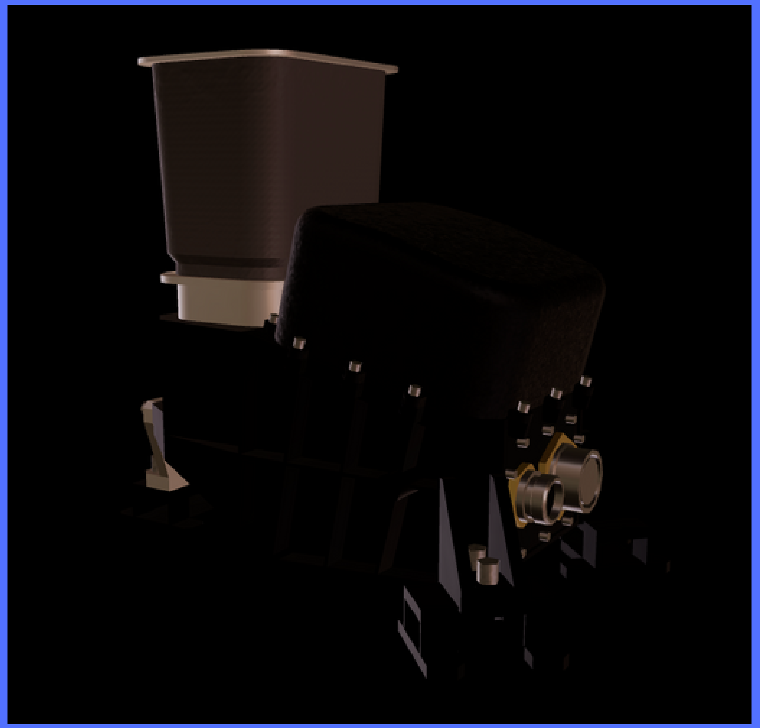


Fig 5; Europa Thermal Emission Imaging System inside Europa Clipper, taken from NASA JPL.

INSTRUMENTATION: VAPOR ASSESMENT

Gas Chromatography

Analyze the chemical ingredients in samples from the vapor from the plumes for identification

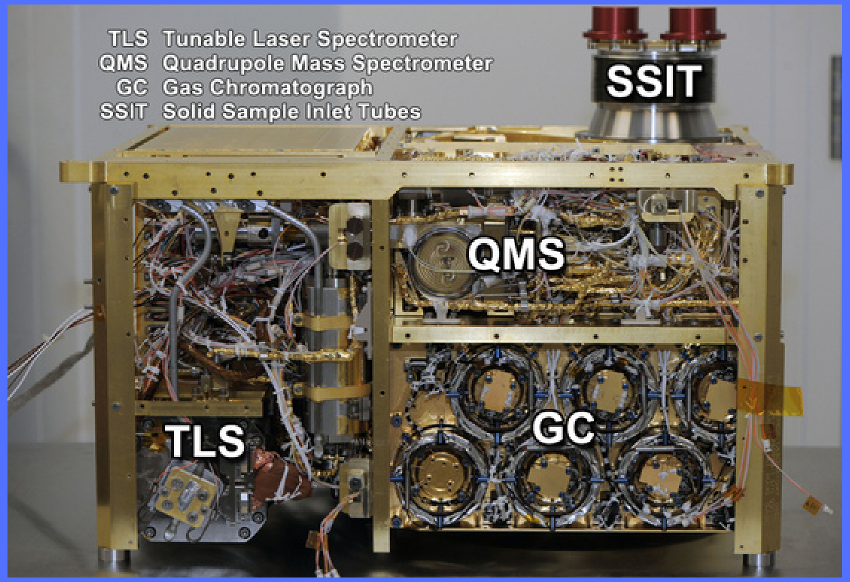


Fig 6: Instrument location on Mars' 2020 rover

INSTRUMENTATION: VAPOR ASSESMENT

High Resolution Mass Spectrometer (HRMS) + Capillary Electrophoresis with Laser Induced Fluorescence (CE-LIF)

The combination of HRMS and CE-LIF allow to determine current habitability and geochemistry parameters of the subsurface ocean and if the building blocks are present in the ocean.

