JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

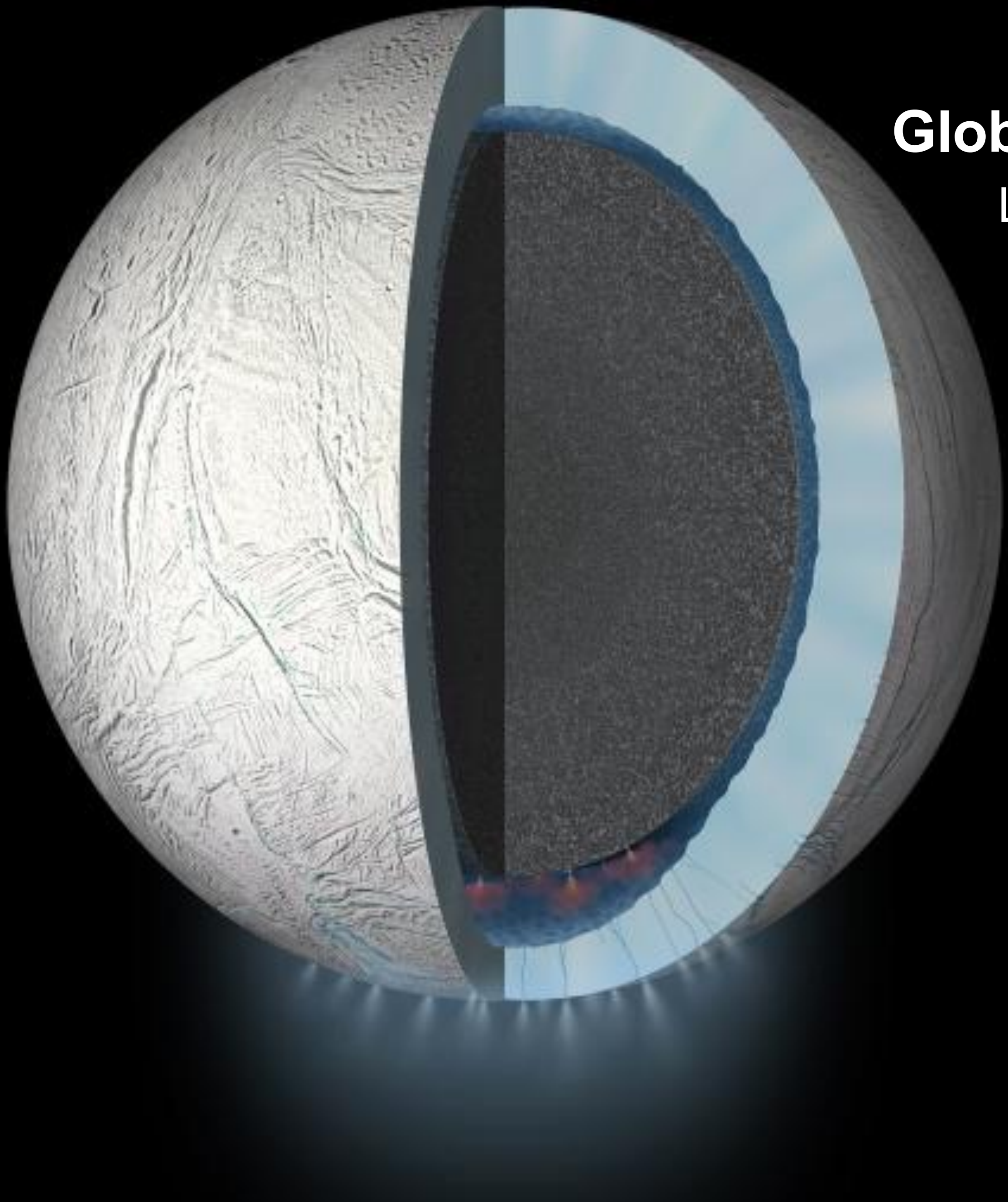
Enceladus Orbilander

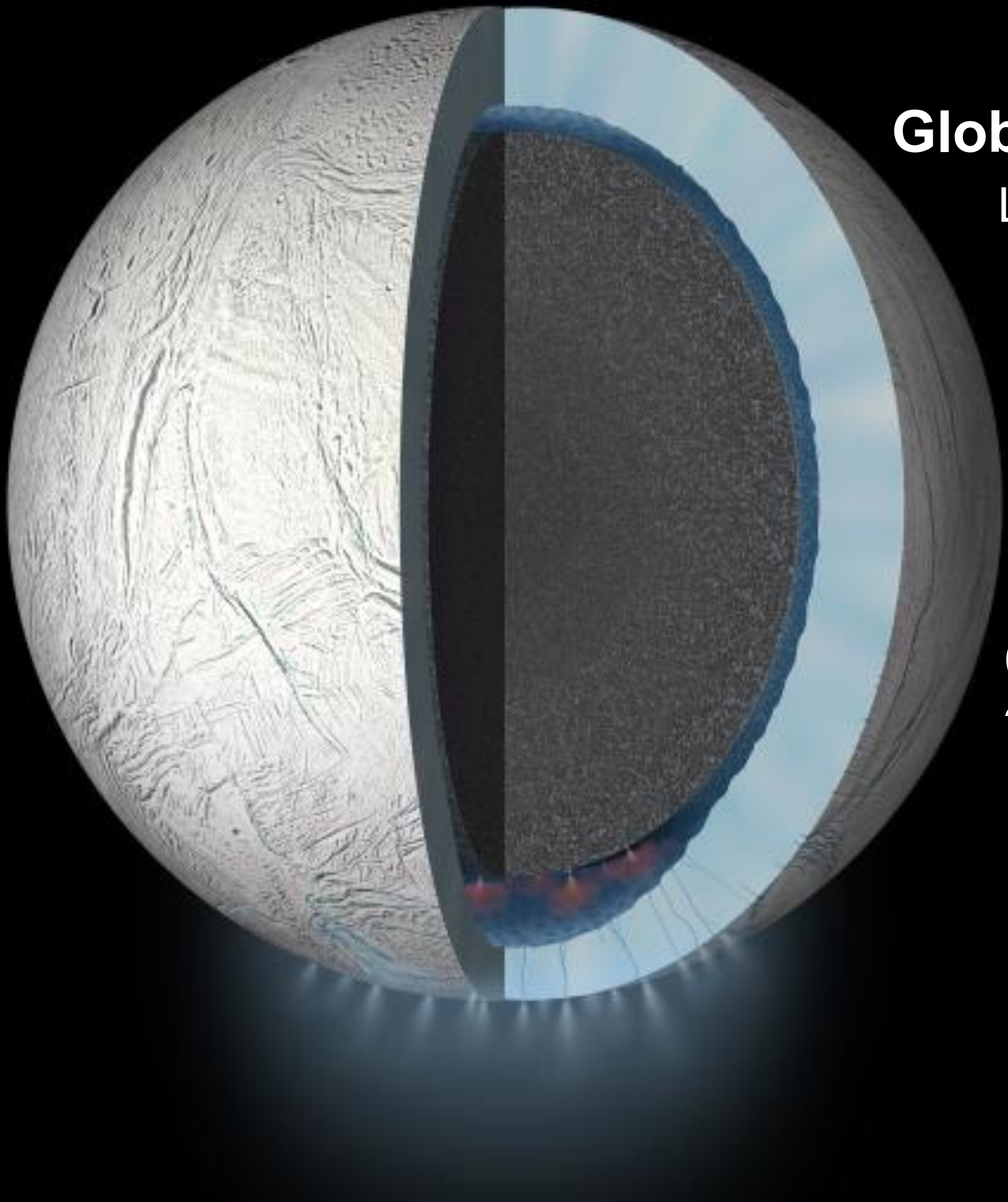
A Predecadal Mission Concept Study to Search for Signs of Life

Shannon MacKenzie, Marc Neveu, Alfonso Davila, Morgan Cable, Kate Craft, Jonathan Lunine, Jen Eigenbrode, Charity Phillips-Lander, Jason Hofgartner, Hunter Waite, Christopher Glein, Chris McKay, and the Orbilander Science and Engineering Team

Global subsurface ocean

Libration *(Thomas et al. 2016)*





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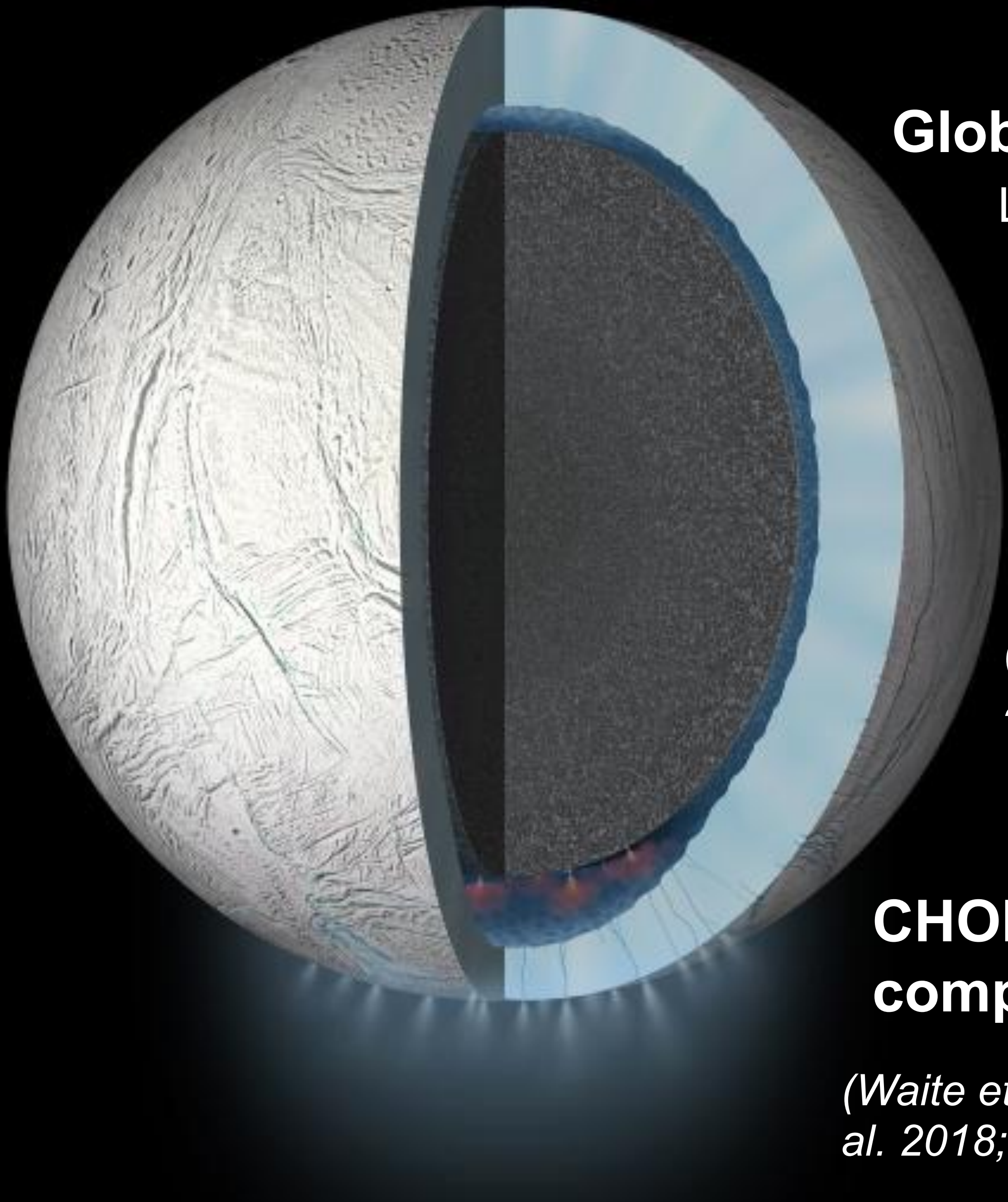
Hydrothermal activity

Nearly pure silica nanograins, chemical redox couples

(Postberg et al. 2011; Hsu et al. 2015; Waite et al. 2017)



