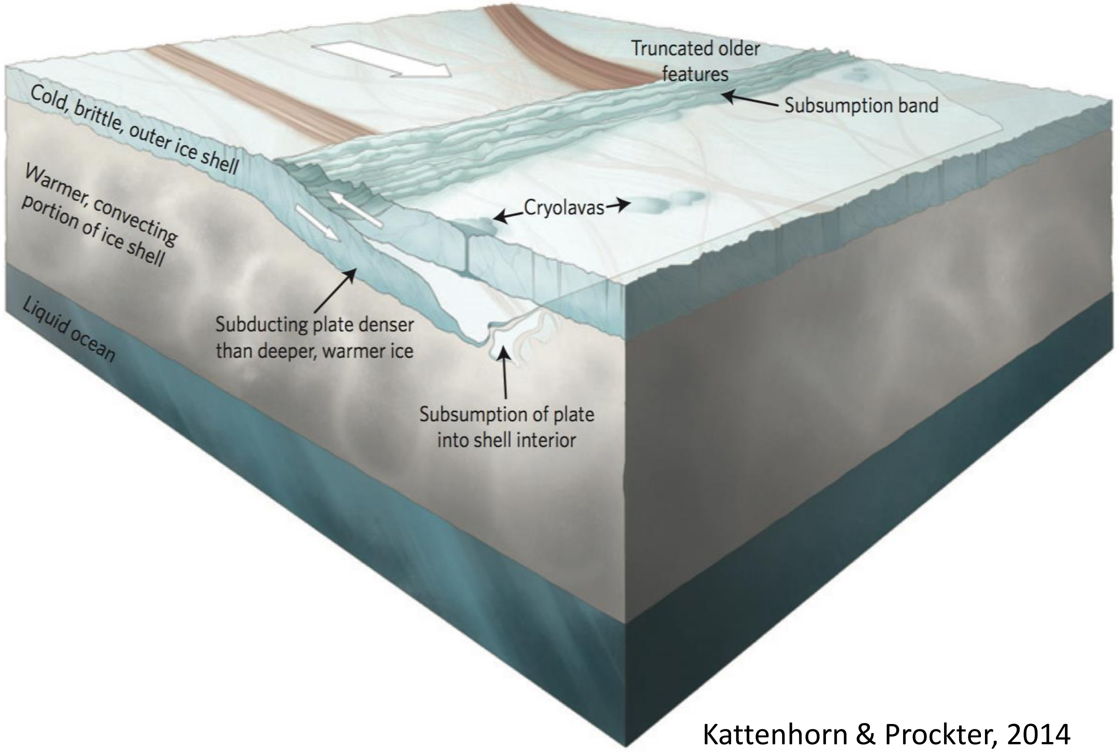
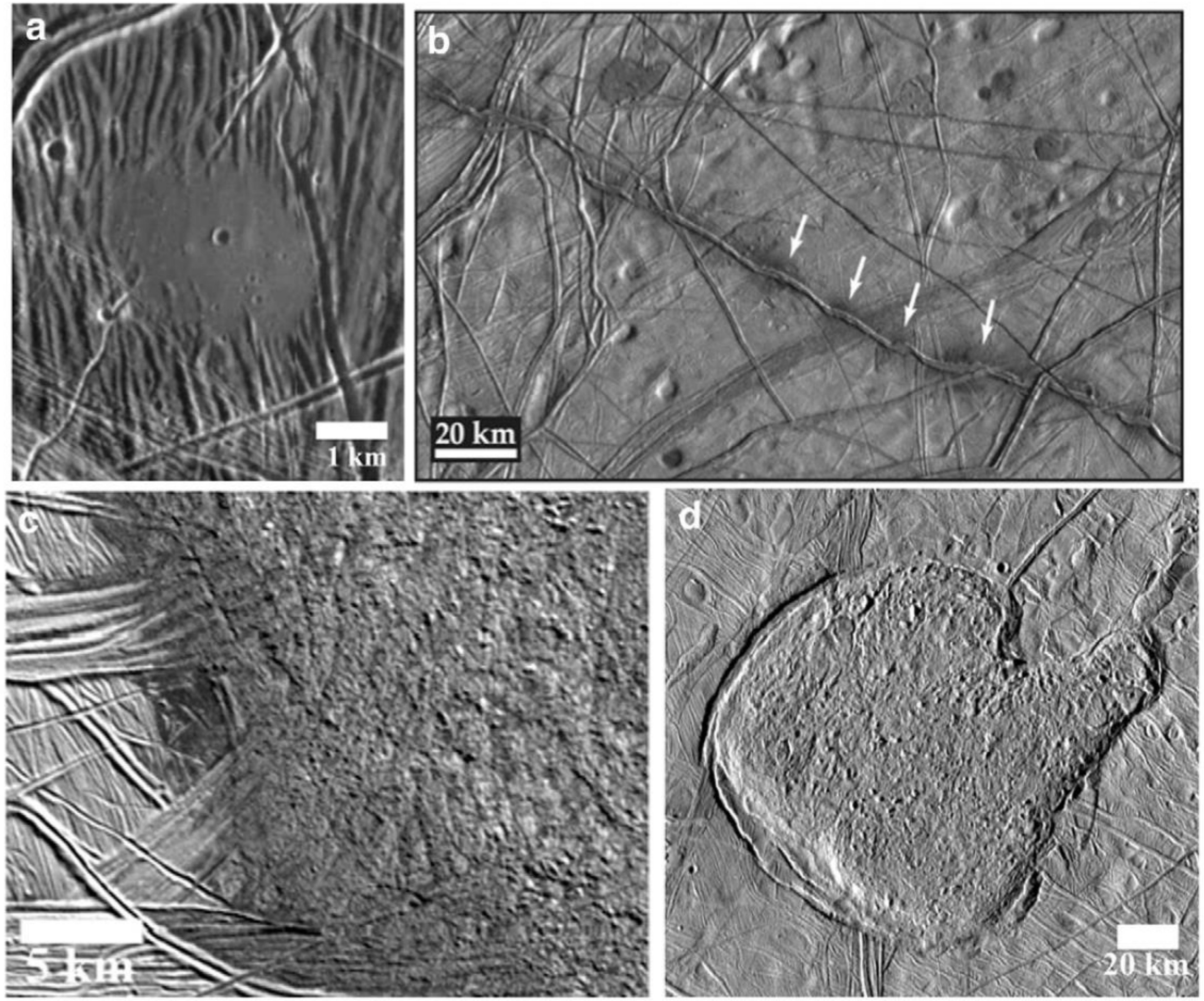
Europa Surface Science

- Key developments since 2011
  - Galileo imagery has provided new insights into ice shell processing and activity.
  - Ground-based telescopic observation have provided new insights into surface chemistry.
  - Space-based observations (HST) have provided a compelling case for active plumes.