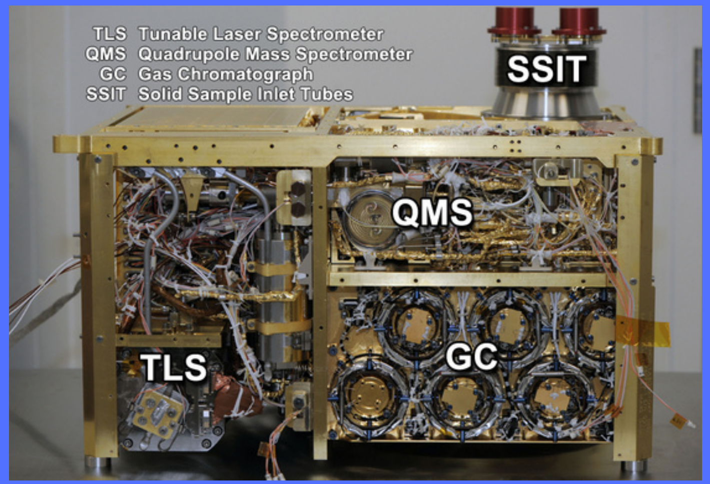


Fig 7: QMS from Sample Analysis at Mars Instrument

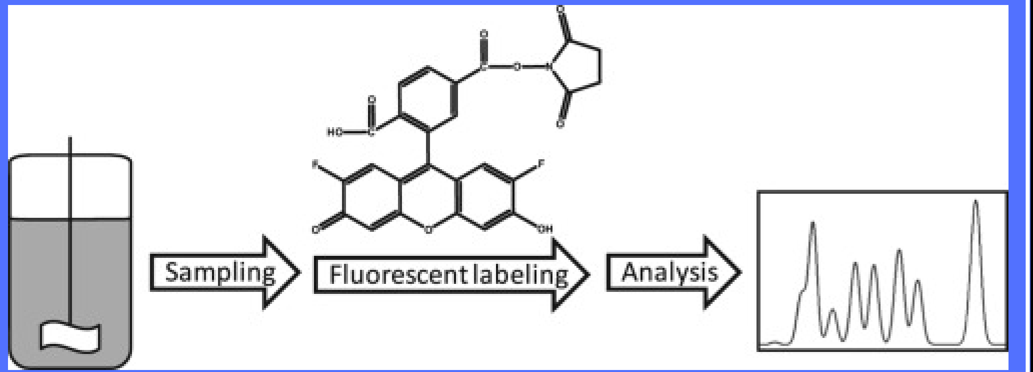
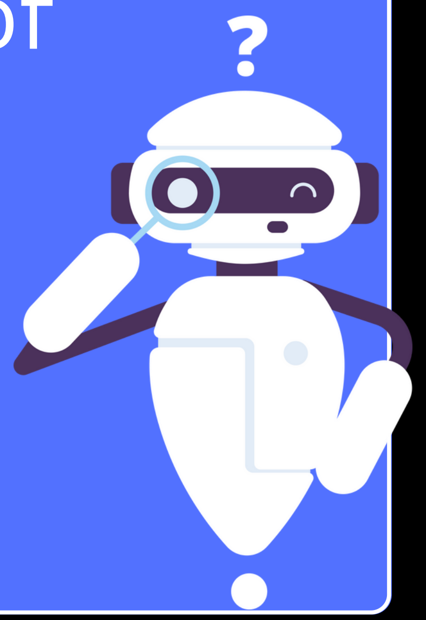