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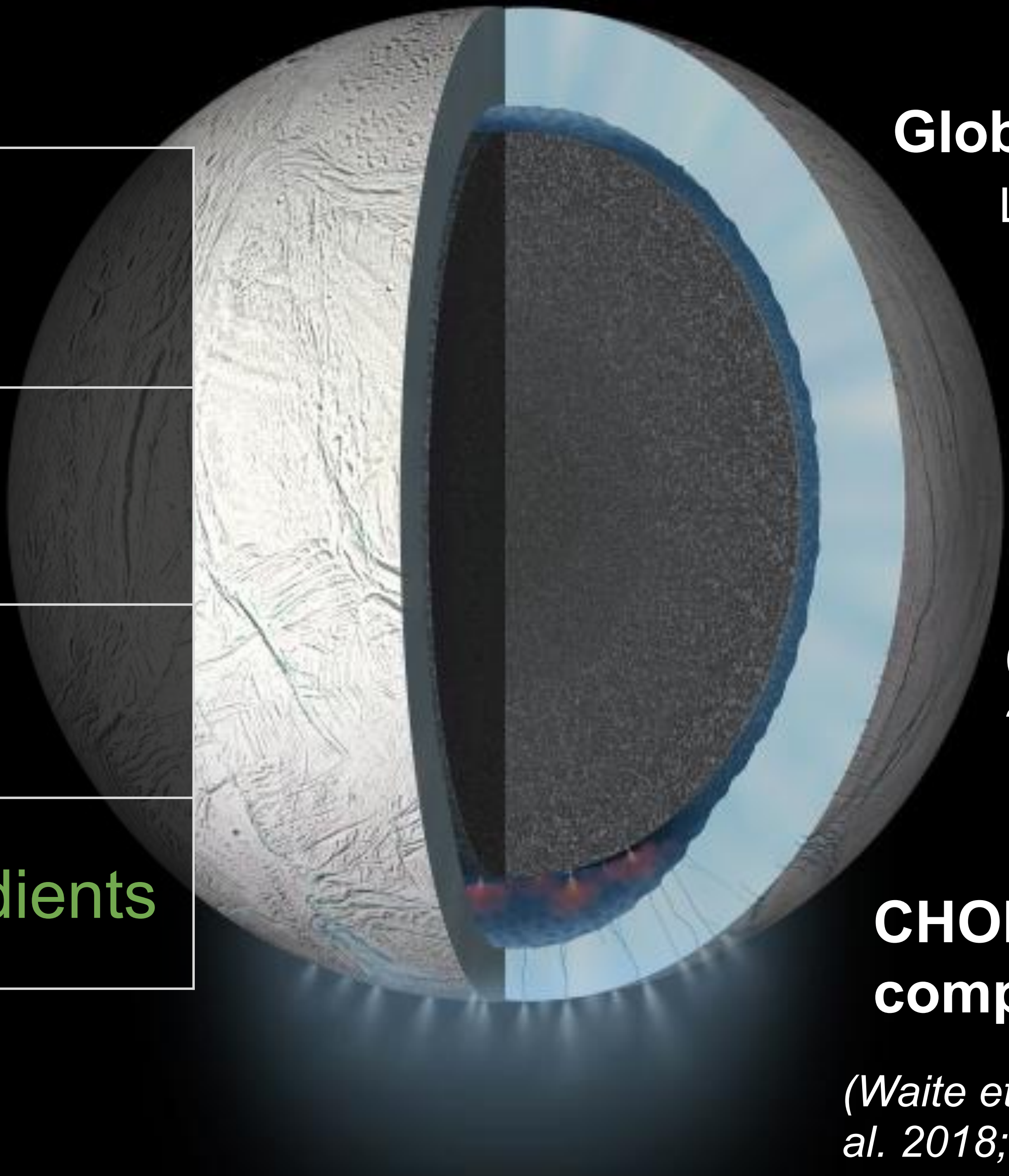
CHON and simple and complex organics

(Waite et al. 2017; Postberg et al. 2018; Khawaja et al. 2019)

Habitability

- ✓ Liquid Water
- ✓ Energy
- ✓ Chemical Ingredients



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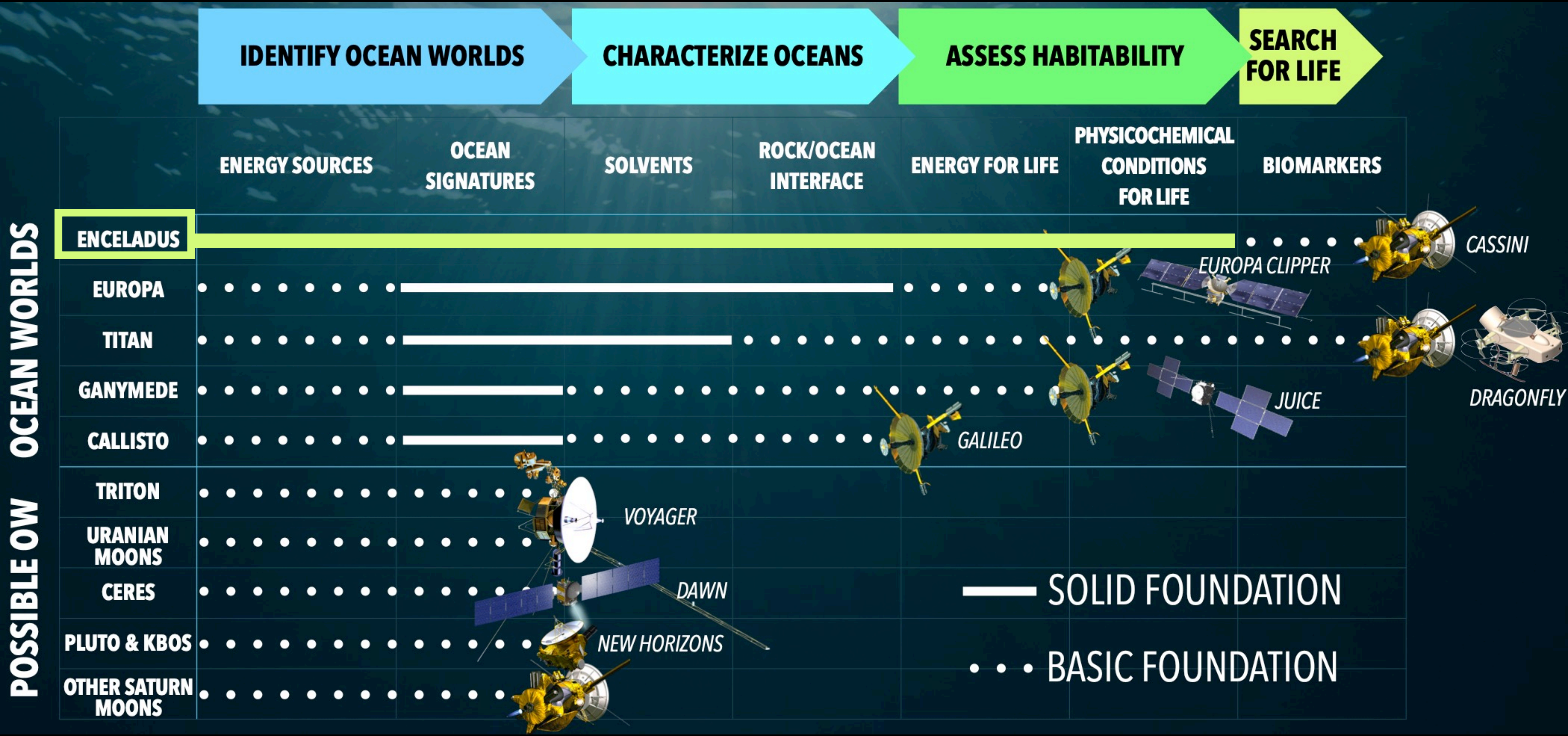
Neveu et al. (2020)



Is Enceladus inhabited?

Science Goals

IS ENCELADUS INHABITED?

<u>CHEMICAL BIOSIGNATURES</u>

1. Amino acid characterization
2. Lipid Characterization
3. Pathway Complexity Index

Science Goals

Is Enceladus Inhabited?

<u>Chemical biosignatures</u>

1. Amino acid characterization
2. Lipid Characterization
3. Pathway Complexity Index

<u>Confirmation biosignatures</u>

4. Genetic biopolymer
5. Cell characterization

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HRMS High Resolution Mass Spectrometer	**GCMS** Separation Capable Mass Spectrometer	**ISE** Ion Selective Electrodes	**µCE-LIF** Microcapillary Electrophoresis with Laser Induced Fluorescence	**Microscope**	**Nanopore** Solid State Nanopore Sequencer

Life Detection Suite (LDS)

Neveu et al. (2018)

complementary →

orthogonal ↑

Category	RUNG Roughly, subjectively ordered by (top to bottom): 1. decreasing strength of evidence for life 2. increasing ease of measurement	FEATURE Listed in no specific order within a given rung	MEASUREMENT	Instruments
LIFE	Darwinian evolution	Changes in inheritable traits in response to selective pressures	Not practical under mission constraints	
LIFE	Growth & Reproduction	Concurrent life stages or identifiable reproductive form,	Cell(-like?) structures in multiple stages	microscope
LIFE	Metabolism	Major element or isotope fractionations indicative of metabolism	Deviation from abiotic fractionation controlled by thermodynamic equilibrium and/or kinetics	HRMS
LIFE	Metabolism	Response to substrate addition	Waste output (compound, heat)	
LIFE	Metabolism	Co-located reductant and oxidant	Deviation from abiotic distribution controlled by thermodynamic equilibrium and/or kinetics	HRMS, ESA
LIFE	Molecules & Structures Conferring Function	Polymers that support information storage and transfer for terran life (DNA, RNA)	Abundance	nanopore
LIFE	Molecules & Structures Conferring Function	Structural preferences in organic molecules (non-random and enhancing function)	Polymer with repeating charge	nanopore
LIFE	Molecules & Structures Conferring Function	Structural preferences in organic molecules (non-random and enhancing function)	Enantiomeric excess > 20% in multiple amino acid types	GCMS, µCE-LIF
LIFE	Molecules & Structures Conferring Function	Pigments as evidence of non-random chemistries (e.g. specific pathways)	Spectral feature and/or color, otherwise see "structural preferences"	microscope
SUSPICIOUS BIOMATERIALS	Potential biomolecule components	Organics not found abiotically (e.g. hopanes, ATP, histidine)	Presence	HRMS
SUSPICIOUS BIOMATERIALS	Potential biomolecule components	Complex organics (e.g. nucleic acid oligomers, peptides, PAH)	Presence	HRMS, GCMS, µCE-LIF
SUSPICIOUS BIOMATERIALS	Potential biomolecule components	Monomeric units of biopolymers (nucleobases, amino acids, lipids for compartmentalization)	Presence	GCMS, µCE-LIF
SUSPICIOUS BIOMATERIALS	Potential metabolic byproducts	Distribution of metals e.g. V in oil or Fe, Ni, Mo/W, Co, S, Se, P	Presence	HRMS
SUSPICIOUS BIOMATERIALS	Potential metabolic byproducts	Patterns of complexity (organics)	Deviation from equilibrium (P(Poisson distribution of pathway complexity) < 0.01?) or abiotic kinetic distribution	HRMS, GCMS, µCE-LIF
SUSPICIOUS BIOMATERIALS	Biofabrics	Textures	Biologically mediated morphologies, preferably with co-located composition	

Science Goals

Is Enceladus Inhabited?

To what extent is Enceladus' ocean able to sustain life and why?

Determine Ejection Mechanics

1. Structure and dynamics of the crust
2. Assent and freezing conditions
3. Physical structure of vent openings and plumbing

Assess Ocean Habitability

1. Ocean pH, temperature, salinity
2. Availability of micronutrients
3. Sources of energy
4. Structure, dynamics, and evolution of the interior

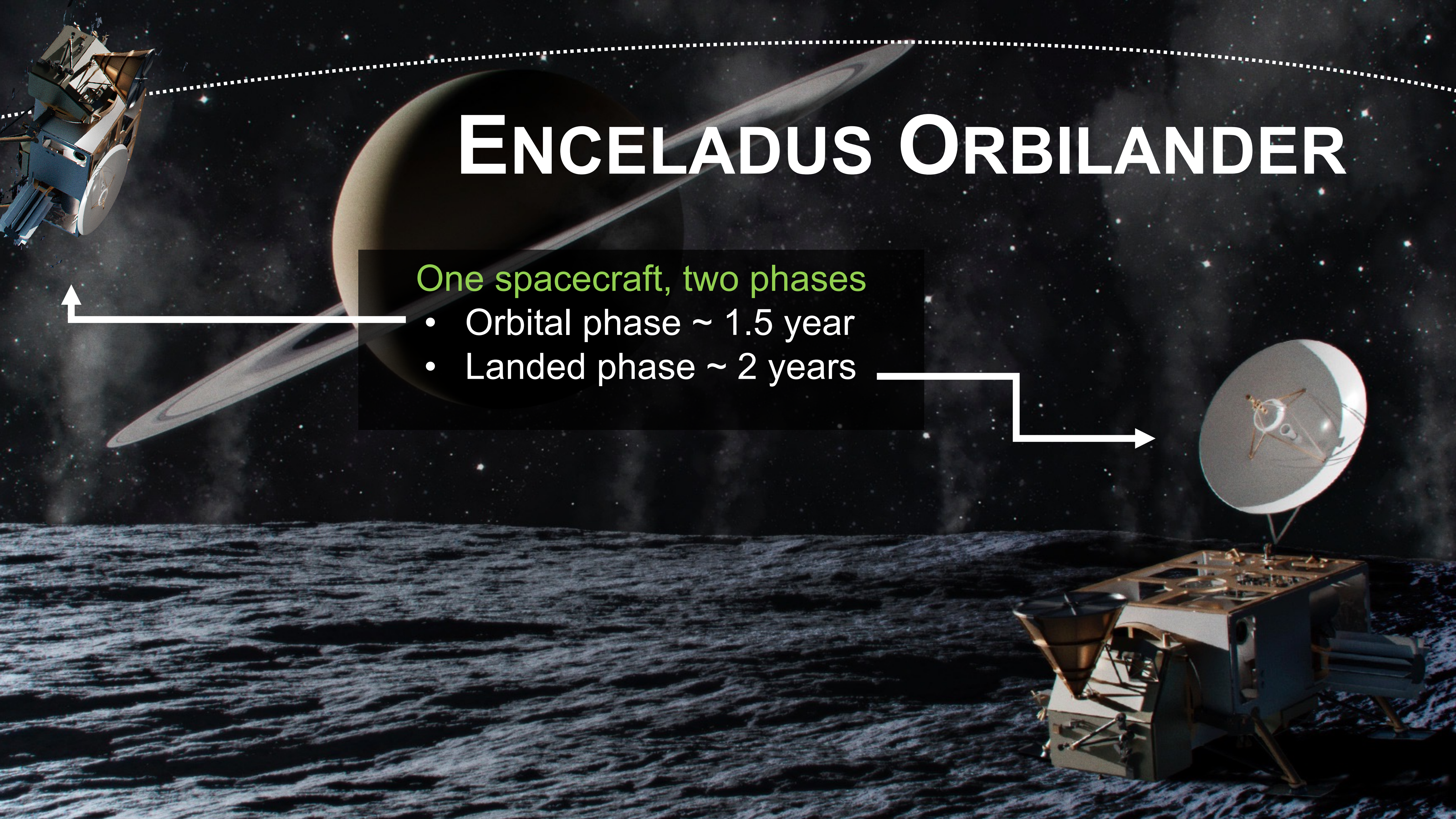
To what extent is Enceladus' ocean able to sustain life and why?