Galileo imagery of ice shell processes



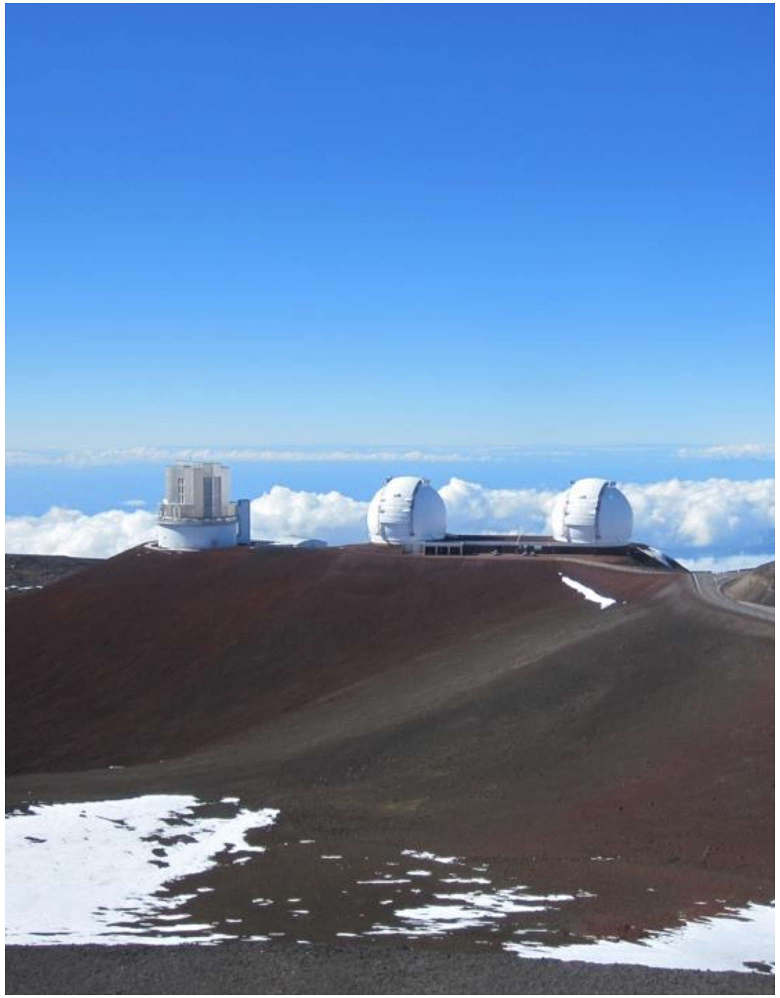
Kattenhorn & Prockter, 2014

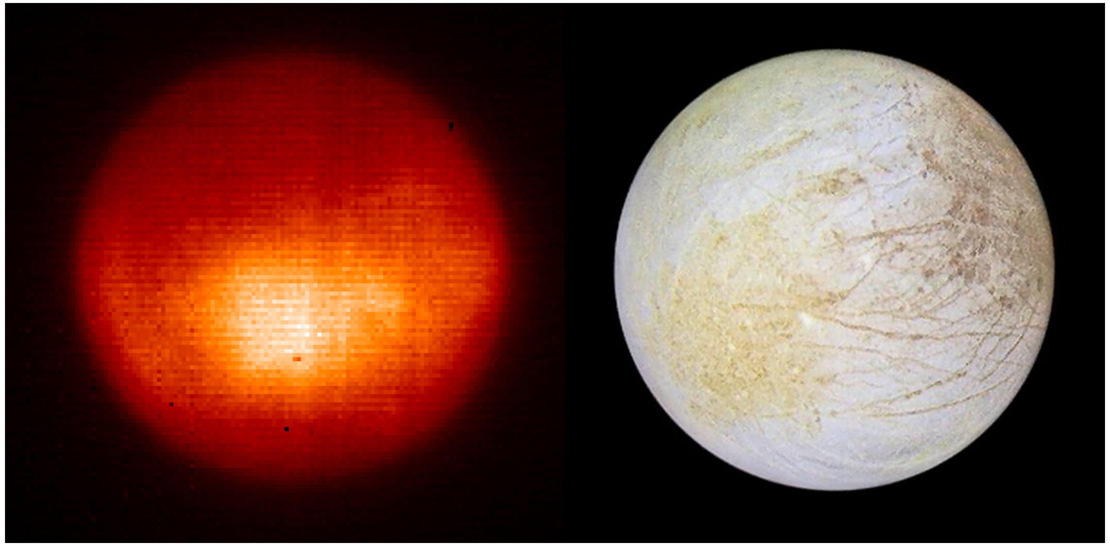


Quick and Marsh, 2016; Quick et al., 2017; Schmidt et al., 2011

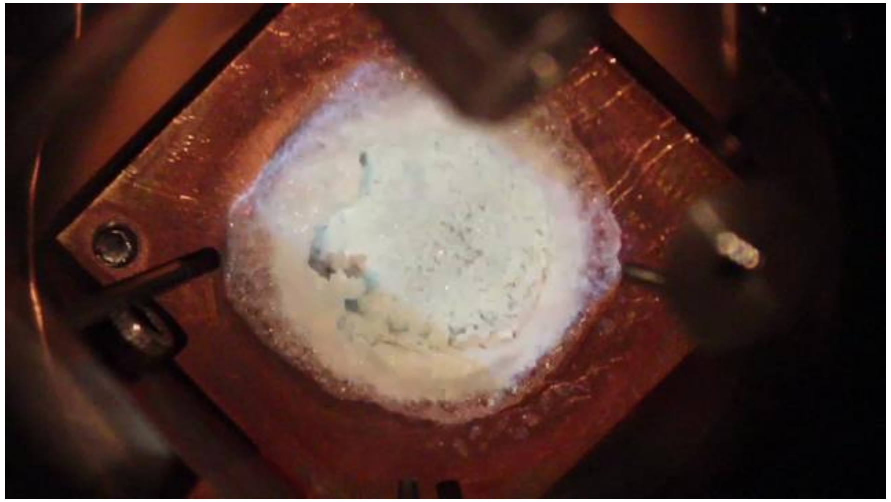
Ground-based Observations

- Keck II telescope





Fischer, Brown, & Hand, 2015

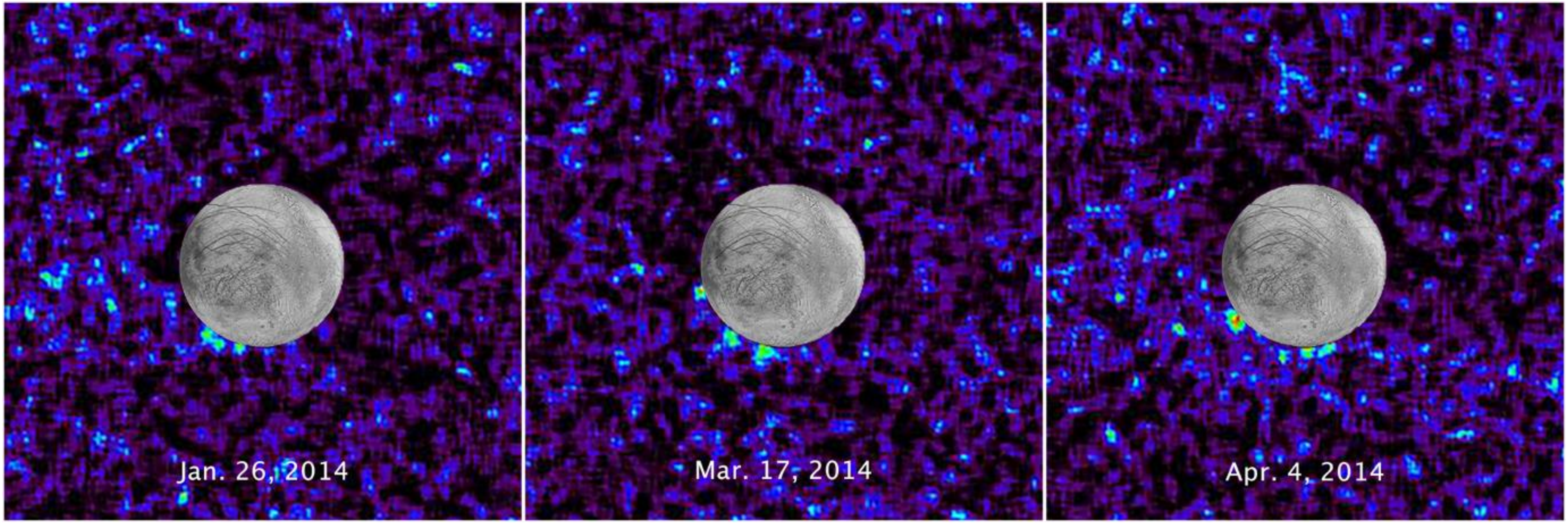


Hand & Carlson, 2014

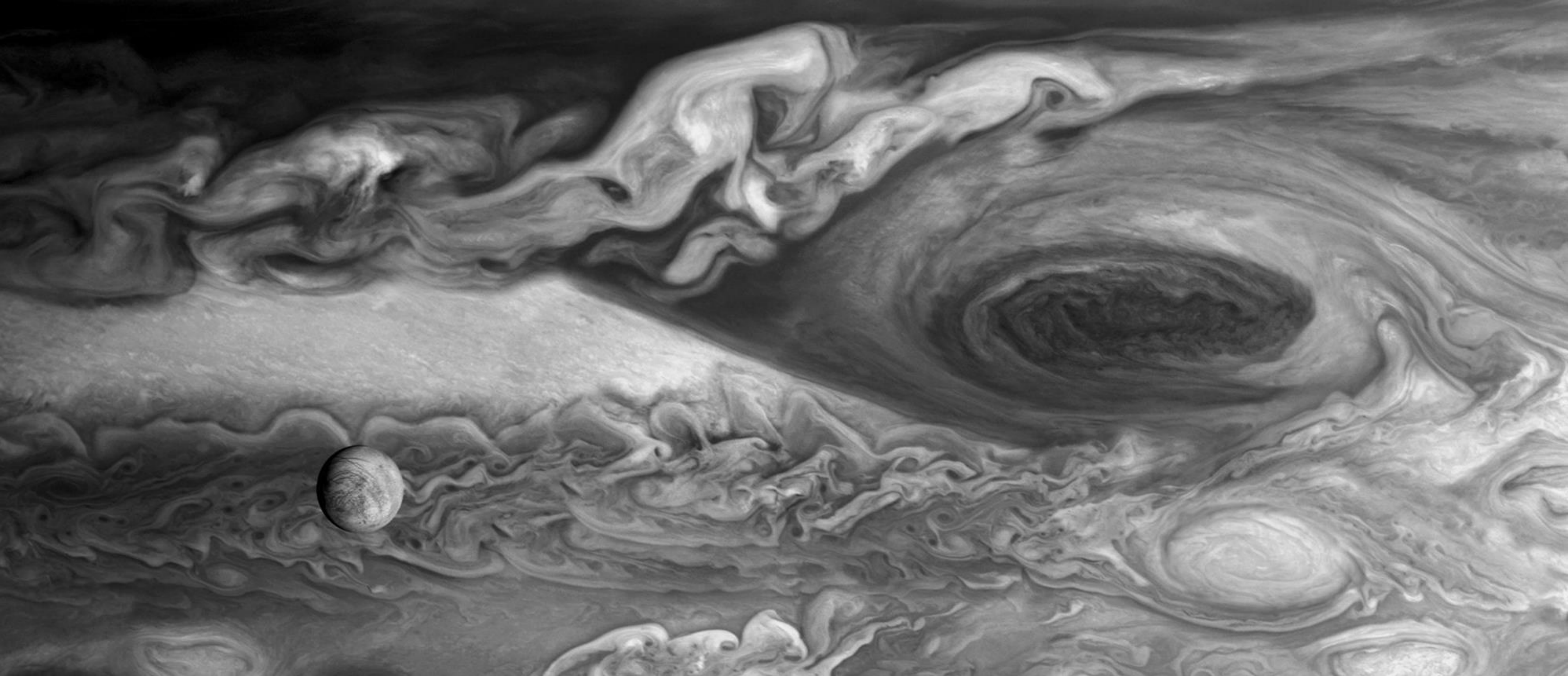
Sodium chloride brine evaporite post-irradiation

Hubble Space Telescope Observations

- Plumes, if they exist, are transient.

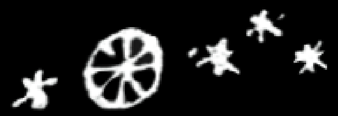


Lorenz et al., 2014a,b; Sparks et al. 2016; Sparks et al., 2017



Kevin Hand, Alison Murray, James Garvin, and the 2016 Europa
Lander Science Definition Team
July 9, 2017

Europa Lander Mission Concept



Programmatic Balance

“Planetary science is shorthand for the broad **array of scientific disciplines** that collectively seek answers to basic questions such as **how do planets form, how do they work, and why is at least one planet the abode of life**. These basic motivations explain why planetary science is an important undertaking, worthy of public support.”