Fig 8: CE-LIF methodology

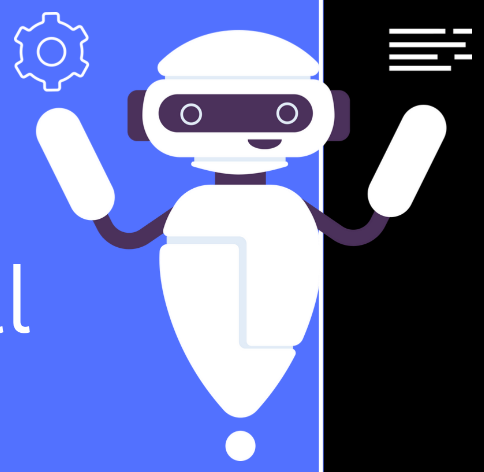
SOFTWARE INTEGRATION

- With the intregation of an AI capable to process the data captured by the instrumetation, such as spectrometers for the analysis of minerals concetration in the surface, the results of the research would be more detailed and reliable.
- A software has to be created capable of combining the AI, with the instruments and the data that is needed. The main focus of the software will be to create a long distance interaction from the Earth to Enceladus, without landing, making it an autonomous system.



SOFTWARE INTEGRATION

- The second part of the software, is for it to be an independent software, capable of making decisions and sending analysis results.
- The AI would be the designeded software for this part.
- Since it all ready has an AI, this will also be in charge of monitoring the deployment and the stated of the rover, as well as keeping safe the samples, for further investigation and analizys.
- Before launching, the software would be train and indicated how to act before certaint scenarios.



ASTROBIOLOGY: QUESTIONS AND OBSERVATIONS

- Are abiotic molecules able to withstand the water-rock interaction conditions in this temperature?
- Can prebiotic molecules be found near the rocky core of Enceladus?
- Can the molecules found be able to sustain known life ?
- Are the plumes grains from the South Pole capable of engaging in catalytic reactions for complex molecule formation such as RNA?
- Is organic aldehyde present in the plume grains concentration enough for a Sketcher reaction ?

SPACECRAFT

- Two model spacecraft capable of assessing analysis of atmospheric and geyser material expulsion