Remote Sensing/Recon

- **Narrow Angle Camera**
- **Wide Angle Camera**
- **Laser Altimeter**
- **Radar Sounder**
- **Thermal Emission Spectrometer**

In Situ

- **Context Imager**
- **Seismometer**


Enceladus Orbilander
One spacecraft, two phases
• Orbital phase ~ 1.5 year
• Landed phase ~ 2 years

ENCELADUS ORBILANDER

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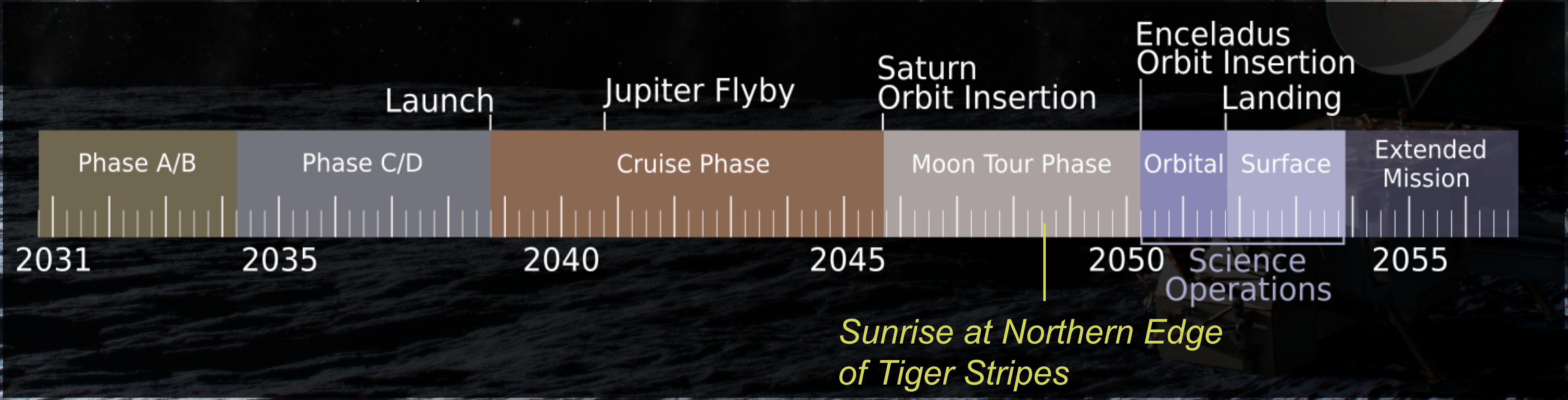
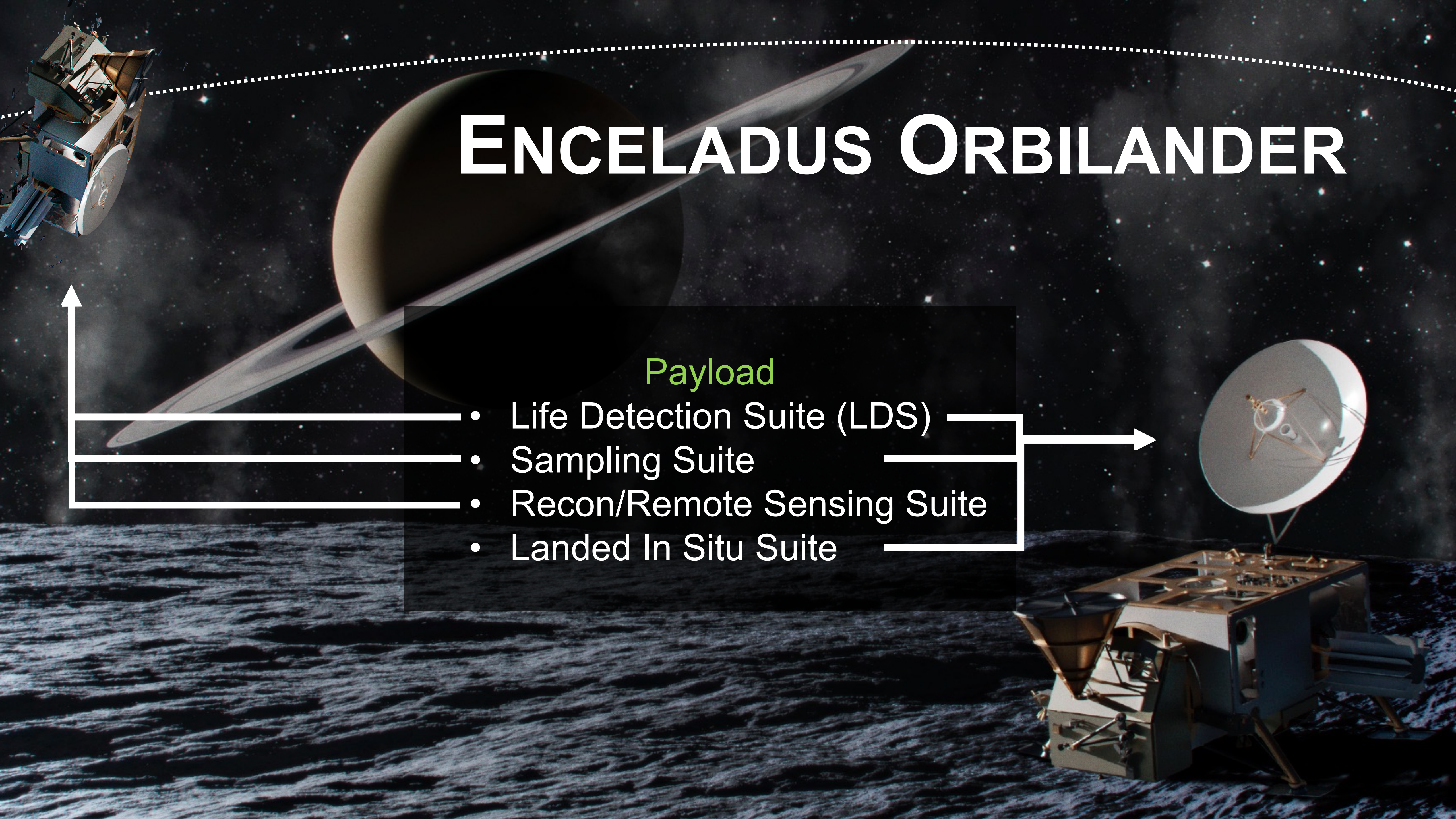
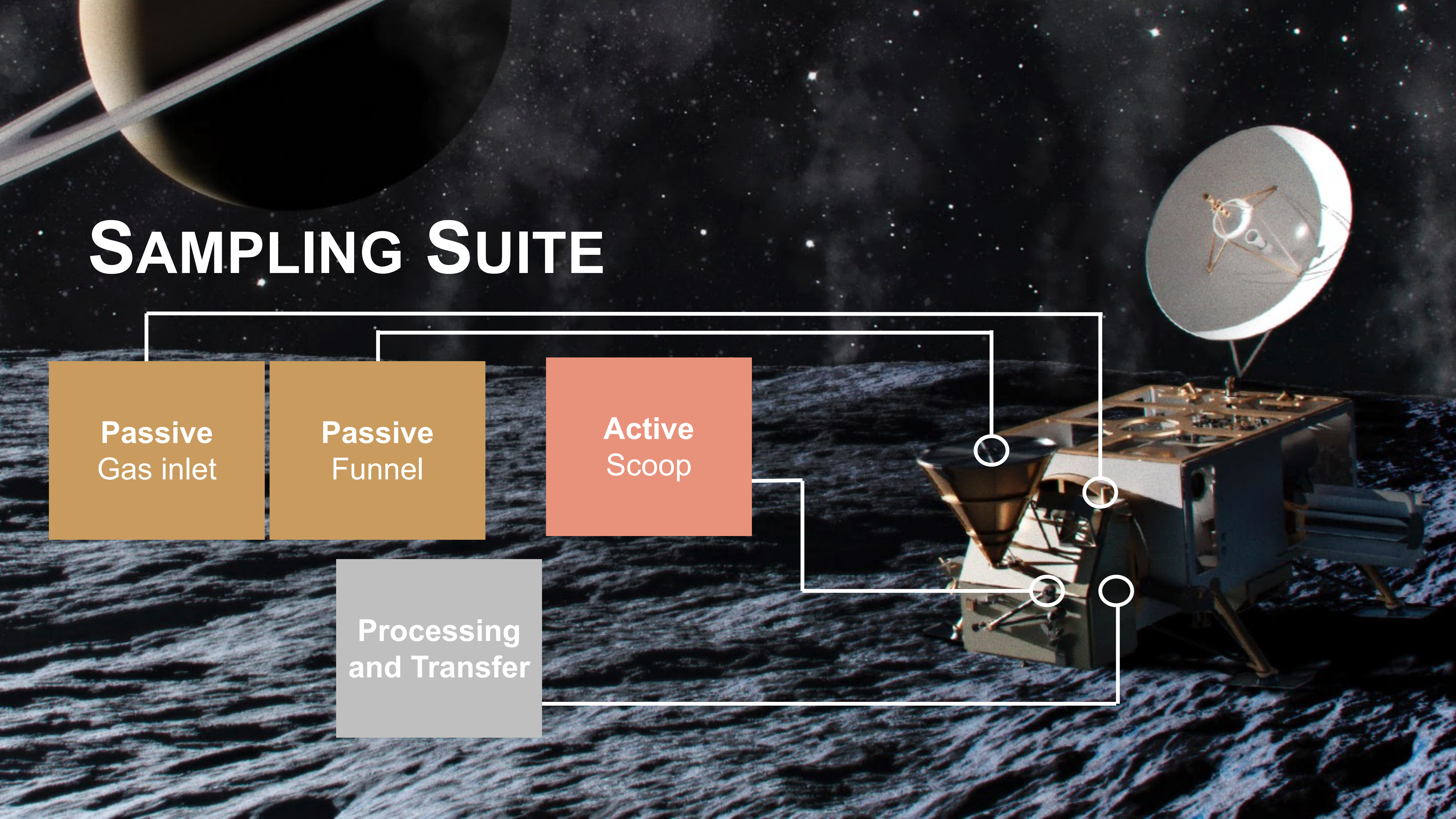
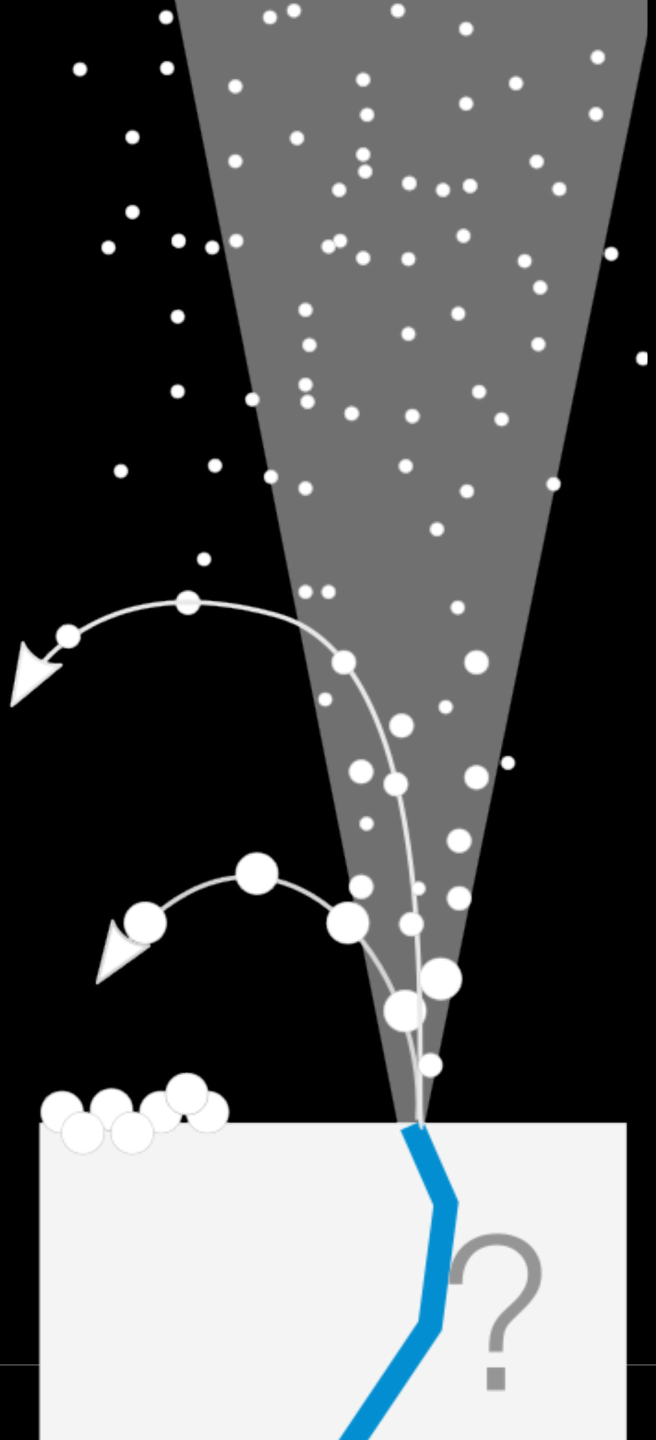