- 2011 V&V Decadal Survey

	Pioneer 10	Pioneer 11	Voyager 1	Voyager 2	Viking 1	Viking 2	Galileo	....	Cassini	GRAIL	MSL	MESSENGER	Dawn	New Horizons	Juno	Insight	OSIRIS-REx	Lucy	Psyche	Mars 2020	Clipper
Physics	X	X	X	X	X	X	X		X	X		X		X	X	X		X	X		X
Geology			X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X
Chemistry			X	X	X	X	X		X		X	X	X	X	X		X			X	X
Biology					X	X														/	

Discovery Missions

	CONTOUR	Genesis	Lunar Prospector	NEAR	Mars Pathfinder	Moon Mineralogy Mapper	Kepler	Stardust	GRAIL	Deep Impact	MESSENGER	Dawn	Insight	Lucy	Psyche
Physics	X	X	X	X			X	X	X		X		X	X	X
Geology	X		X	X	X	X			X	X	X	X	X	X	X
Chemistry		X				X		X		X	/	X			
Biology															

Programmatic Balance

New Frontiers Missions

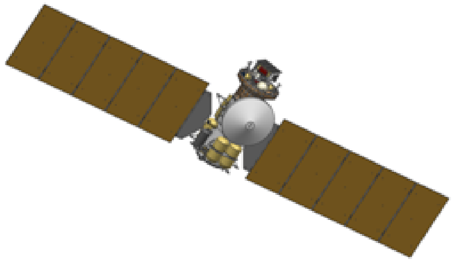
	New Horizons	Juno	OSIRIS-REx
Physics	X	X	
Geology	X		X
Chemistry	X	X	X
Biology			

Programmatic Balance

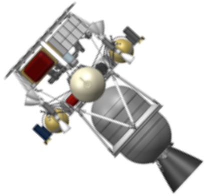
Flagship Missions

	Voyager 1	Voyager 2	Viking 1	Viking 2	Galileo	Cassini	MSL	Mars 2020	Clipper
Physics	X	X	X	X	X	X	X	X	X
Geology	X	X	X	X	X	X	X	X	X
Chemistry	X	X	X	X	X	X	X	X	X
Biology			X	X				/	

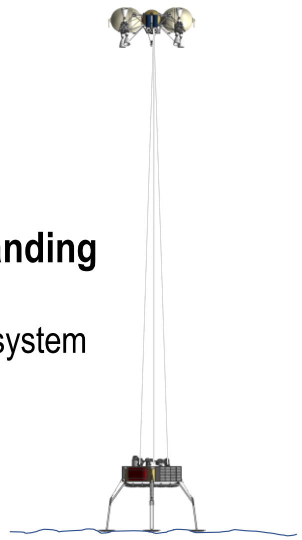
Europa Lander Mission Concept

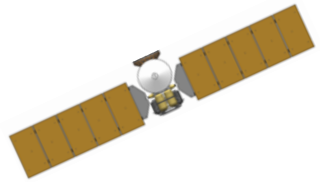


Cruise/Jovian Tour
- Jupiter orbit insertion Apr 2030
- Earliest landing on Europa: Dec 2031

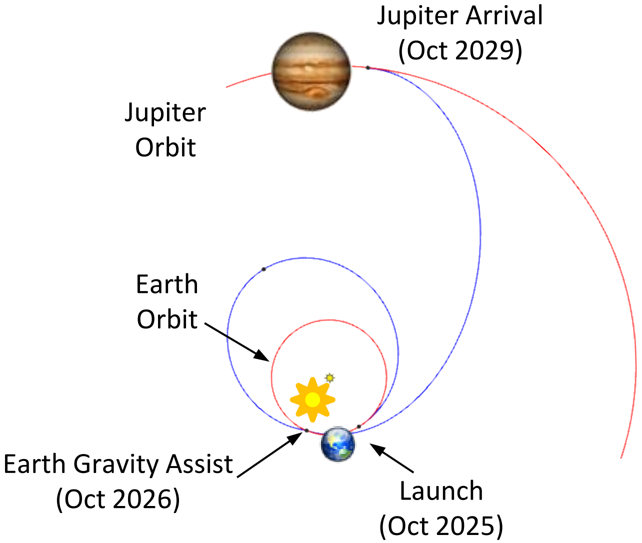


Deorbit, Decent, Landing
- Guided deorbit burn
- Sky Crane landing system
- 100-m accuracy



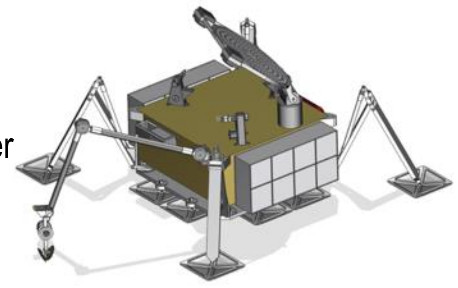


Carrier Relay Orbit
- 24 hour period
- >10 hours continuous coverage per orbit
- 2.0 Mrad radiation exposure

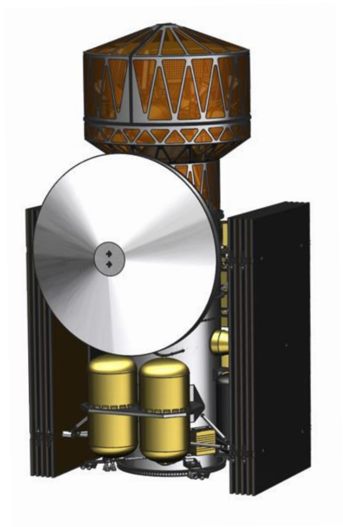


Launch
- SLS Block 1B
- Oct. 2025

Surface Mission
- 20+ days
- 5 samples
- Relay comm through Carrier or Clipper (backup)
- 3–4 Gbit data return
- 45 kWh battery
- 1.5 Mrad radiation exposure

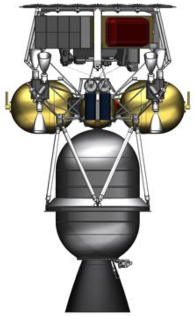


Europa Lander Flight System:
2/3 of Total Mass Devoted to Propulsive Needs



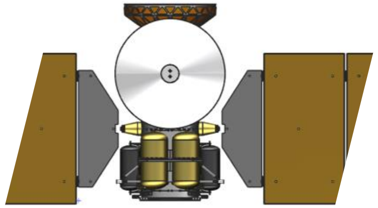
Cruise Vehicle (CV)

Launch Mass:
16,380 kg

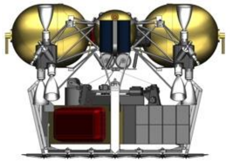


Deorbit Vehicle (DOV)
(aka, the Lander Stack)

+



Carrier and Relay Stage (CRS)

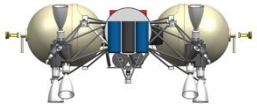


Powered Descent Vehicle (PDV)

+

Deorbit Stage (DOS)

De-Orbit Vehicle:
2,670 kg



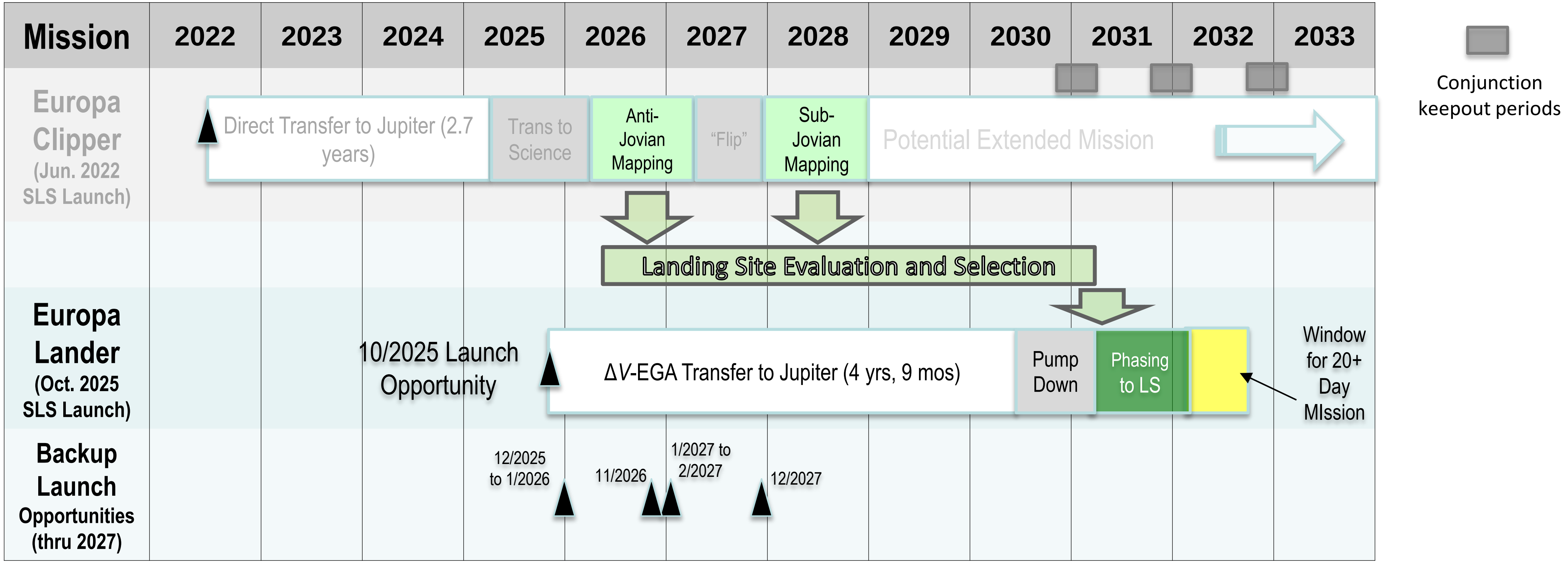
Descent Stage (DS)