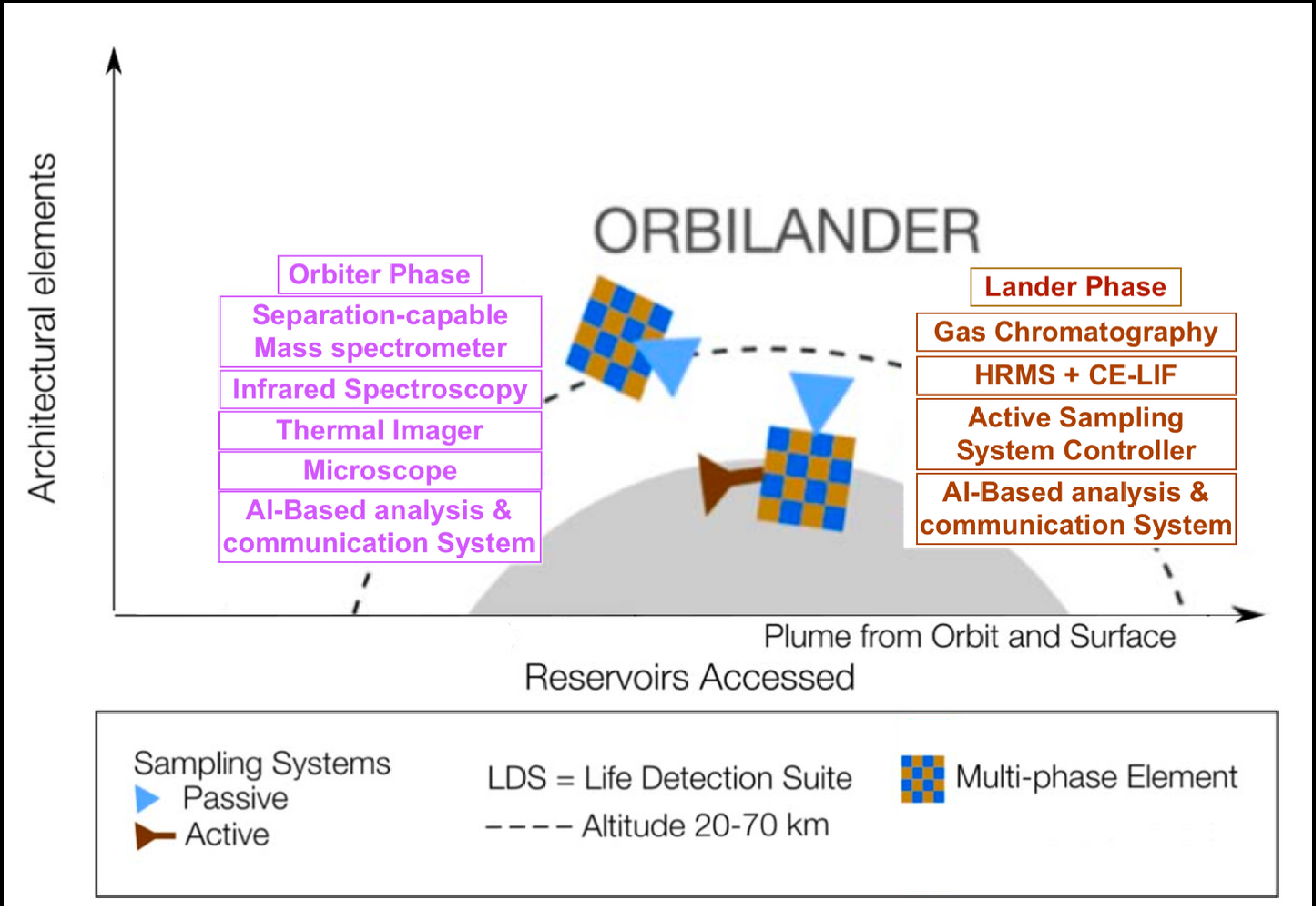