ENCELADUS ORBILANDER
Payload
• Life Detection Suite (LDS)
• Sampling Suite
• Recon/Remote Sensing Suite
• Landed In Situ Suite

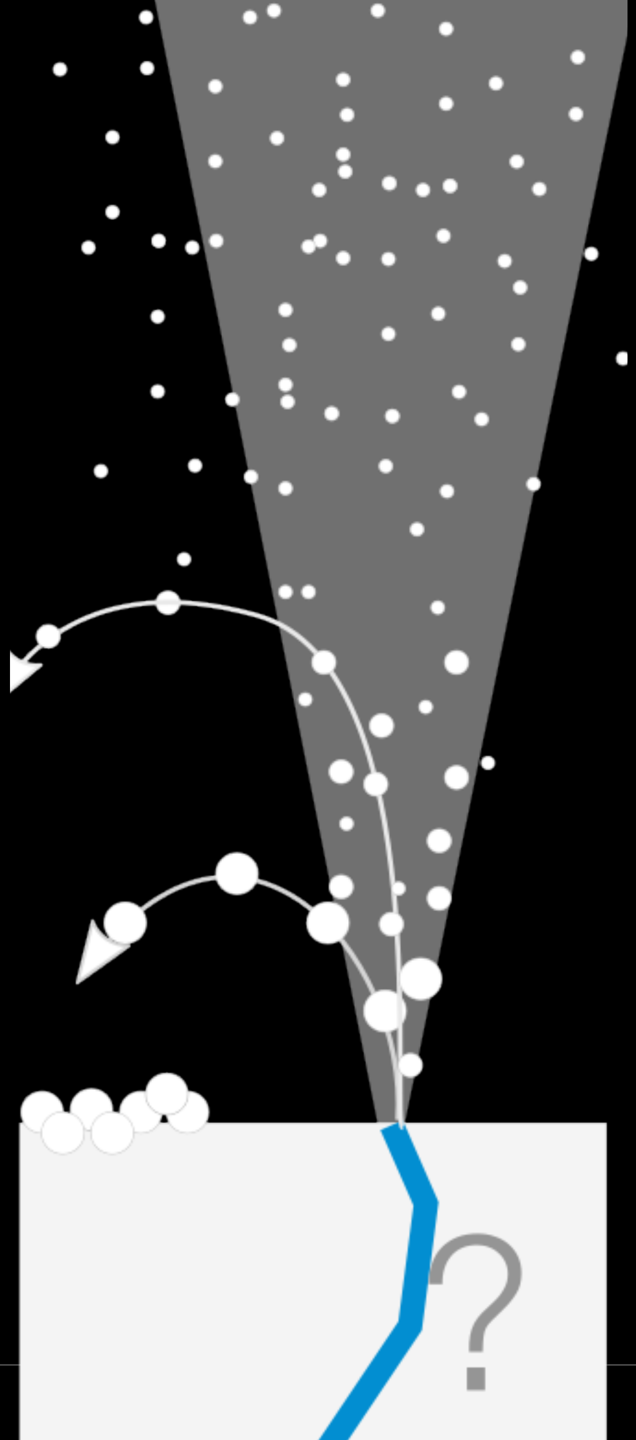

SAMPLING SUITE
Passive
Gas inlet
Passive
Funnel
Active
Scoop
Processing
and Transfer



mixed plume (> 40 km)

high likelihood of vapor sampling

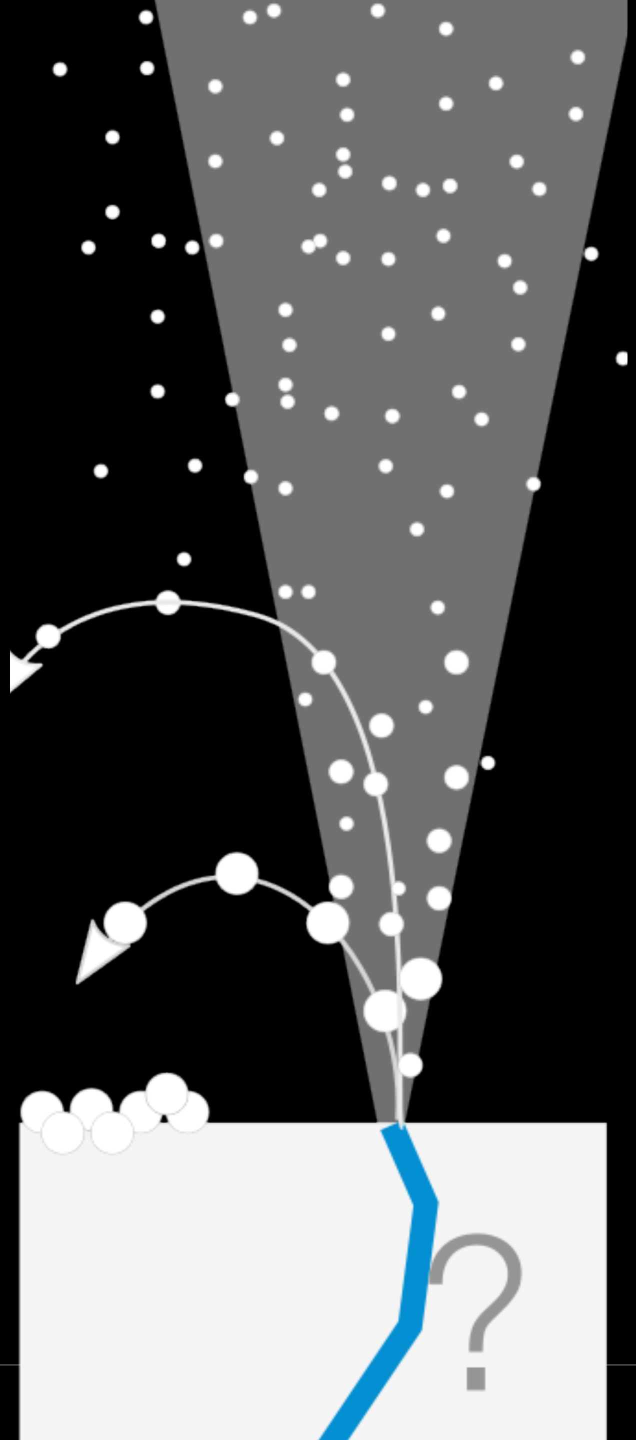
nm-sized particles

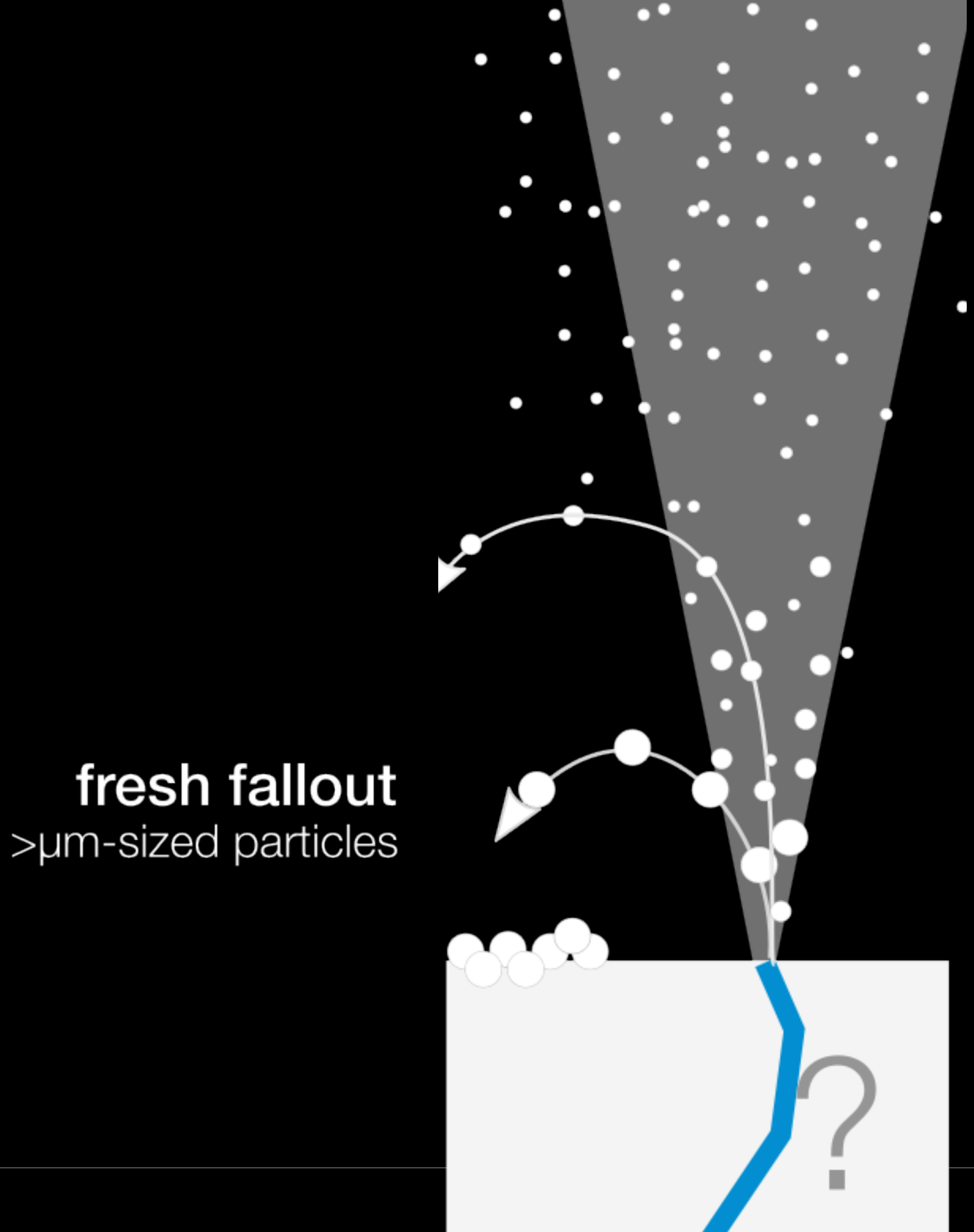


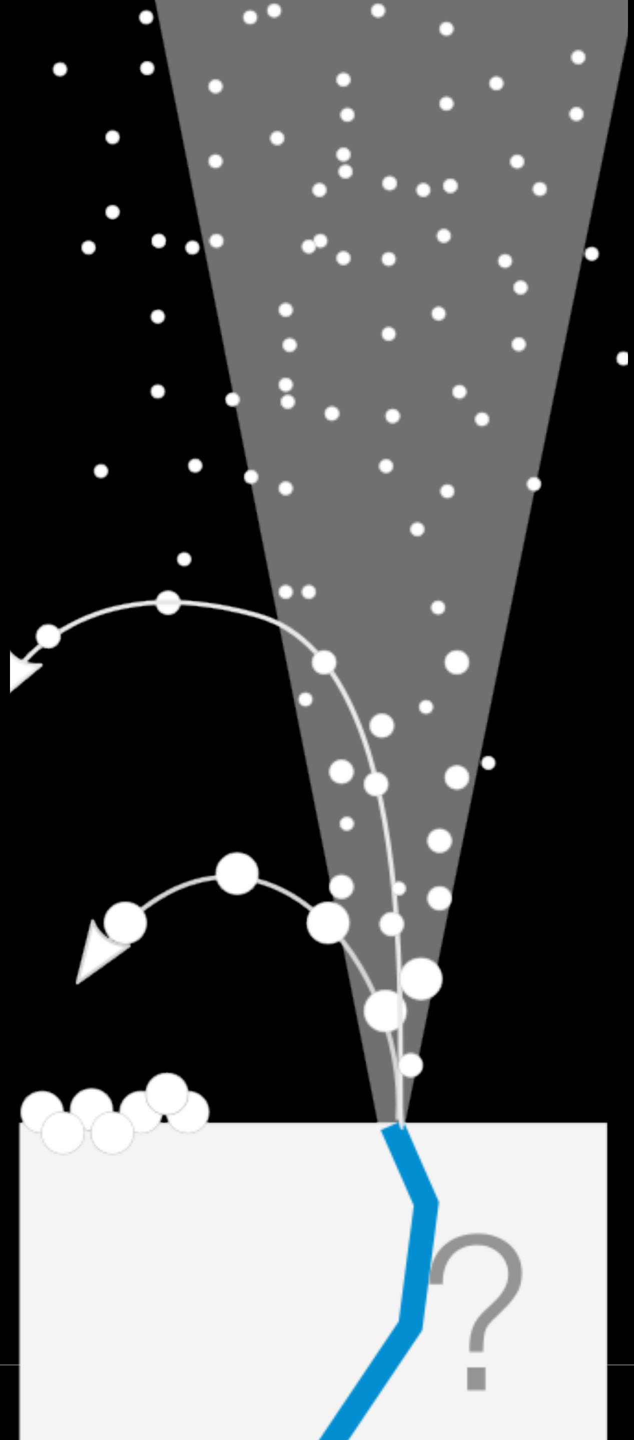
collimated plume (~20 km)

some vapor sampling

μm-sized particles




fresh fallout
>µm-sized particles
?