+

Lander

Landed Mass:
480 kg

Europa Clipper and Lander Reference Timelines
Support Site Selection Using Clipper Reconnaissance



Science Definition Team

Co-Chairs: Alison Murray, DRI/Univ. NV Reno, James Garvin, GSFC, Kevin Hand, JPL

- Ken Edgett, MSSS
- Bethany Ehlmann, Caltech
- Jonathan Lunine, Cornell
- Alyssa Rhoden, ASU
- Will Brinkerhoff, GSFC
- Alexis Templeton, CU Boulder
- Michael Russell, JPL
- Tori Hoehler, NASA Ames
- Ken Nealson, USC
- Sarah Horst, JHU
- Peter Willis, JPL
- Alex Hayes, Cornell
- Brent Christner, Univ FL
- Chris German, WHOI
- Aileen Yingst, PSI
- David Smith, MIT
- Chris Paranicas, APL
- Britney Schmidt, GA Tech

Planetary scientists, Microbiologists, Geochemists

Europa Lander Mission Concept

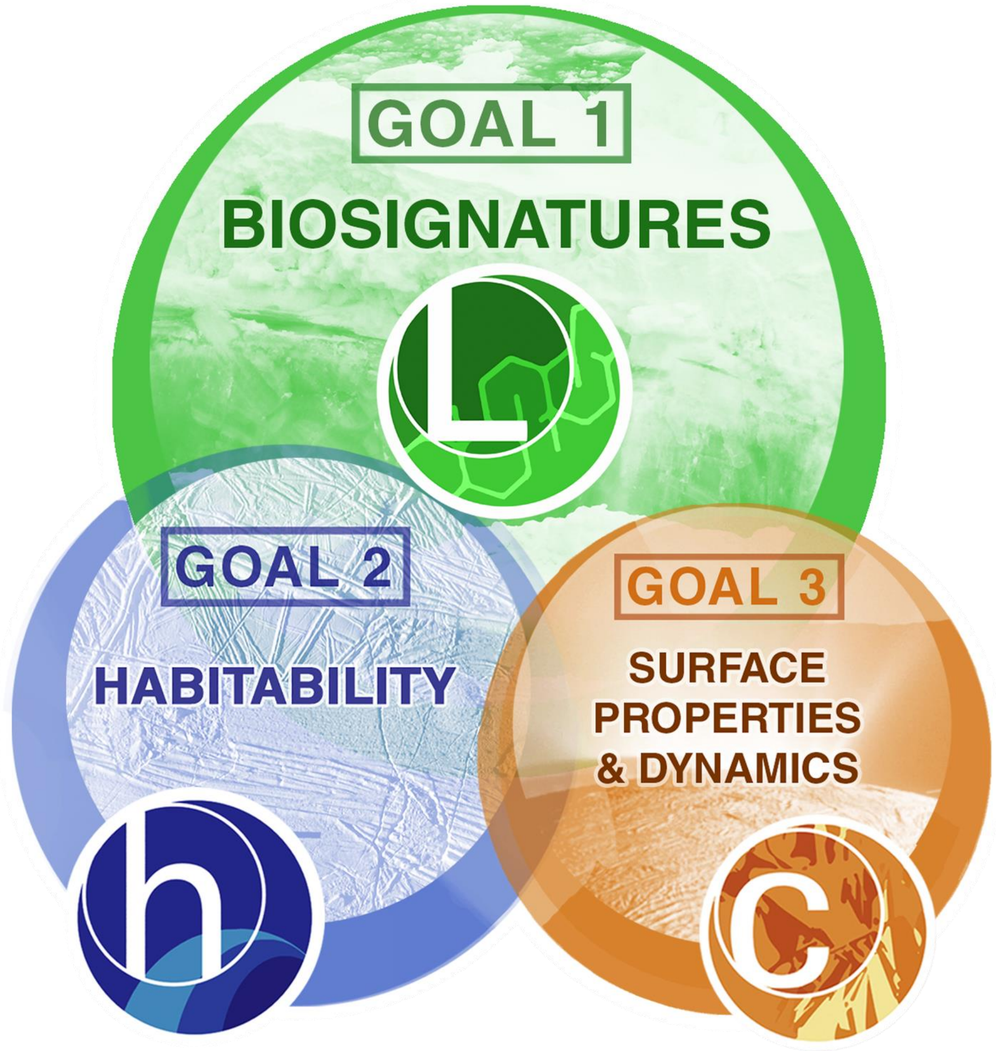
Key Parameters for Science:

- Lander would be launched as a separate mission, enabling improved recon and data return.
- Battery powered mission: 20+ day surface lifetime.
- Spacecraft provides 42.5 kg allocation for science payload (with reserves).
- Baseline science includes:
  - Analyses of 5 samples,
  - Samples acquired from 10 cm depth or deeper (beneath radiation processed regolith) and from 5 different regions within the lander workspace,
  - Each sample must have a minimum volume of 7 cubic centimeters.

Presentations to, and Feedback from, the Scientific Community

- Town Hall #1: Lunar & Planetary Sciences Conference, February 2017.
  - Approximately 6 hours of presentations and Q&A with HQ assembled committee and LPSC attendees (open to public/conference attendees).
- Town Hall #2: Astrobiology Science Conference, March 2017.
  - Approximately 6 hours of presentations and Q&A with HQ assembled committee and LPSC attendees (open to public/conference attendees)
  - 15-minute presentation during conference week.
- Outer Planets Assessment Group (OPAG)
  - Progress report presentation, Summer 2016.
  - Full report 2-hour out-brief with Q&A, Winter 2017.
- Committee on Astrobiology & Planetary Sciences (NRC CAPS)
  - Progress report presentation, Fall 2016.
  - Full report outbrief March, 2017.
- Seven presentations, total of >16 hours of briefing and Q&A.
- Town Hall Executive Committee feedback to be addressed through response letter to NASA.
- Mission Concept Review, June 19-22nd, 2017.

Europa Lander Goals:
A Robust Approach to Searching for Signs of Life



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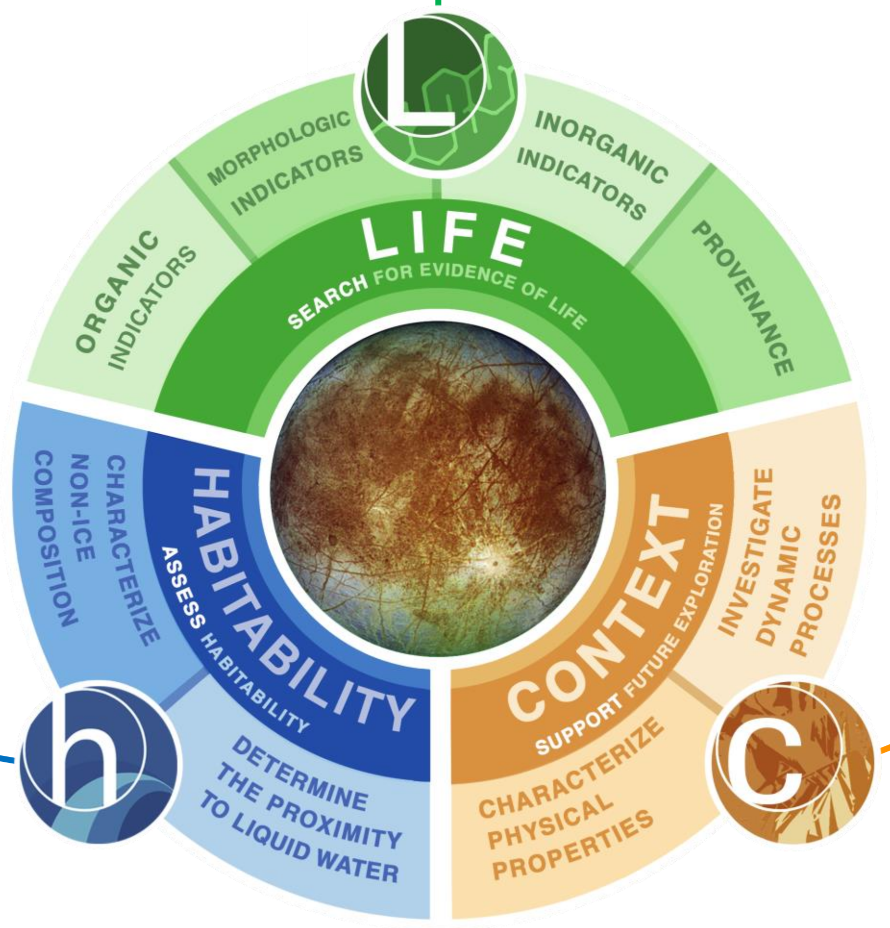
Pre-Decisional Information – For Planning and Discussion Purposes Only