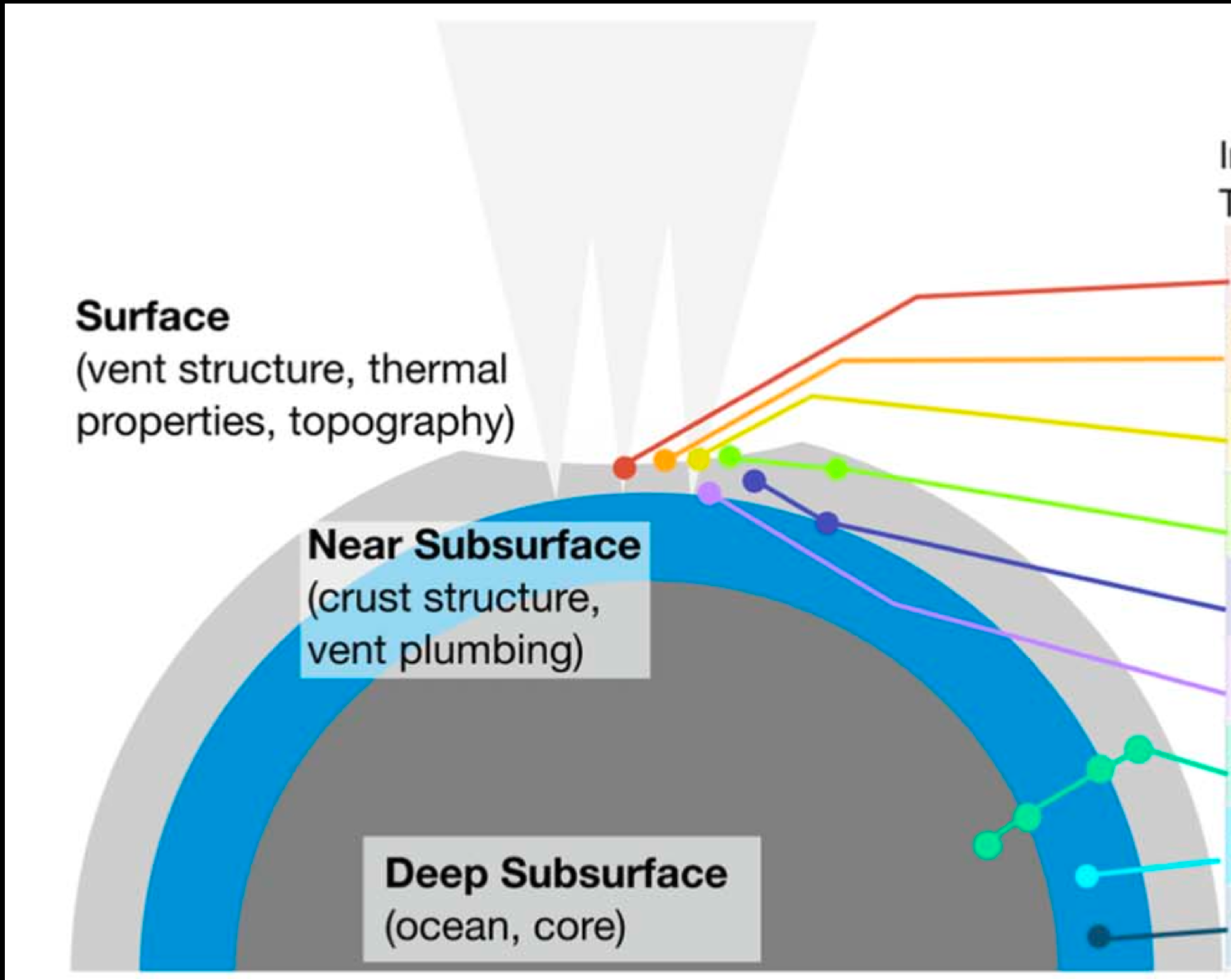