surface deposits

>µm-sized particles,

possibly modified

Enceladus Orbilander

One spacecraft, two phases

- Orbital phase ~ 1.5 year
- Landed phase ~ 2 years

Payload

- Life Detection Suite (LDS)
- Sampling Suite
- Recon/Remote Sensing Suite
- Landed In Situ Suite

1.1Tb data return capacity

2 RTGs, 1 Battery

Direct-to-Earth Communication

$2.6B (FY25)

Improves resiliency to biomass uncertainty

Current knowledge of
Enceladus energy supply
(5 order-of-mag uncertainty)
and cell energy demand
(6 order-of-mag uncertainty[1])

Number of microbial cells per mL ocean water

10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4}

Biomass density if energy-limited (Cable et al. 2020)

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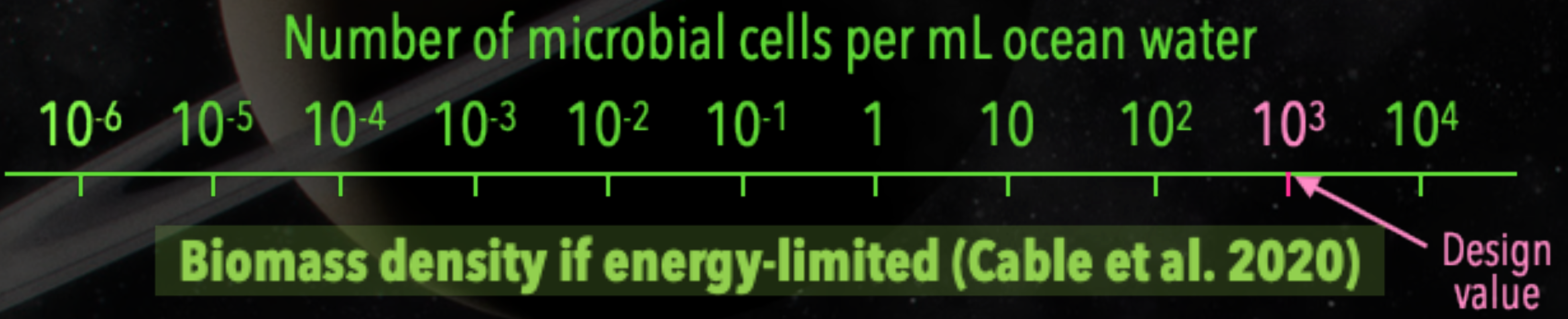

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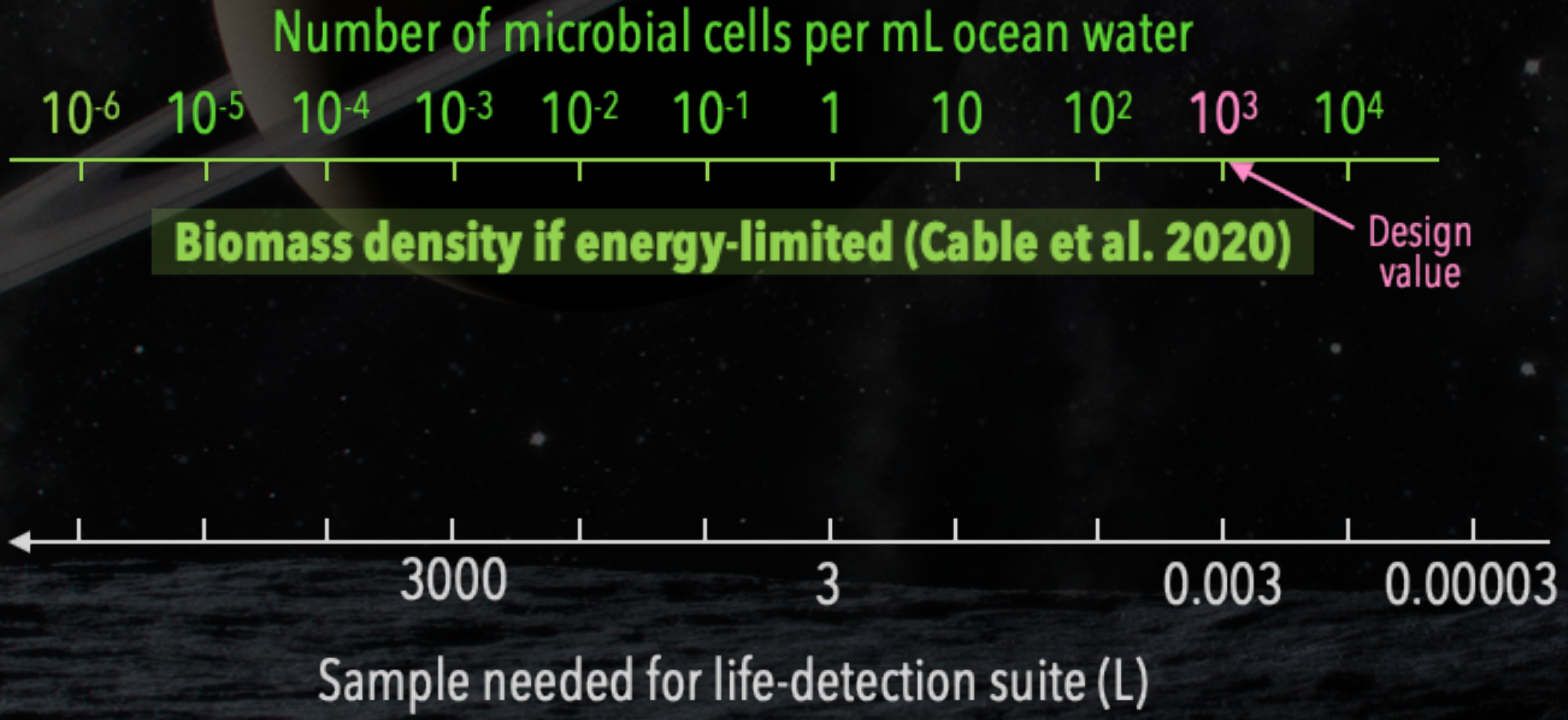

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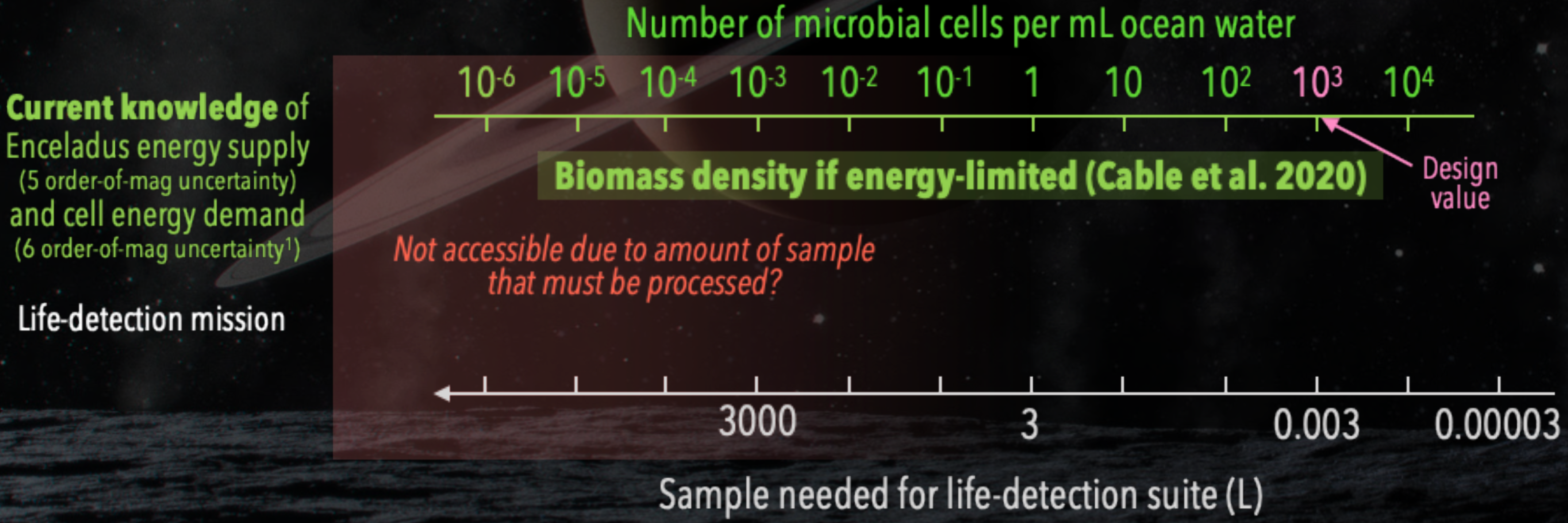

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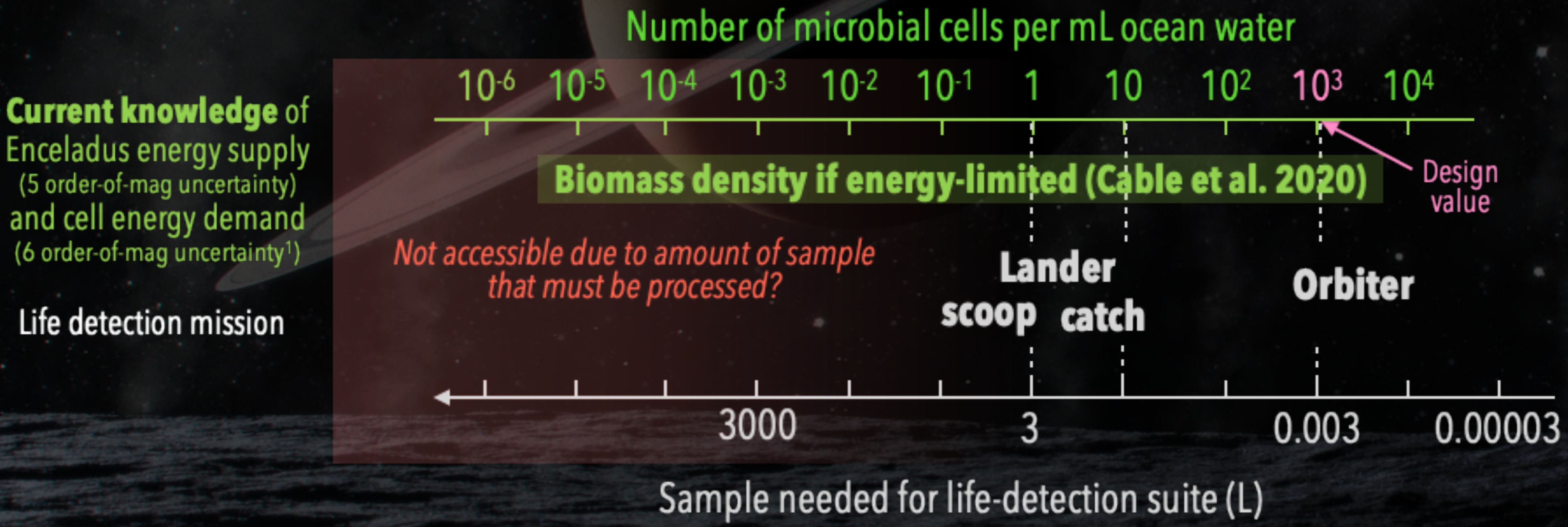

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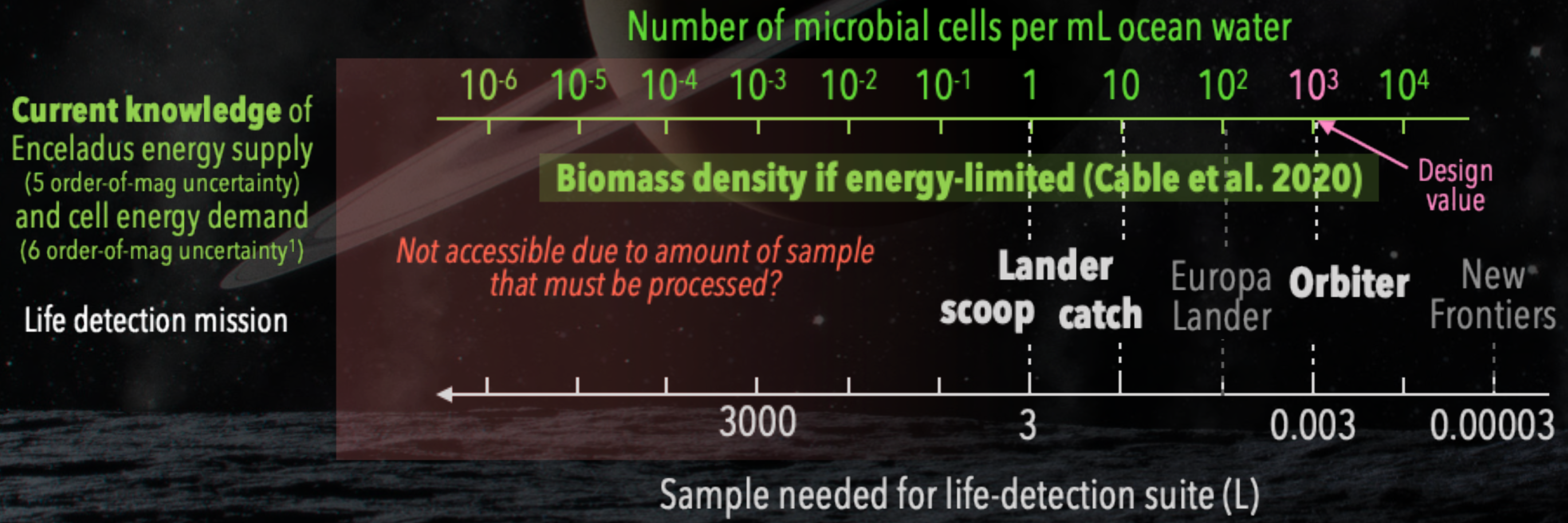