A Connected Set of Goals & Objectives Addressed with a Focused Model Payload

GC-MS | Microscope | Raman spectrometer | Context cameras



Raman spectrometer
GC-MS
Context cameras
Geophone

Raman spectrometer
Microscope
GC-MS
Context cameras
Geophone

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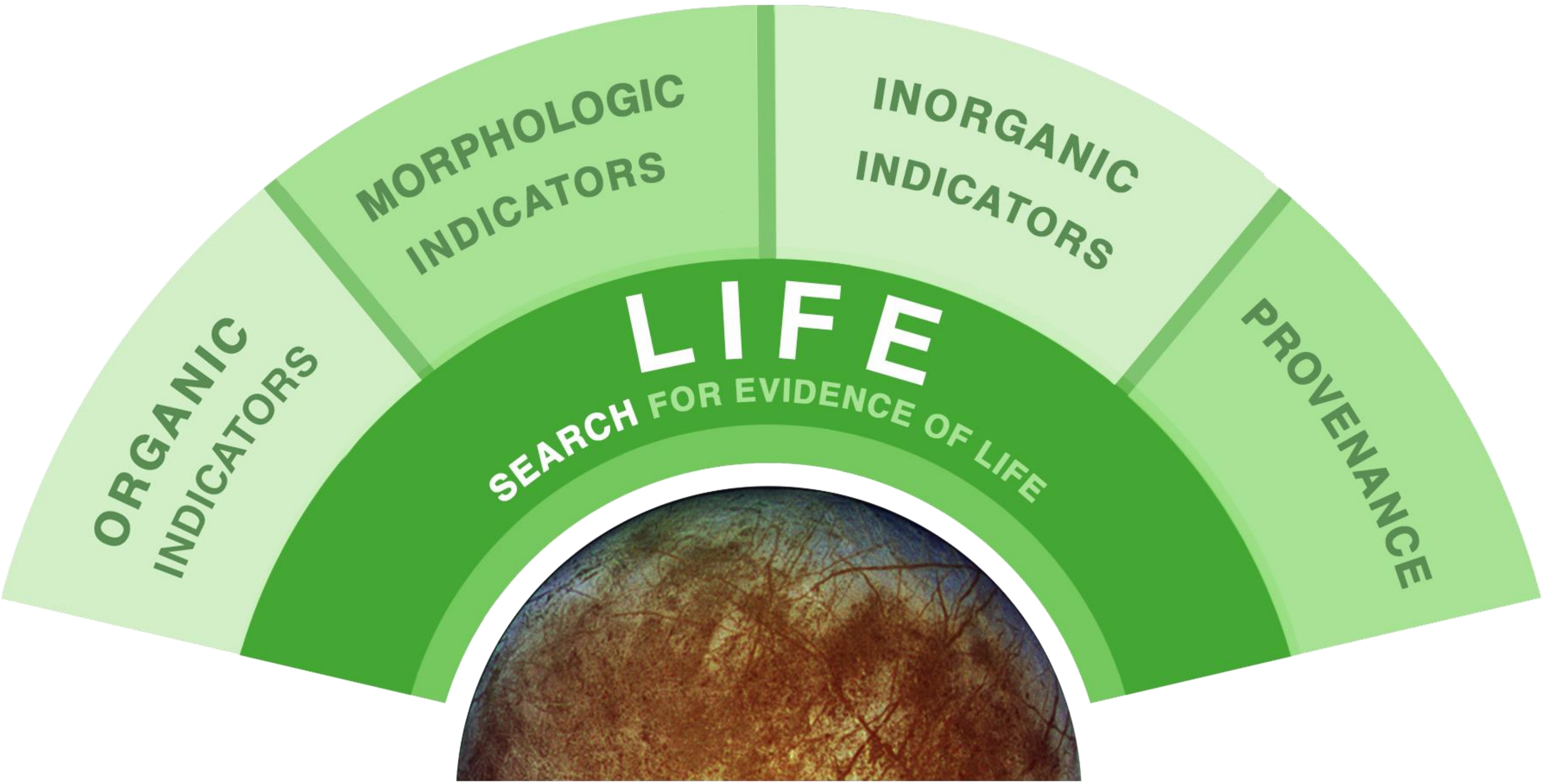
Goal 1: Search for Evidence of Life



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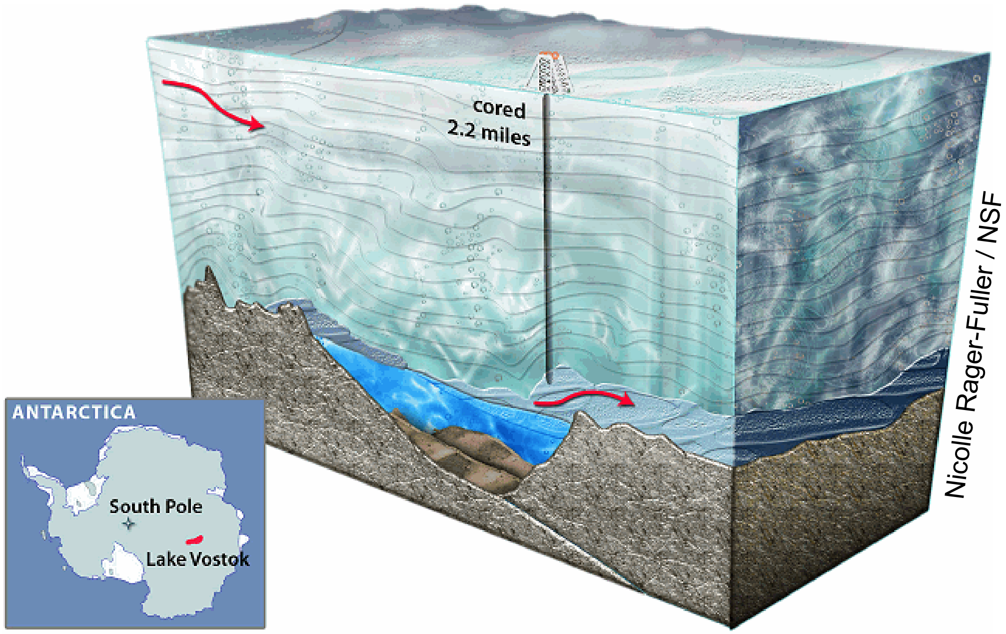
Benchmark environments for Biosignatures

What biosignatures exist?

What limits are needed for detecting signs of life?

Signs of life

- Chemical indicators
  - Organic abundance
  - Organic composition
- Physical indicators
  - Size and shape
  - Abundance
  - Properties



Nicolle Rager-Fuller / NSF

H Dugan/UIC

AE Murray /DRI

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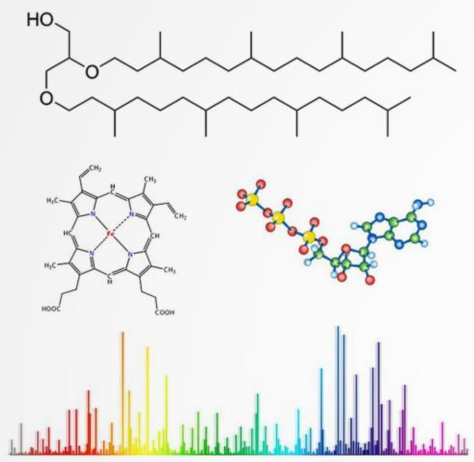
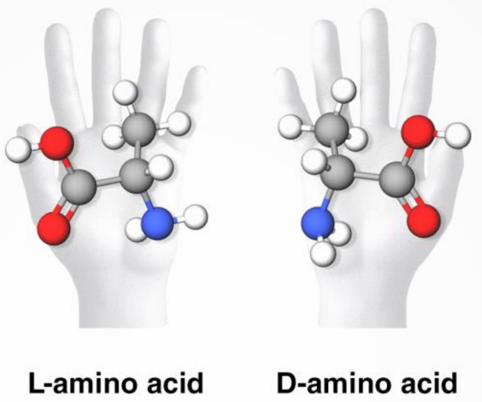
Detection Limits & Measurement Requirements: Earth Environments as a Benchmark for Life Detection

	Lake Vostok (Subglacial)			Lake Vida (Salty)		Winter Circumpolar Deep Water (Deep Ocean) [4]
	Accretion Ice (Type I)[1]	Accretion Ice (Type II) [1]	Glacial Ice[1]	Brine[2,3]	Ice[3]	
Organic carbon (μM)	65	35	16	64,700	n.a.	**41 ± 3**
DFAA (nM); DFAA % Org. Carbon	1-45; ≤ 0.006-0.17%	**50-174; 0.08-0.49%**	20-62; 0.6 – 1.2 %	n.a.*	n.a.	88 ±16 ; 0.7 ± 0.1 %
Total Asp (nM)	15-49	8	11-39	n.a.*	n.a.	n.a.
DF L-Asp (nM)	6-10^	n.d.	10^^	n.a.*	n.a.	3-9#
Cell density (cells mL^{-1})	**260**	**80**	**120**	49,000,000	444,000	30,000 to 100,000
Microbial size (μm)	~0.3 - 3.0	~0.3 - 3.0	~0.3 - 3.0	0.1-1	~0.5 - 2	**0.2 – 1**