Figure 9: Orbilander Representation for Mission Architecture to analyze both plumes and the E-ring

SPACECRAFT

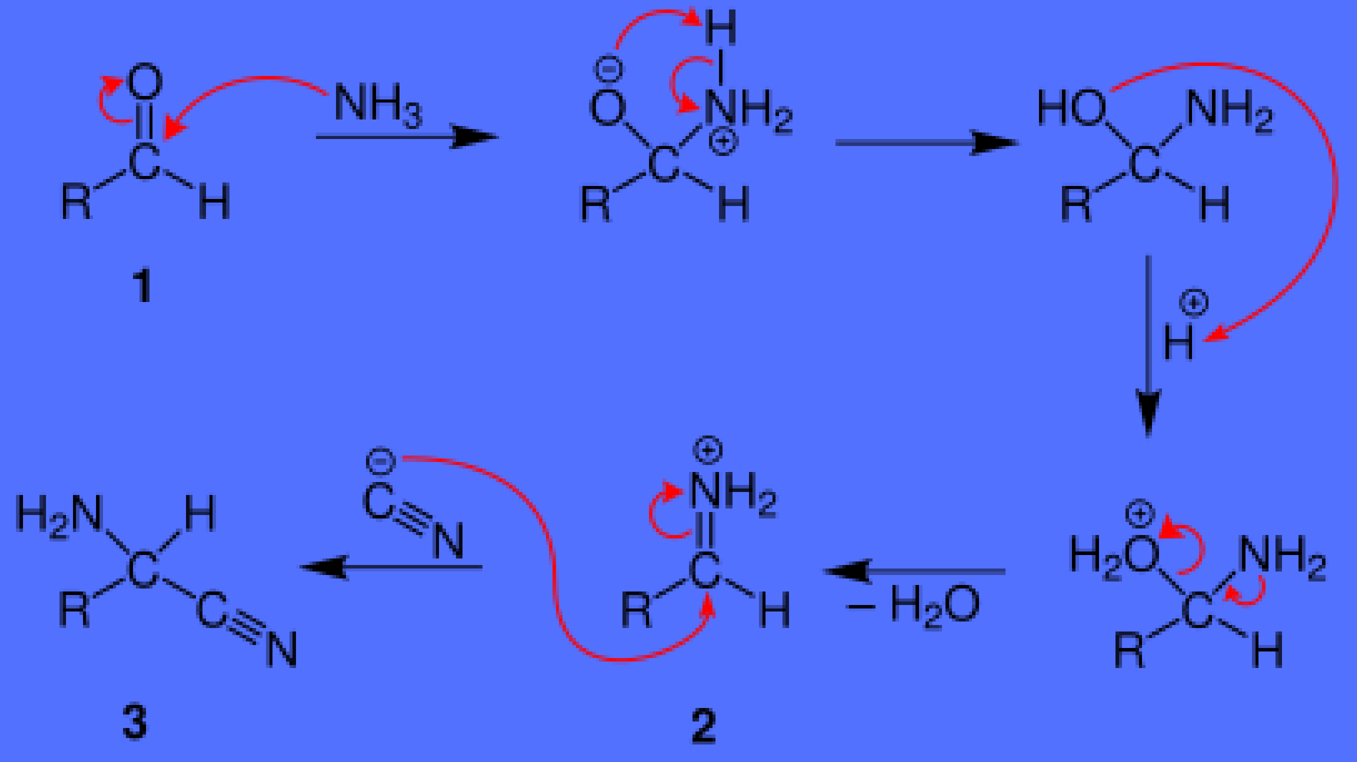


Instrument Type	Orbiter	Orbilander	Small Lander	Large Orbiter	Small Orbiter	Large Lander
ice particle counter	x			x	x	
thermal emission spectrometer	x			x	x	
camera	x	x		x	x	
laser altimeter	x	x		x	x	
radar sounder	x	x		x	x	
microscope	x	x		x		x
seismometer		x	x			x
HRMS	x	x		x		x
ESA	x	x		x		x

Figure 10: Description on the comparison of different mission models and their possible reach

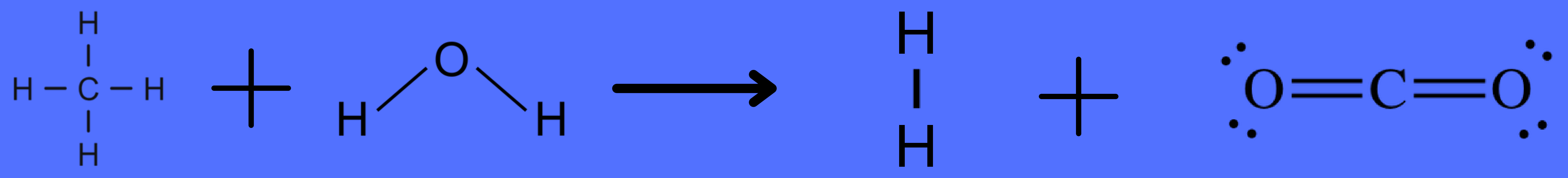
ASTROBIOLOGY: SYNTHESIS

With the presence of aldehydes along with the ammonia found by Cassini following the Strecker reaction, amino acid synthesis is possible under the right parameters.

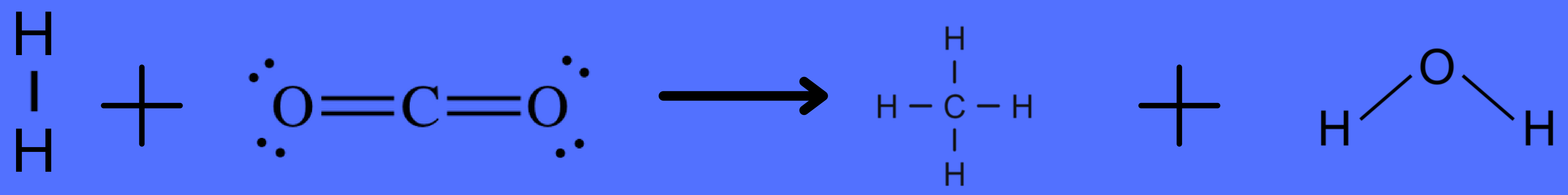


ASTROBIOLOGY: ENERGY SUPPLY

The energy supply can be possible through a thermal process enabling a methane cycle on Enceladus