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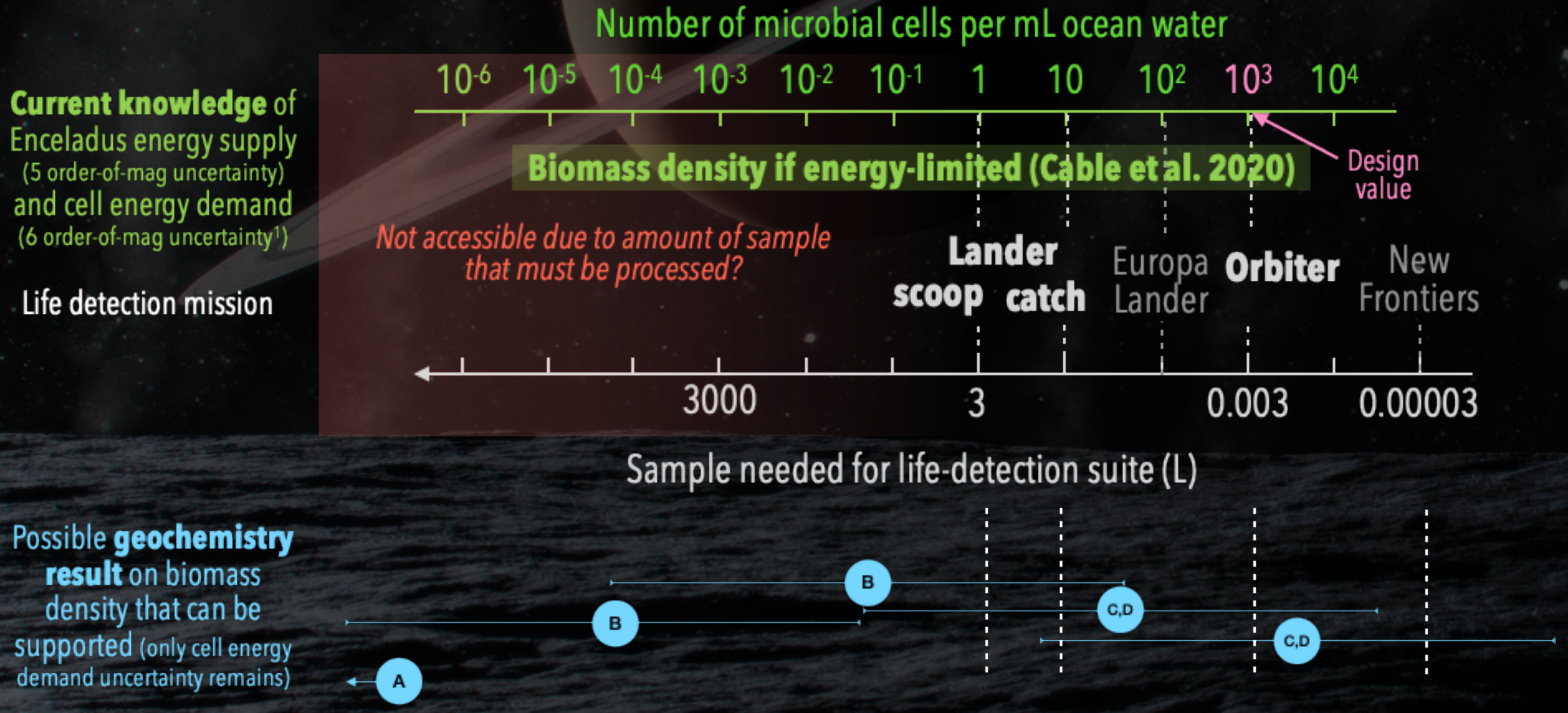

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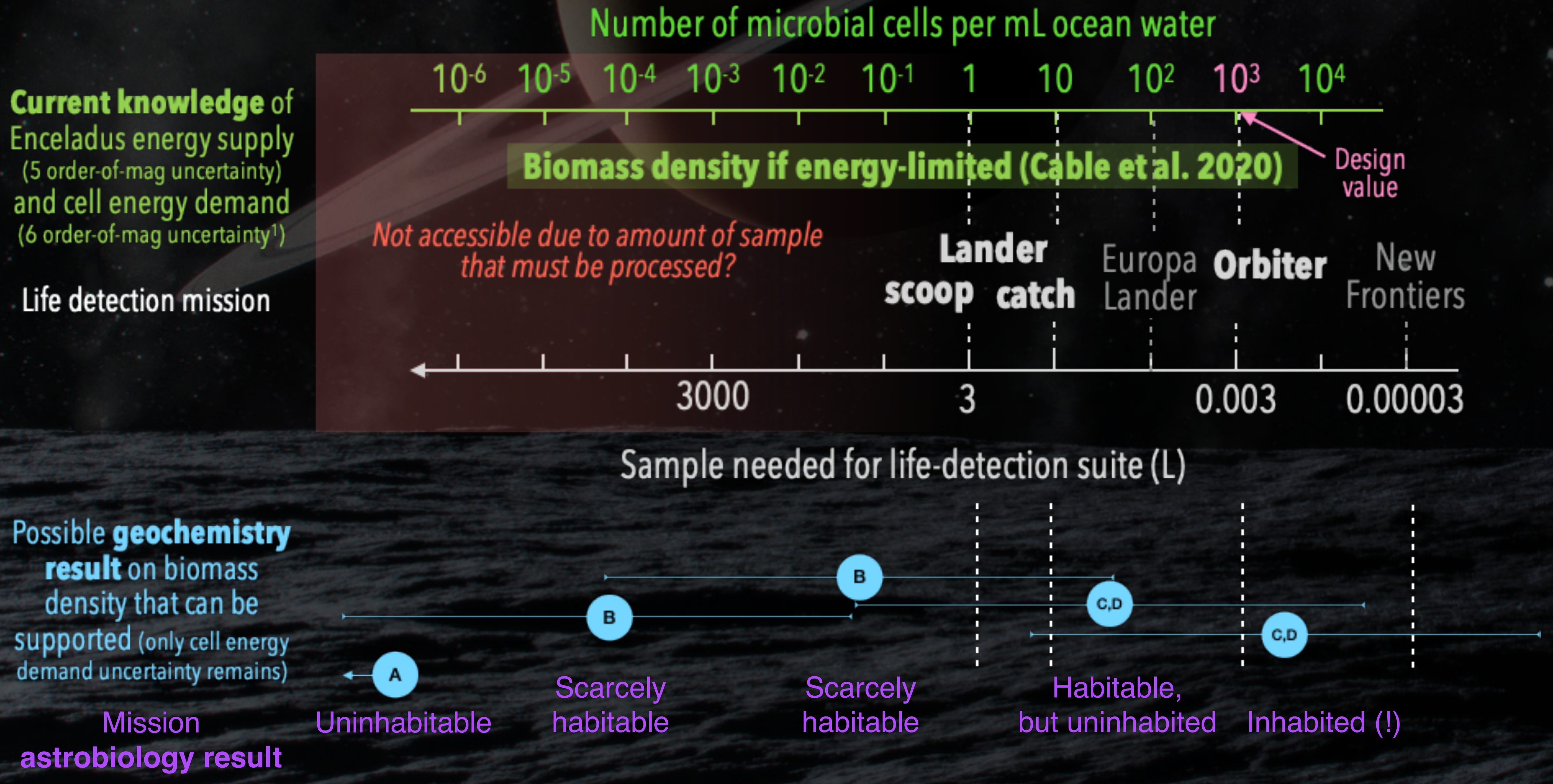

The Enceladus Orbilander Mission Concept Design demonstrates

- the feasibility of a resource-conscious flagship architecture
- the search for signs of life at Enceladus is executable in the next decade
- complementary investigations into the geophysical and geochemical environment are within resources
- Cassini data are sufficient for planning the next mission to Enceladus
- large volumes of oceanic material accessible from orbit and from the surface lead to increased resiliency to low biomass availability

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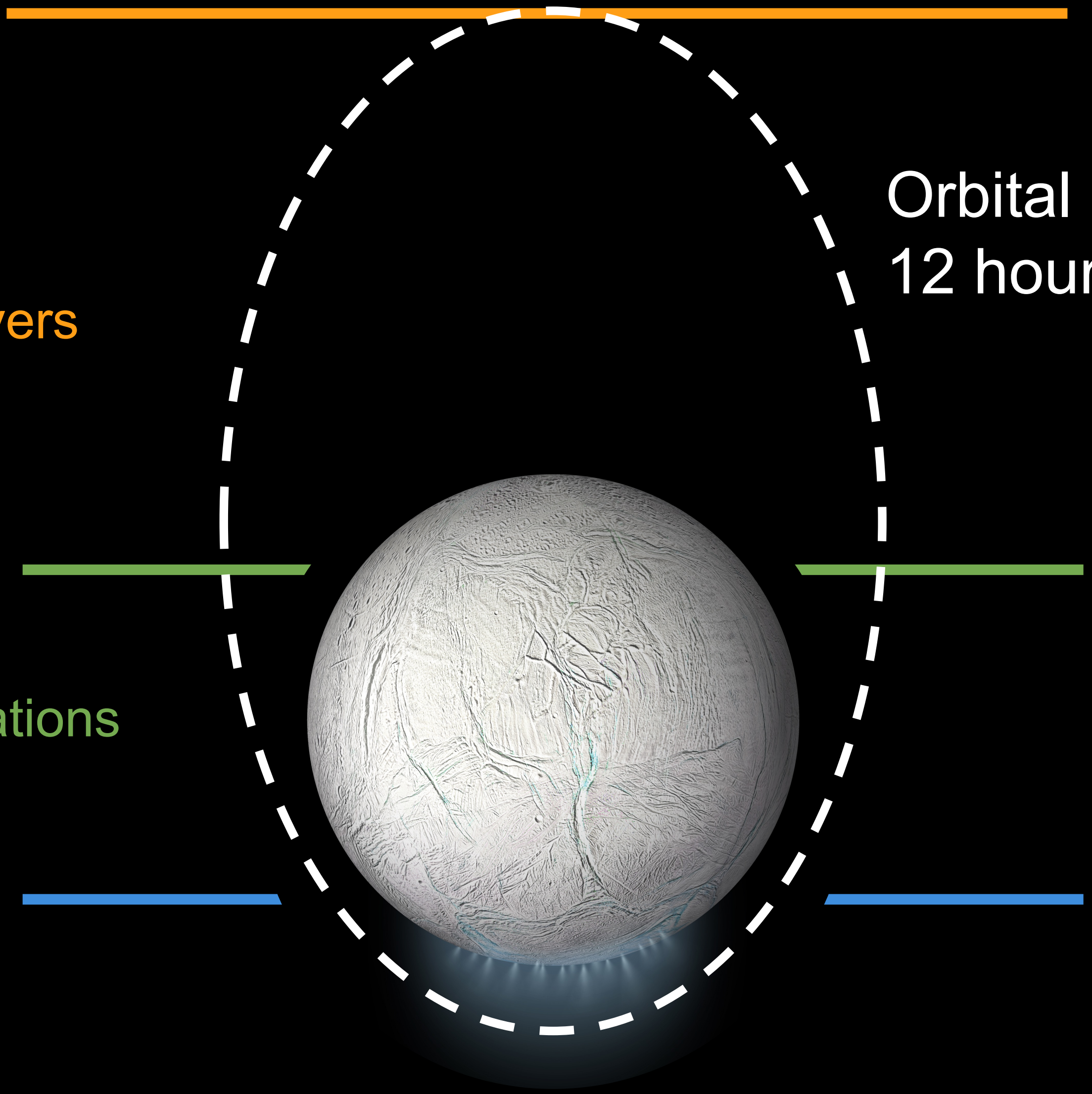
Orbital phase



> 400 km

Communications
Station keeping maneuvers

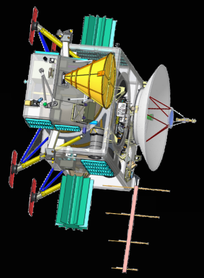
100-400 km
Station keeping observations

<100 km
Primary Science

Orbital period:
12 hours

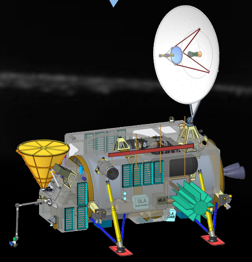
Periapsis: 20-70 km

Threshold



- **Orbital phase** (~1.5 year)
  - 1 LDS (-nanopore)
  - Vapor sampling
  - <m scale regional imaging
  - Regional topography
  - Thermal measurements
  - Radar sounding

- **Landed phase** (~1.5 years)
  - 1 passive LDS (- nanopore)
  - 3 passive LDS
  - 3 active LDS
  - >200 Esols of seismic monitoring
  - Scooping site images