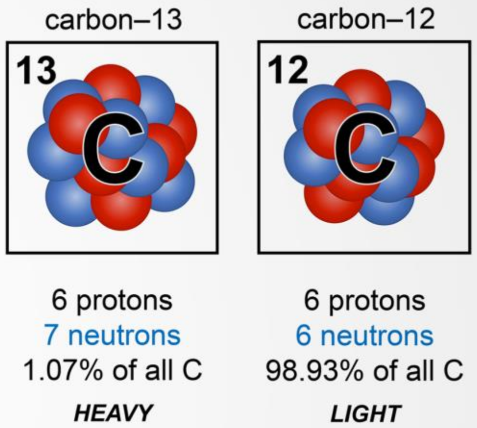
Goal 1 ORGANIC INDICATORS



ORGANIC DETECTION, CHARACTERIZATION, COMPOSITION



ENANTIOMERIC EXCESS

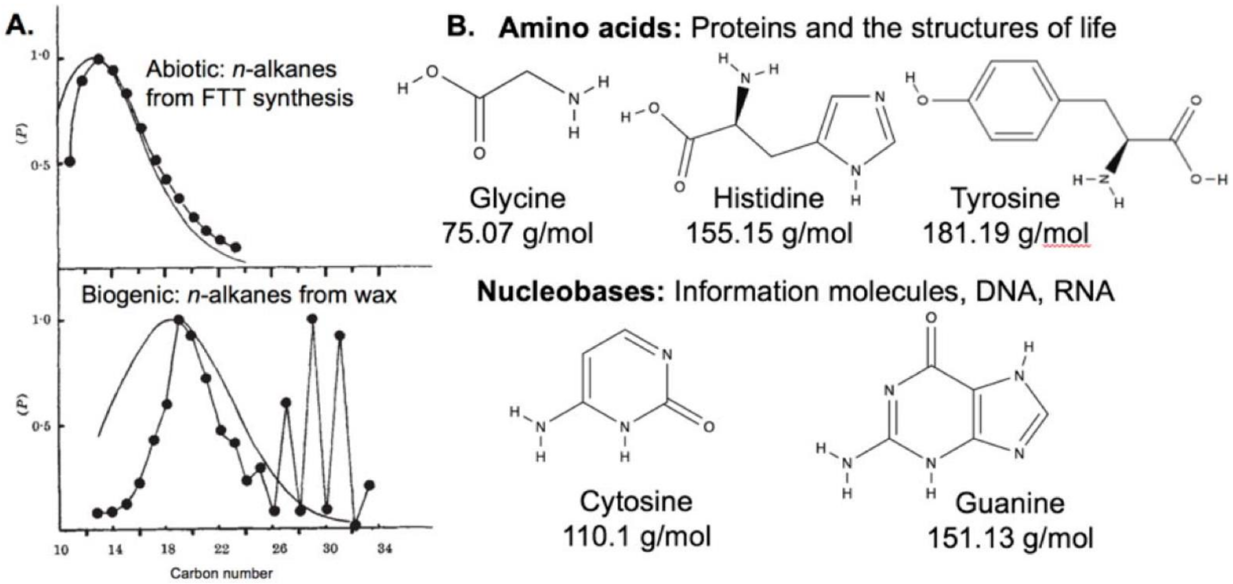


ISOTOPIC INDICATORS

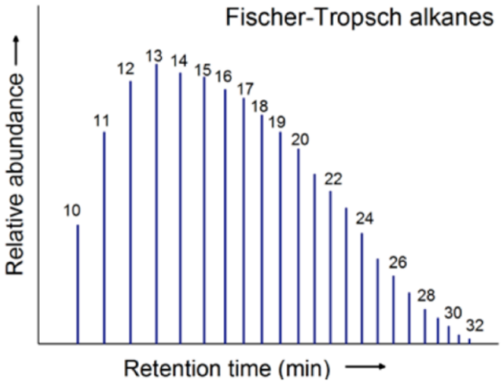
Organic Detection & Characterization

- **Determine the presence, identities, and relative abundances of amino acids, carboxylic acids, lipids, and other molecules of potential biological origin (biomolecules and metabolic products) at compound concentrations as low as 1 picomole in a 1 gram sample of europan surface material.**

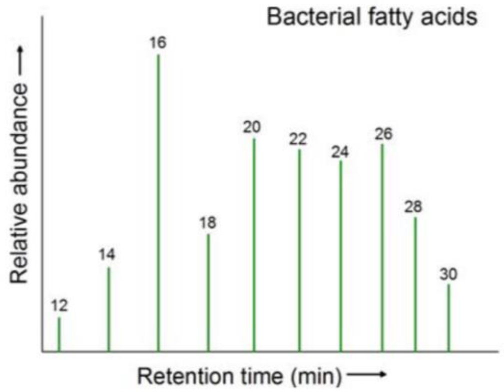
- **Determine the broad molecular weight distribution to at least 500 Da (Threshold) and bulk structural characteristics of any organics at compound concentrations as low as 1 picomole in a 1 gram sample of europan surface material.**



Abiotic organic synthesis
- Low specificity



Biological organic synthesis
- High specificity



McCollom et al. (2007) Hartgers et al. (2000)

Organic Detection & Characterization

- Model Payload employs complimentary techniques for organic detection and characterization:
  - Organic Compositional Analyzer:
    - Gas Chromatograph-Mass Spectrometer
  - Vibrational Spectrometer:
    - Raman spectrometer

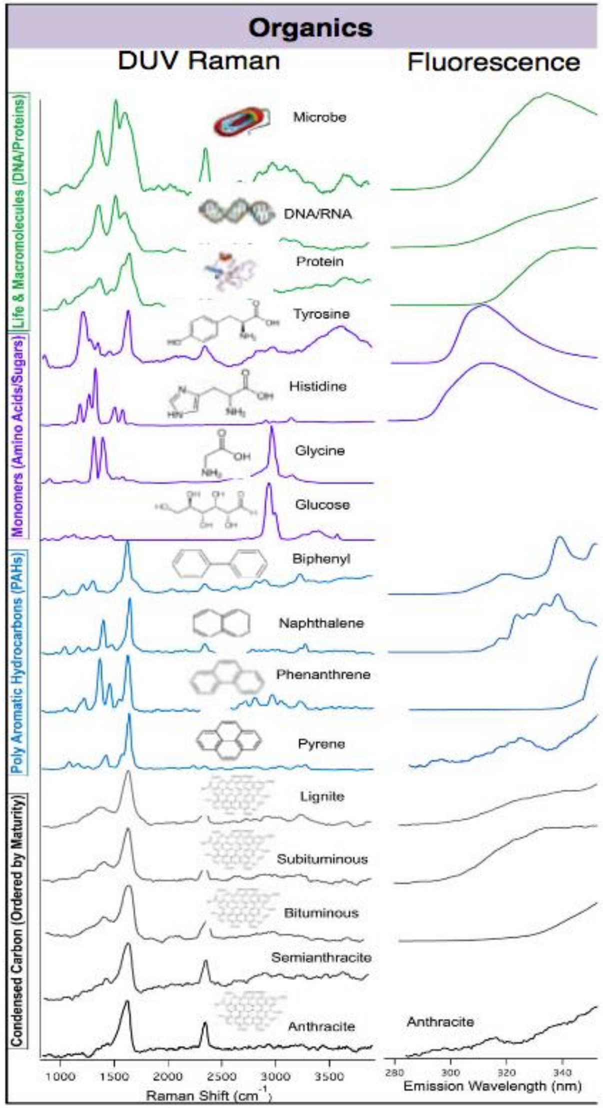
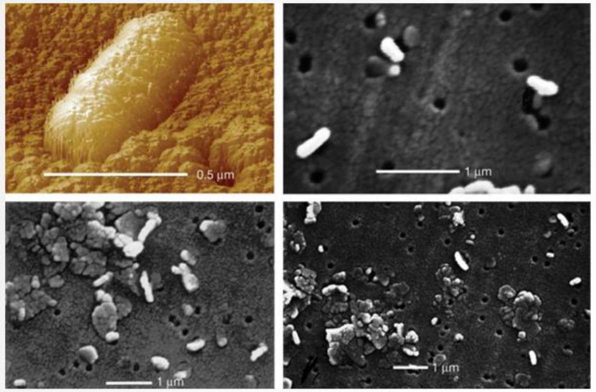


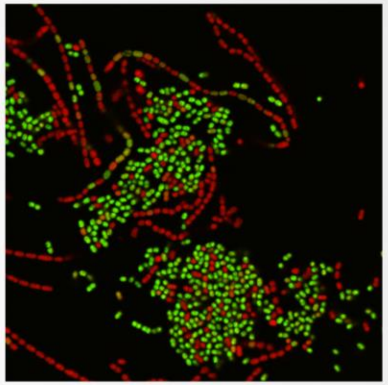
Image courtesy Beegle et al.

GOAL 1 MORPHOLOGIC INDICATORS



MICROSCALE STRUCTURES

MACROSCALE STRUCTURES

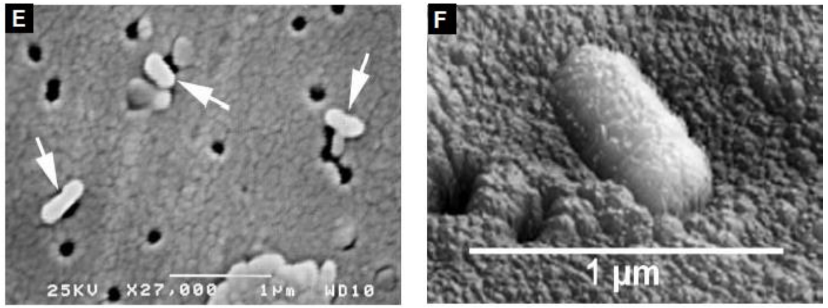


CELLULAR PROPERTIES

Microscale & Macroscale Structures

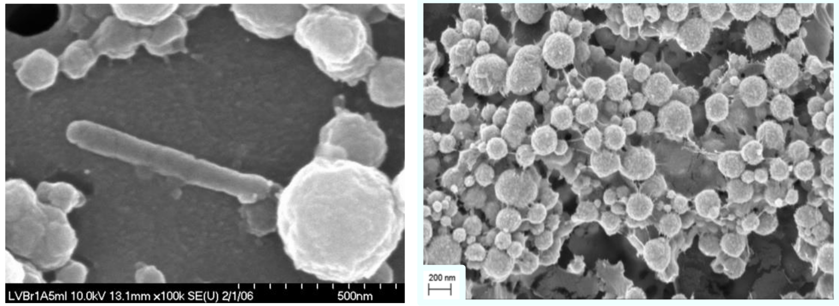
Micro:

Lake Vostok Accretion ice



Priscu et al. 1999, Science.