Rock methane cycle assumption in a T>500 °C



Subsurface ocean methane cycle assumption

REFERENCES

[1] SwRI-led researchers study methane-rich plumes from Saturn's icy moon. (2021, June 7). Southwest Research Institute. https://www.swri.org/press-release/swri-led-researchers-study-methane-rich-plumes-saturn%E2%80%99s-icy-moon-enceladus#.VQHTa9LF98G
[2] Peter, J. S. (2023, January 12). Detection of HCN and diverse redox chemistry in the plume of Enceladus. arXiv.org. https://arxiv.org/abs/2301.05259
[3] Postberg F, Khawaja N, Abel B, Choblet G, Glein CR, Gudipati MS, Henderson BL, Hsu HW, Kempf S, Klenner F, Moragas-Klostermeyer G, Magee B, Nölle L, Perry M, Reviol R, Schmidt J, Srama R, Stolz F, Tobie G, Trieloff M, Waite JH. Macromolecular organic compounds from the depths of Enceladus. Nature. 2018 Jun;558(7711):564-568. doi: 10.1038/s41586-018-0246-4. Epub 2018 Jun 27. PMID: 29950623; PMCID: PMC6027964.
[4] Blaney, Diana L., et al. "The Europa Clipper mapping imaging spectrometer for Europa (MISE): using compositional mapping to understand Europa." 50th Annual Lunar and Planetary Science Conference. No. 2132. 2019.
Instrumentation Plume 2
[5] Rathbun, Julie A., et al. "A review of thermophysical surface models in preparation for e-themis observations of europa." AAS/Division for Planetary Sciences Meeting Abstracts# 48. Vol. 48. 2016.
[6] Mahaffy, P. R., Webster, C. R., Cabane, M., Conrad, P. G., Coll, P., Atreya, S. K., ... & Mumm, E. (2012). The sample analysis at Mars investigation and instrument suite. Space Science Reviews, 170, 401-478.
[7] M. Chodas et al., "Enceladus Vent Explorer Mission Architecture Trade Study," 2023 IEEE Aerospace Conference, Big Sky, MT, USA, 2023, pp. 1-16, doi: 10.1109/AERO55745.2023.10115635.
[8] MacKenzie, Shannon M., et al. "The Enceladus Orbilander mission concept: Balancing return and resources in the search for life." The Planetary Science Journal 2.2 (2021): 77
Synthesis
[9] Domagal-Goldman SD., et al. "The Astrobiology Primer v2.0. Astrobiology" 2016 Aug;16(8):561-653. doi: 10.1089/ast.2015.1460. Erratum in: Astrobiology. 2020 Jan;20(1):161. PMID: 27532777; PMCID: PMC5008114.
[10]McKay CP, Porco CC, Altheide T, Davis WL, Kral TA. The possible origin and persistence of life on Enceladus and detection of biomarkers in the plume. Astrobiology. 2008 Oct;8(5):909-19. doi: 10.1089/ast.2008.0265. PMID: 18950287.
[11] Bouquet, A., Mousis, O., Waite, J. H. and Picaud, S. (2015), Possible evidence for a methane source in Enceladus' ocean. Geophys. Res. Lett., 42: 1334–1339. doi: 10.1002/2014GL063013.

THANK YOU VERY MUCH!