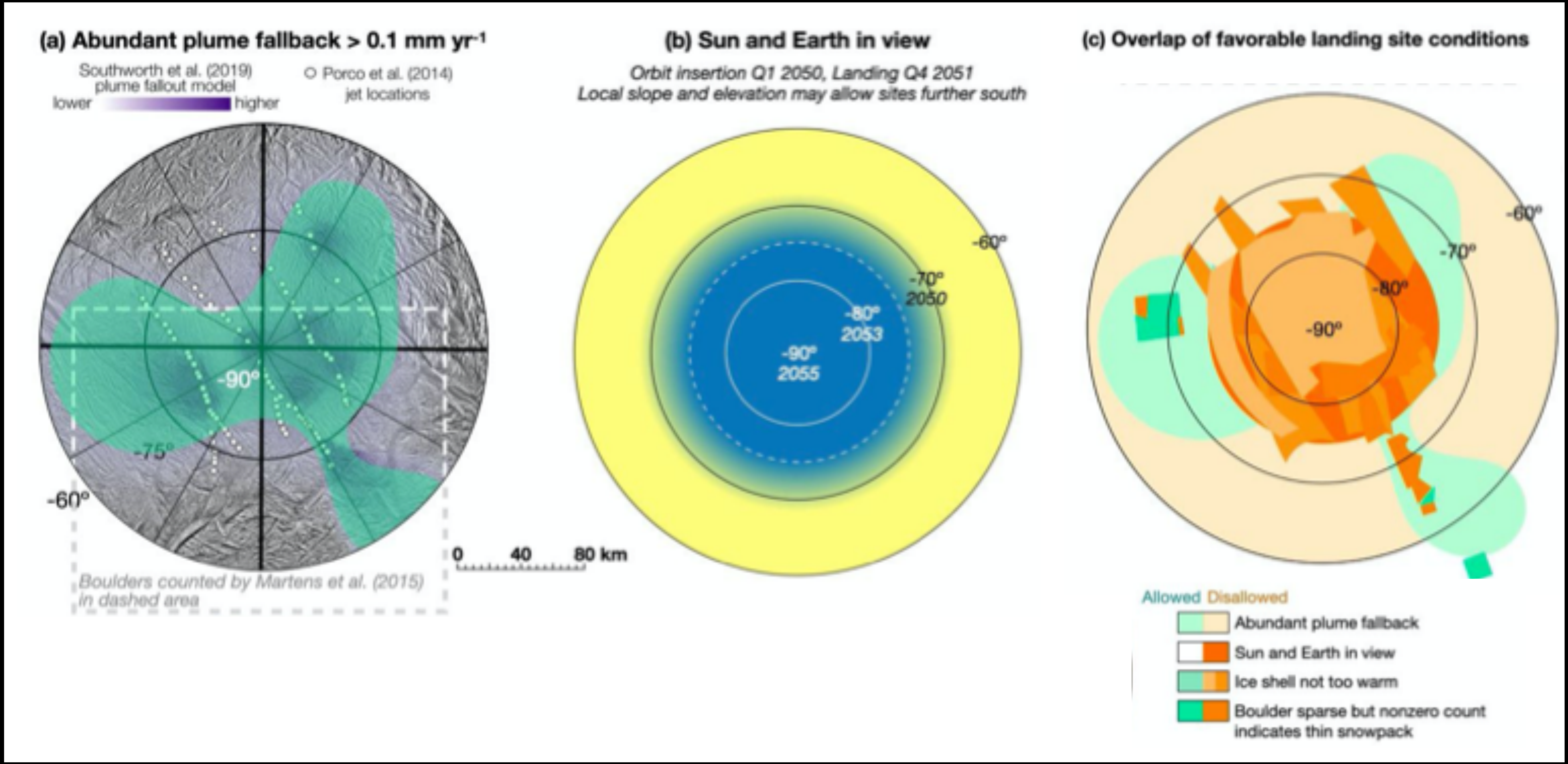


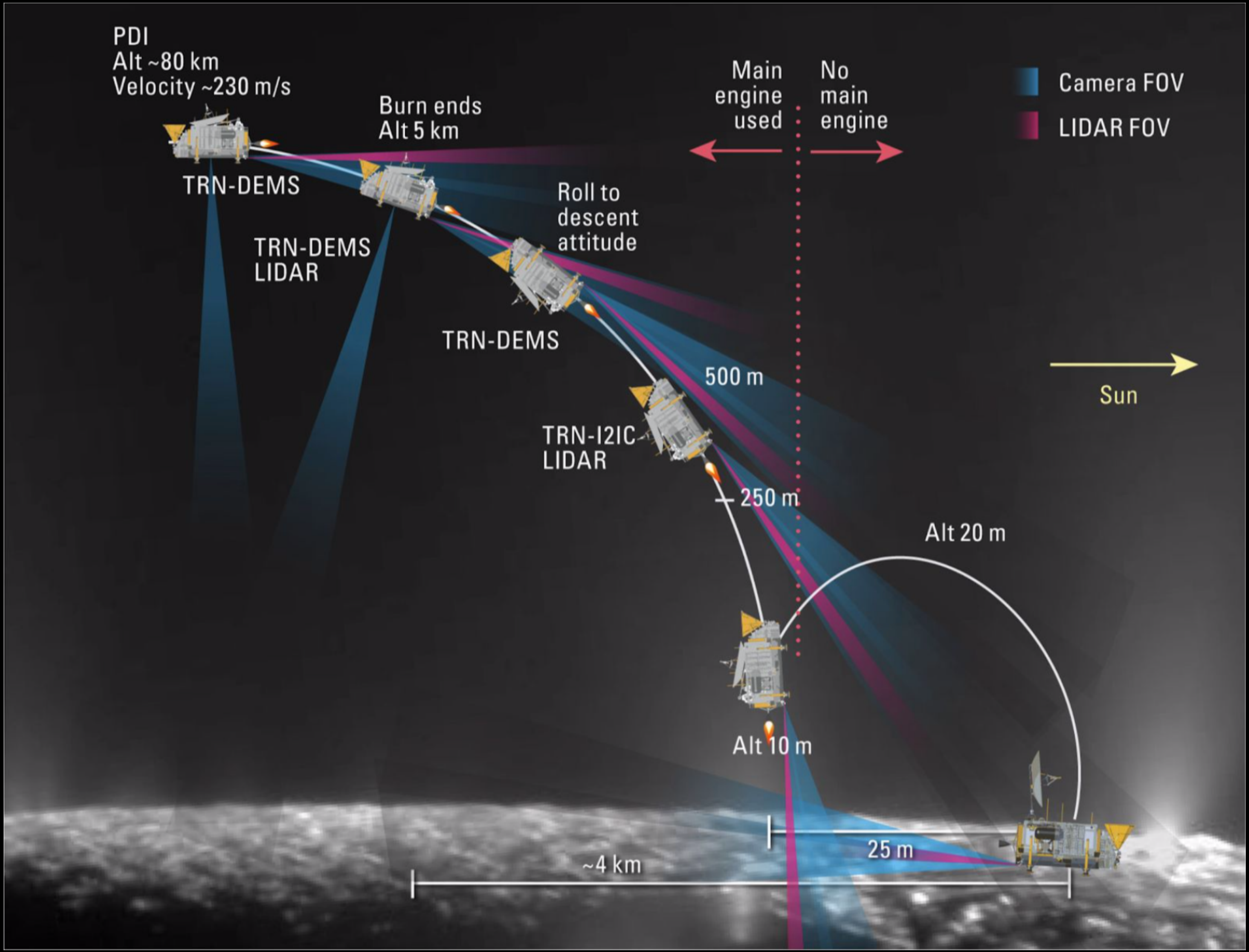
Landing Site Selection

- Sites selected based on four criteria:
    1. Receives daylight
    2. Low but non-zero boulder count
    3. Slopes < 10^{o}
    4. Not in a valley
    5. Temperatures < 85K
    6. Fallout > 0.01 mm/yr

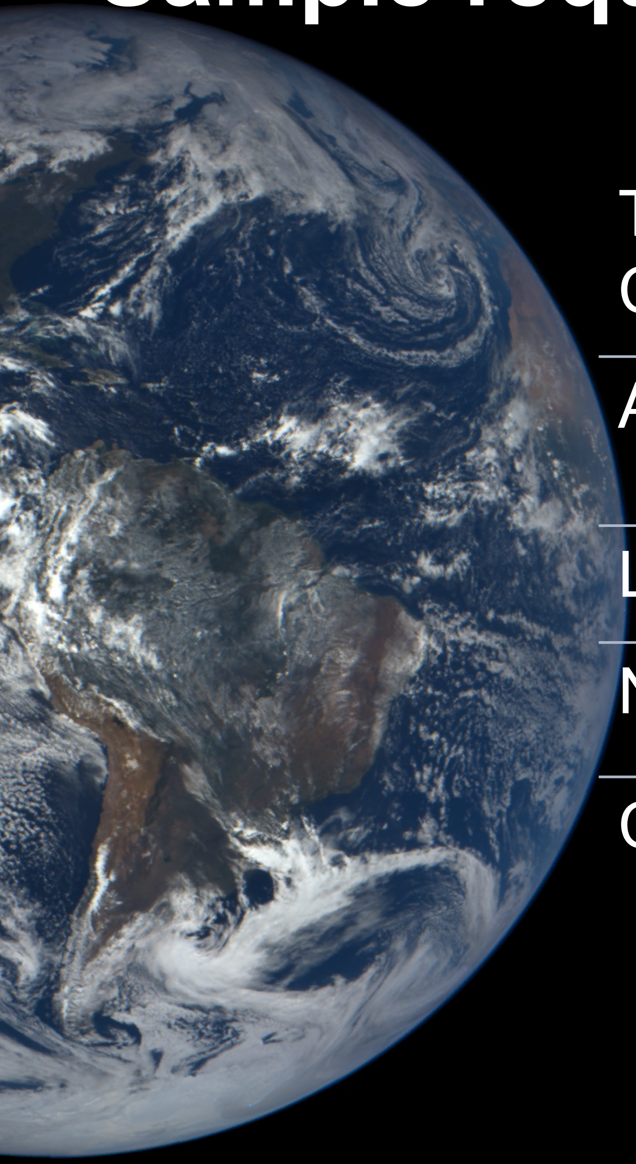
- Landing sequence requires TRN for hazard avoidance
    - Nav cameras
    - Descent lidar

Adequate landing sites are expected based on Cassini data

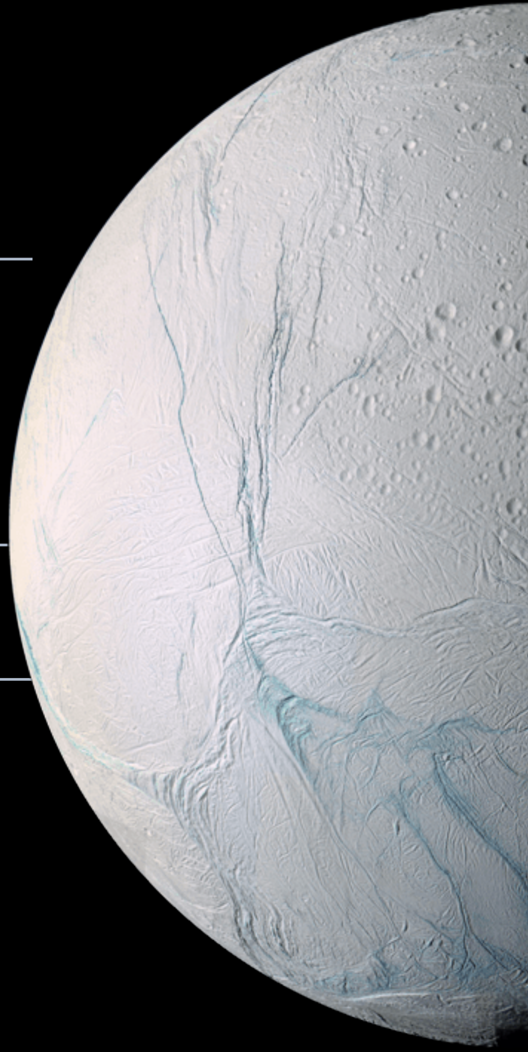



PDI
Alt ~80 km
Velocity ~230 m/s
Burn ends
Alt 5 km
TRN-DEMS
TRN-DEMS
LIDAR
Roll to
descent
attitude
TRN-DEMS
Main
engine
used
No
main
engine
Camera FOV
LIDAR FOV
500 m
TRN-I2IC
LIDAR
250 m
Sun
Alt 20 m
Alt 10 m
25 m
~4 km

Sample requirements



Total Organic Content (TOC)	30 µM	ELSDT : 41 µM Terrestrial oceans
Amino Acid (AA)	TOC/200	Terrestrial ratio
Lipids	AA/5	
Nanopore	10^{-15} g/µL	Free DNA in terrestrial oceans
Cell density	1 /µL	ELSDT: 0.1 cells/µL 10-100 cells/uL *(Porco et al. 2017, Steel et al . 2017)*