Lake Vida Brine

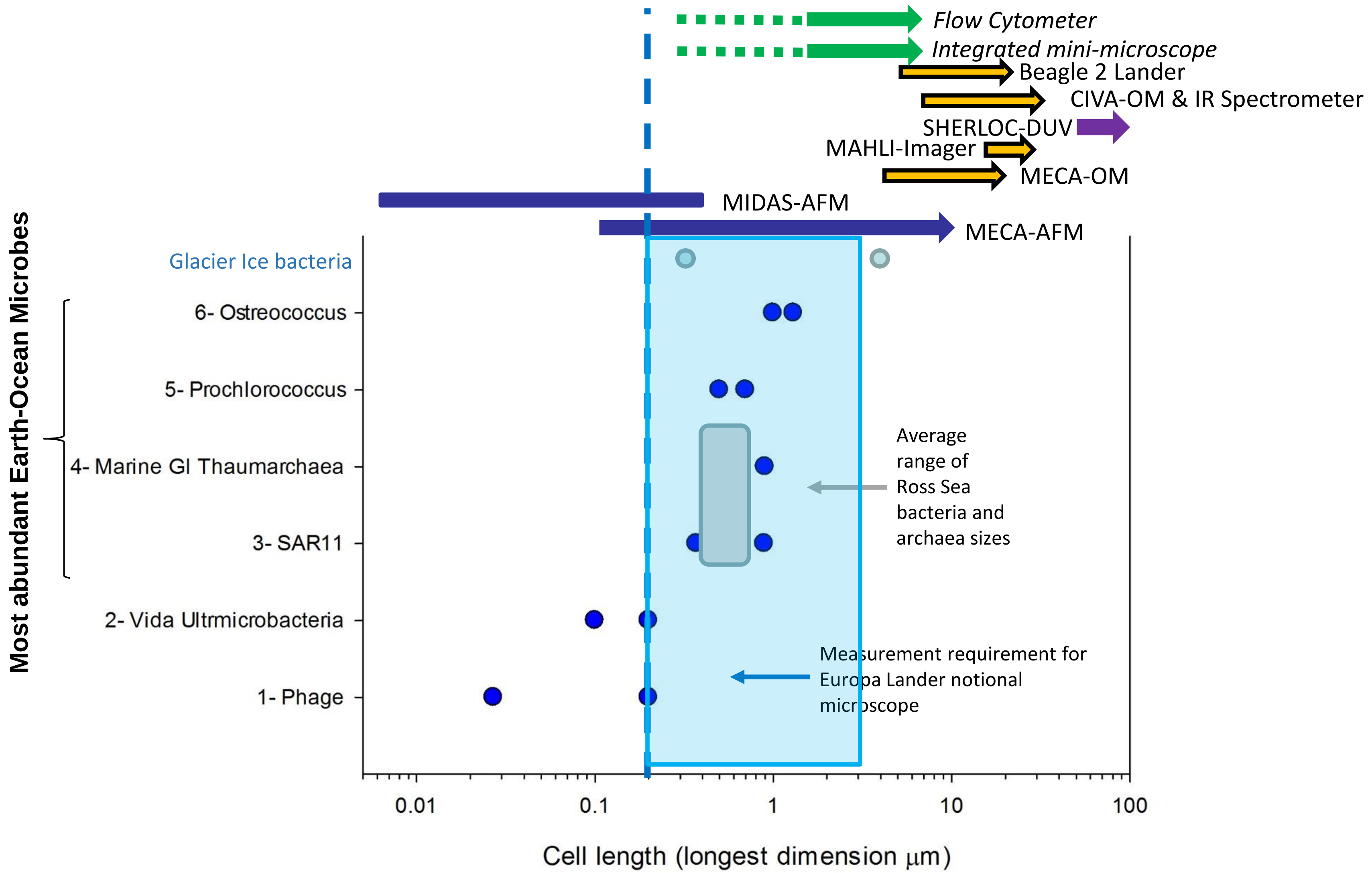


Murray et al. 2012 PNAS.

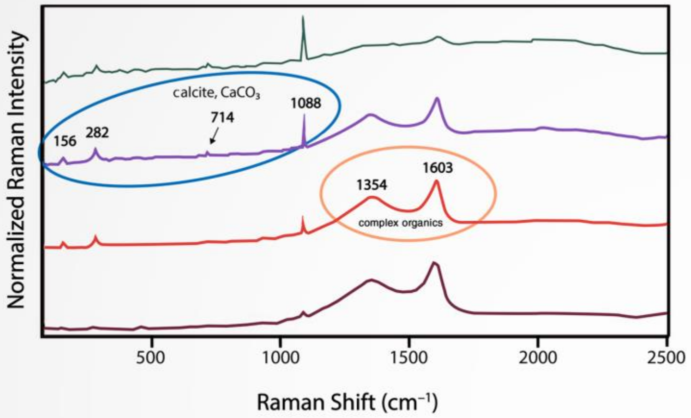
Macro:

- Pigments
- Filamentous aggregations
- Biomineral structures

Earth Benchmarks: Size ranges of microbial life

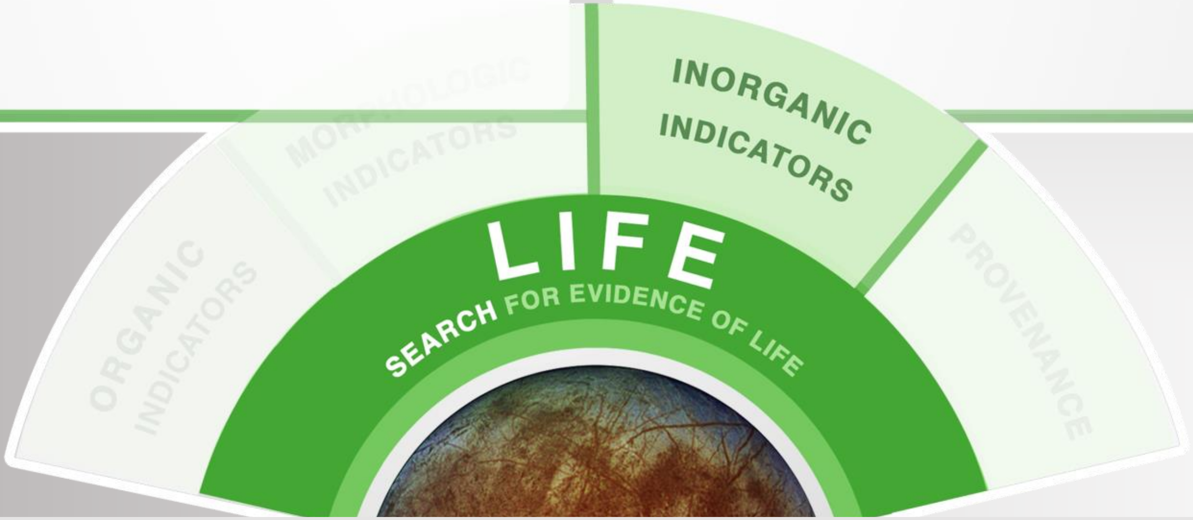


GOAL 1 INORGANIC INDICATORS



INORGANIC COMPOSITION

BIOMINERALS

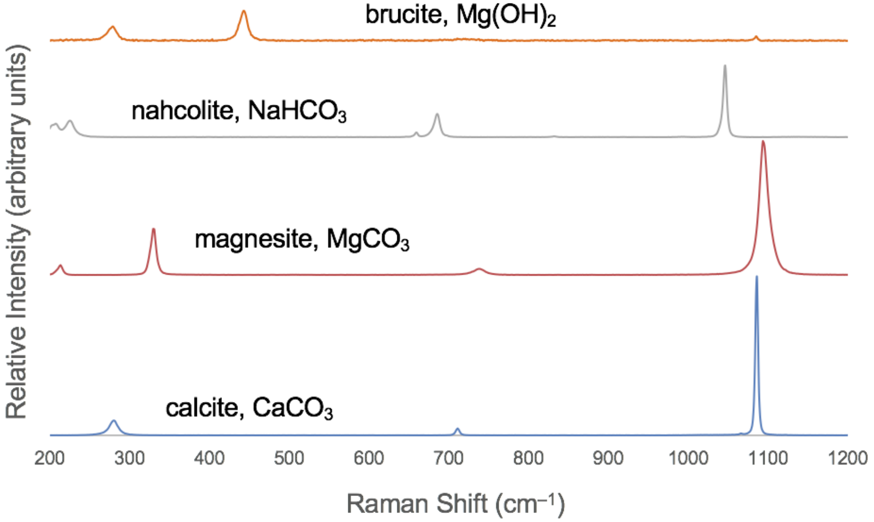


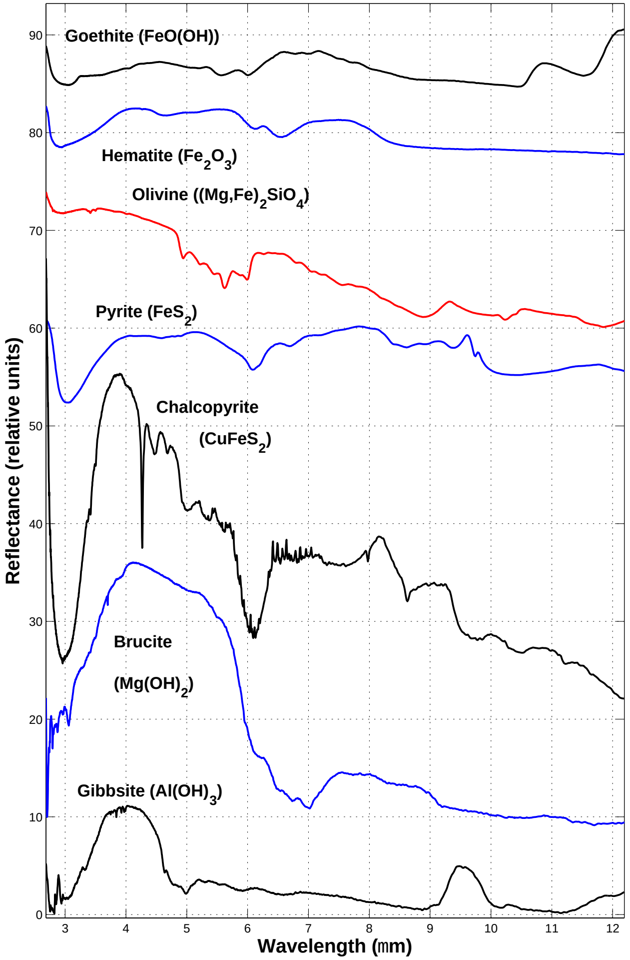
Inorganic Indicators of Life

- Life and biological processes utilize a variety of inorganic compounds for metabolic processes and structures.
- Iron, sulfur, silicon and calcium compounds and minerals provide just a few examples.