Backup Slides

Table 1. Cassini Measurements in Enceladus' Plumes [a]

Species	Mixing Ratio	X/H_2O	x_K^{gas}	x_K^{comet}
H_2O	0.87	1	1	
H_2	0.11	0.126		
CO_2	5.2×10^{-3}	5.98×10^{-3}	0.399	0.23
CH_4	1.9×10^{-3}	2.18×10^{-3}	0.133	0.06
NH_3	6.1×10^{-3}	7.01×10^{-3}		
CO	$\leq 6.4 \times 10^{-3}$	7.36×10^{-3}	0.233	0.46
N_2	$\leq 6.1 \times 10^{-3}$	7.01×10^{-3}	0.233	0.18
HCN	$\leq 1.2 \times 10^{-3}$	1.38×10^{-3}		
H_2S	2.1×10^{-5}	3.26×10^{-5}	2.17×10^{-3}	0.06
Ar	N/A	N/A	1.5×10^{-2}	1.5×10^{-2}
Kr	N/A	N/A	9.0×10^{-6}	9.0×10^{-6}
Xe	N/A	N/A	8.8×10^{-7}	8.8×10^{-7}

Table 2: The EVE science traceability matrix derives instruments and functional requirements from high level science goals tied to decadal objectives.

Science Goals	Science Objective	Measurement	Instrument	Functional Requirement
Goal 1: Determine the origin and evolution of Enceladus, including exchange between surface and subsurface.	1a: Determine which formation scenario for Enceladus is most likely: (1) in the Saturn subnebula, (2) from debris of previous moons, or (3) from the current rings of Saturn.	Camera images of surface at a range of true anomalies	NAC, WAC	Orbit for at least 6 months
		Seismograms of activity with orbital period of Enceladus	Seismometer	Surface operations for at least 6 months
	1b: Identify the thermal evolution of Enceladus throughout its history, including the degree of surface/subsurface exchange.	Images of South Polar Terra in for crater counting	NAC, WAC	Orbit for at least 6 months
		Net heat flow	Thermal spectrometer	Orbit for at least 6 months
		Images of faults, fractures, or other evidence of past or present tectonic activity.	NAC, WAC;	Orbit for at least 6 months
		Seismograms for current tectonic activity	Seismometer	Surface operations for at least 6 months
		Hot spot identification	Thermal spectrometer	Orbit for at least 6 months
		Images of plume flux at a range of true anomalies	NAC, WAC	Orbit for at least 6 months
		Plume particle composition on surface and at depth	HRMS CE-LIF	Collect depth transect of plume accumulates at surface
Goal 2: Determine whether organic synthesis continues today on Enceladus, and whether this supports an extant biosphere.	2a: Determine the current habitability and geochemistry of the Enceladus ocean.	Composition of organic and inorganic materials/ions with depth into plume accumulates	HRMS CE-LIF	Collect plume accumulates on surface and depth transect of ocean materials
		Composition of dissolved gases available for metabolism (e.g. H_2, O_2, CH_4, CO_2, CO, H_2S, NH_3)	HRMS CE-LIF	Collect ocean material sample
		Ocean salinity	Ion selective electrodes CE-LIF	Collect ocean material sample
		Ocean pH	Ion selective electrodes CE-LIF	Collect ocean material sample
	2b: Determine if the building blocks of life, including cellular vesicles (which could be prebiotic or biological in origin) are present within the Enceladus ocean.	Composition and concentration of amino acids on the surface and in the vent	HRMS CE-LIF	Collect plume accumulates on surface and depth transect of ocean materials
		Composition and concentration of small membrane-forming molecules (lipids) on the surface and in the vent	HRMS CE-LIF	Collect plume accumulates on surface and depth transect of ocean materials
		Composition and concentration of N-heterocycles on the surface and in the vent	HRMS CE-LIF	Collect plume accumulates on surface and depth transect of ocean materials
		Microscopic images/videos identifying cells via fluorescent staining and/or non-Brownian motion	DHM	Collect plume accumulates on surface and depth transect of ocean materials