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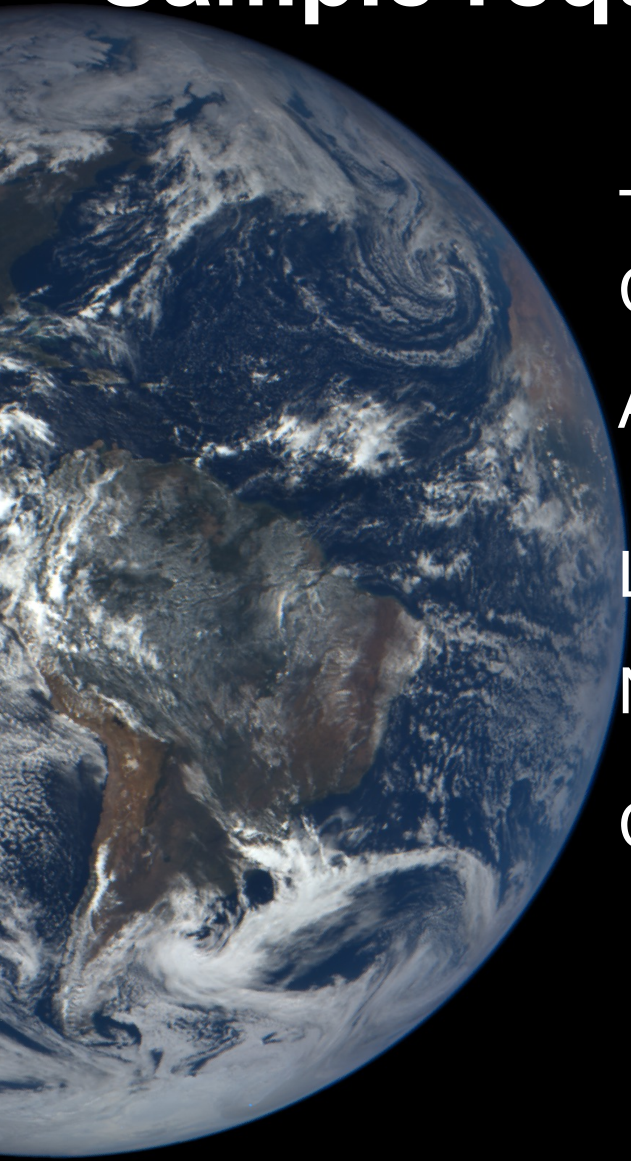


Total Organic Content (TOC)

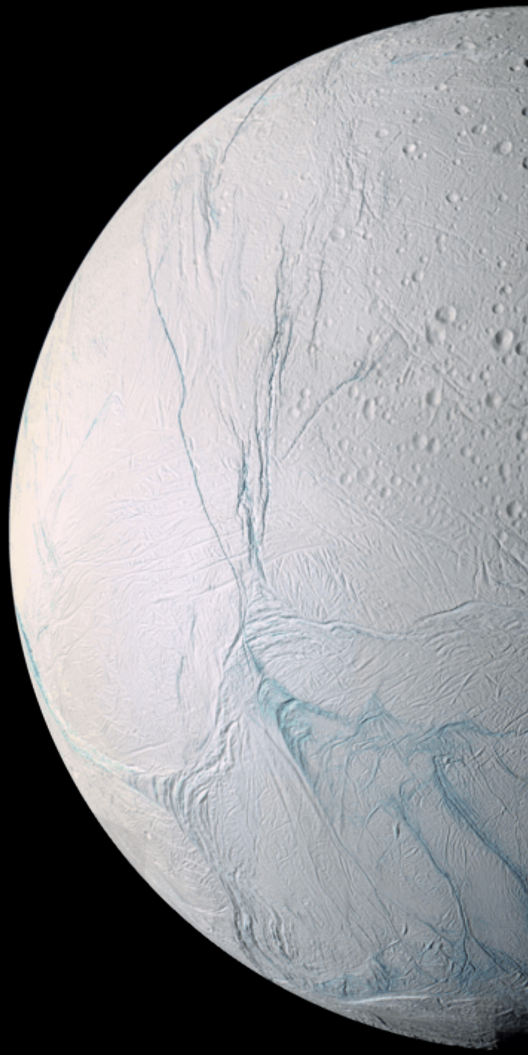
Amino Acid (AA)

Lipids

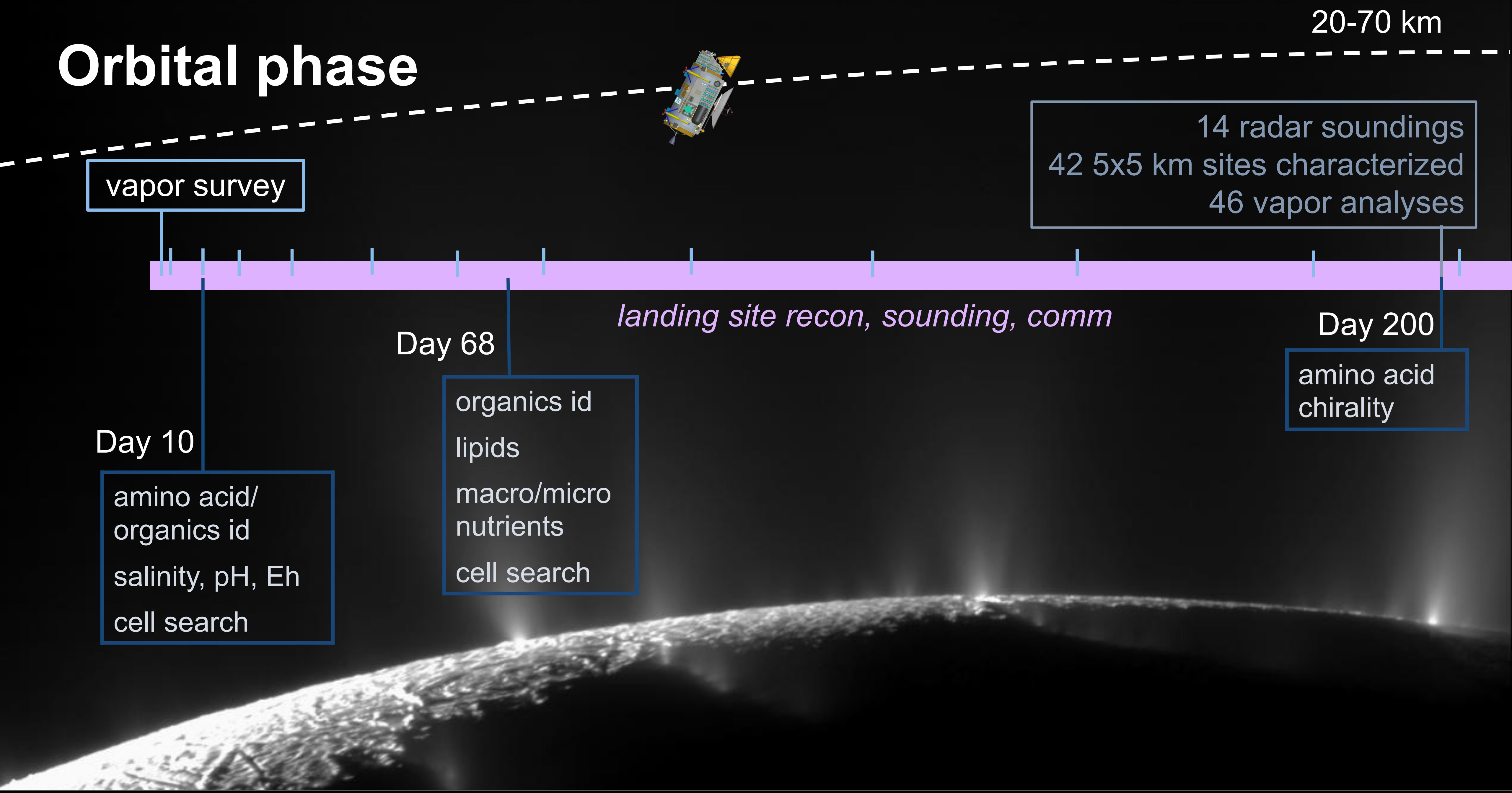
Nanopore

Cell density

Instrument type	Objective	Total plume material	
HRMS	organics survey	0.0025	µL
Sep. MS	amino acids lipids	2000 500	µL
µCE-LIF	amino acids	75	µL
ISE	macro-nutrients micro-nutrients pH salinity Eh	375	µL
Microscope	cells	5	µL
Nanopore	polyelectrolyte	30	mL



Orbital phase



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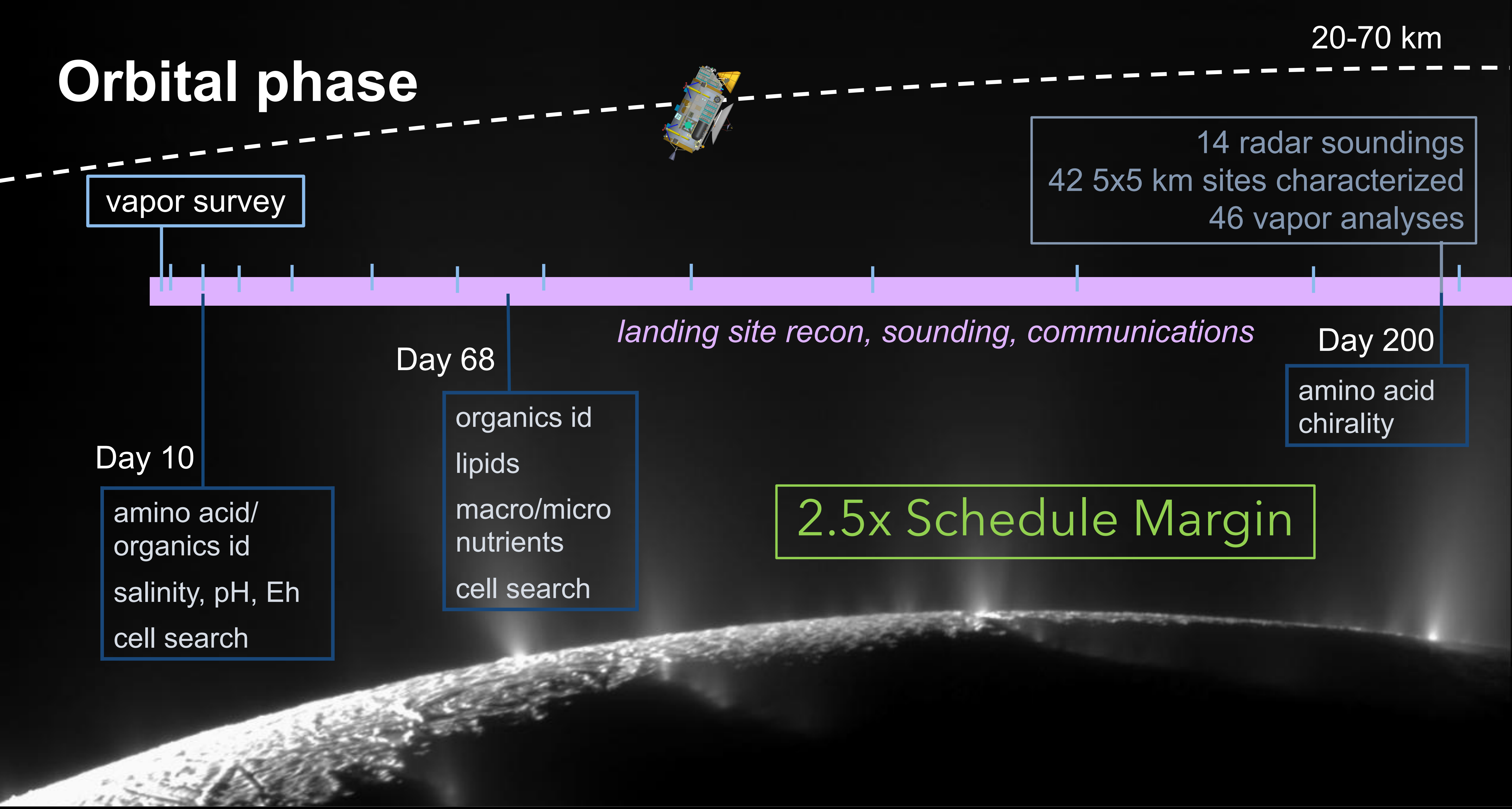

Landed Phase

Days 15-22
Passive LDS
(-nanopore)

Days 40-47
Passive LDS

Days 71-77
Active LDS

Days 101-107
Active LDS

Days 116-123
Passive LDS

Days 146-152
Active LDS

seismic monitoring, communications

Days 1-14
Checkouts
Seismometer deployment
Scoop recon

Days 22-40
Imaging
Try out arm
Flush LDS

Days 48-70
Flush LDS
Dig

Days 78-100
Flush LDS
Dig

Days 108-115
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Days 124-145
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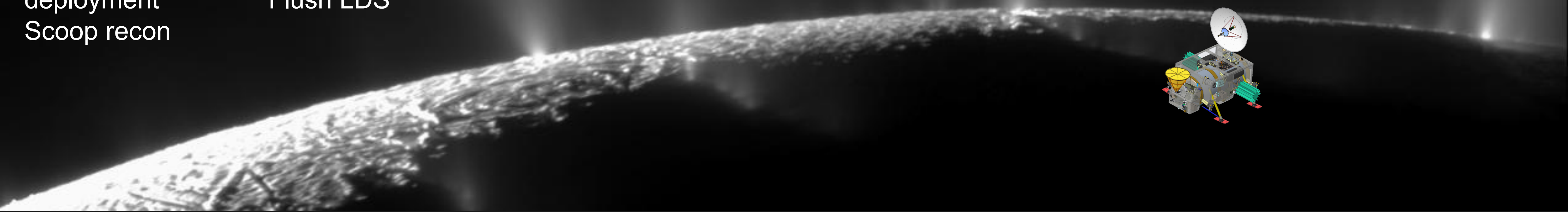
Dig



Landed Phase

4.1x Schedule Margin

Days 15-22
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