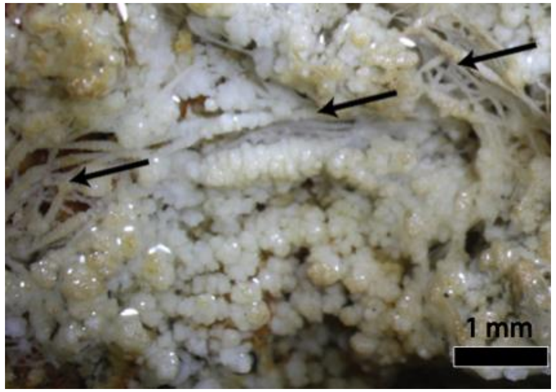
Measurement requirement:

- Identify inorganic and volatile components in the sample at 10's to 100's of part per thousand level.

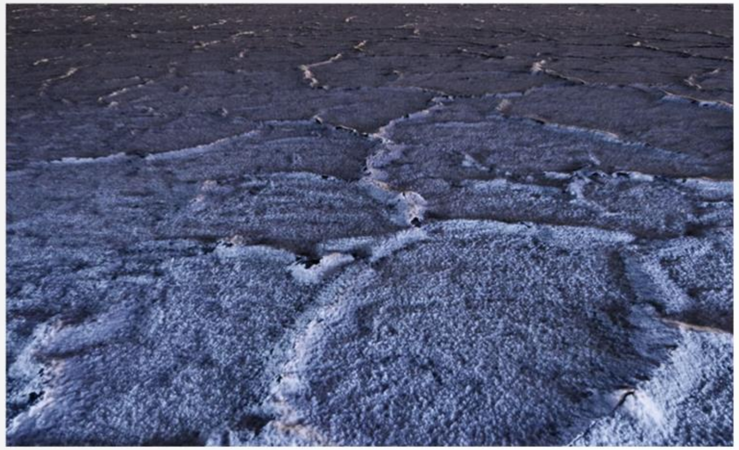


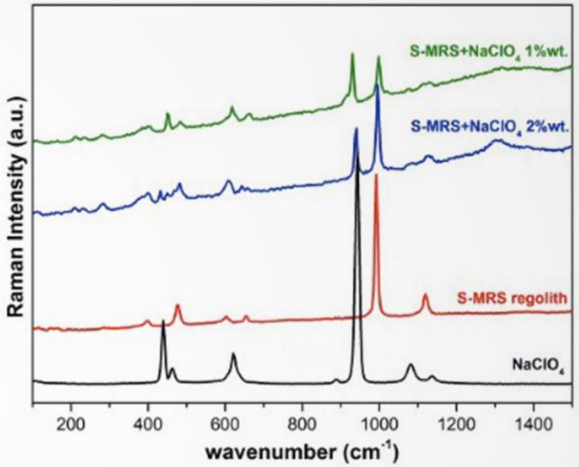


Priscu et al. (1999)



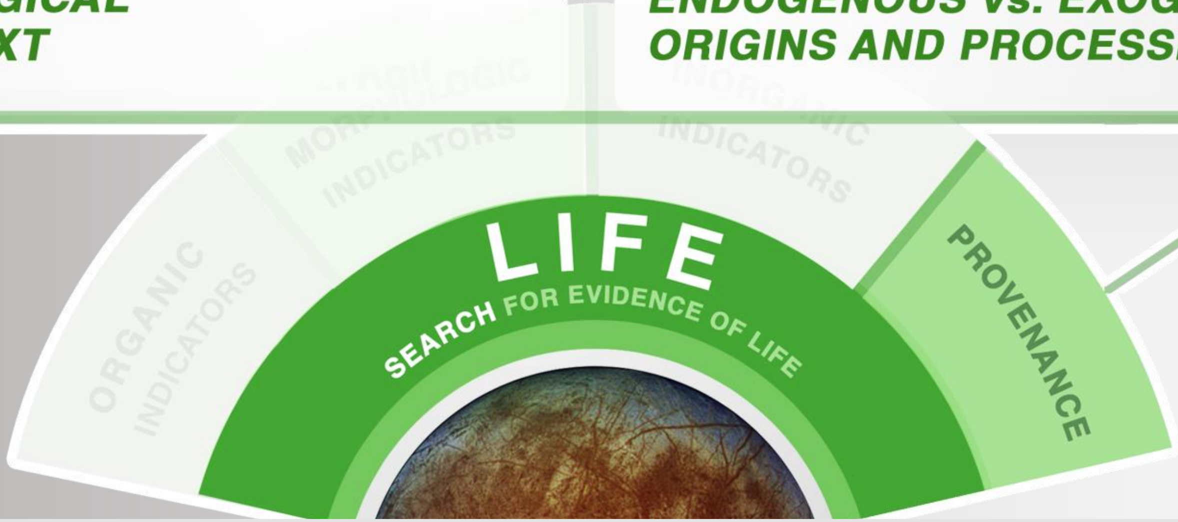
GOAL 1 PROVENANCE





GEOLOGICAL CONTEXT

ENDOGENOUS vs. EXOGENOUS ORIGINS AND PROCESSING



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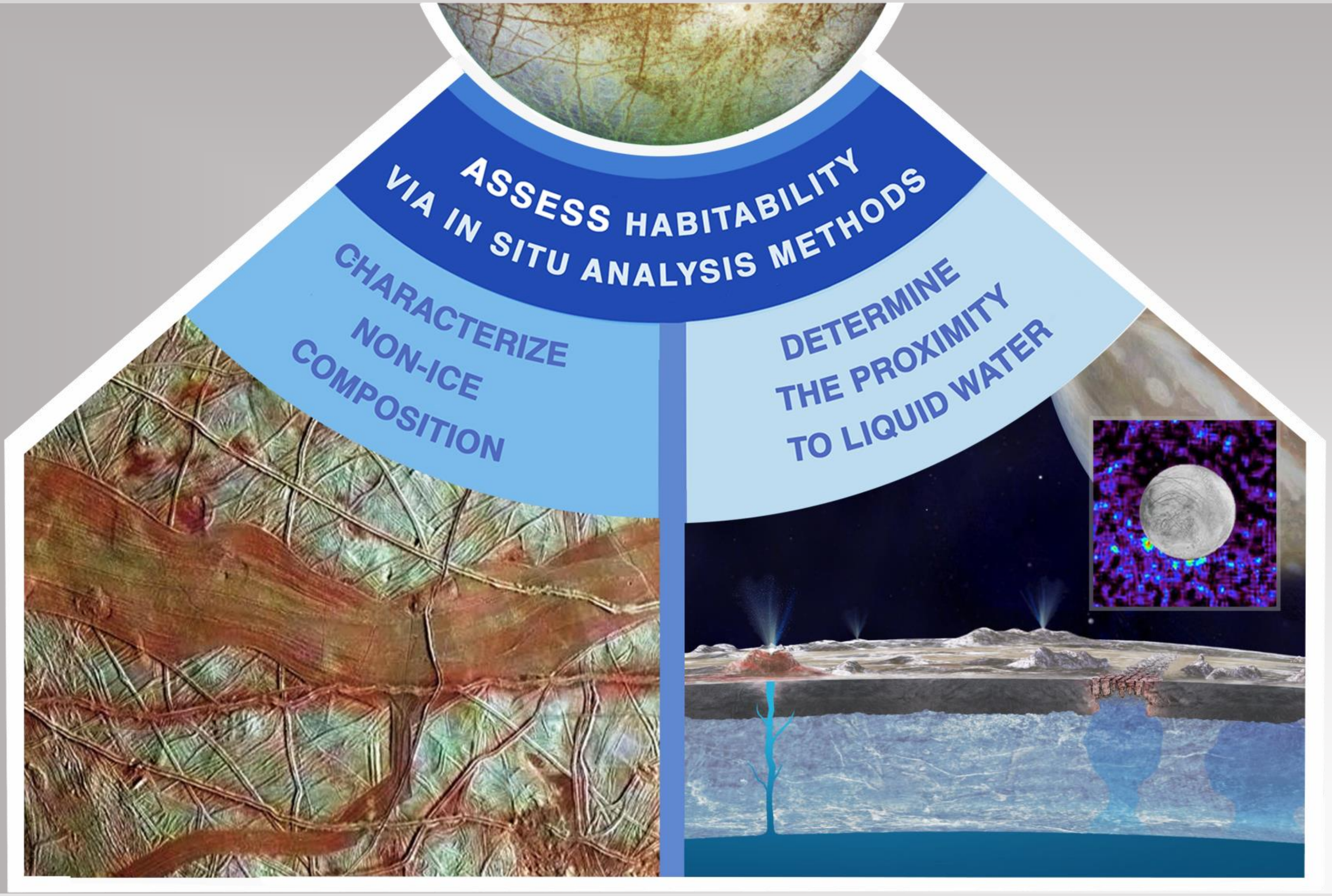
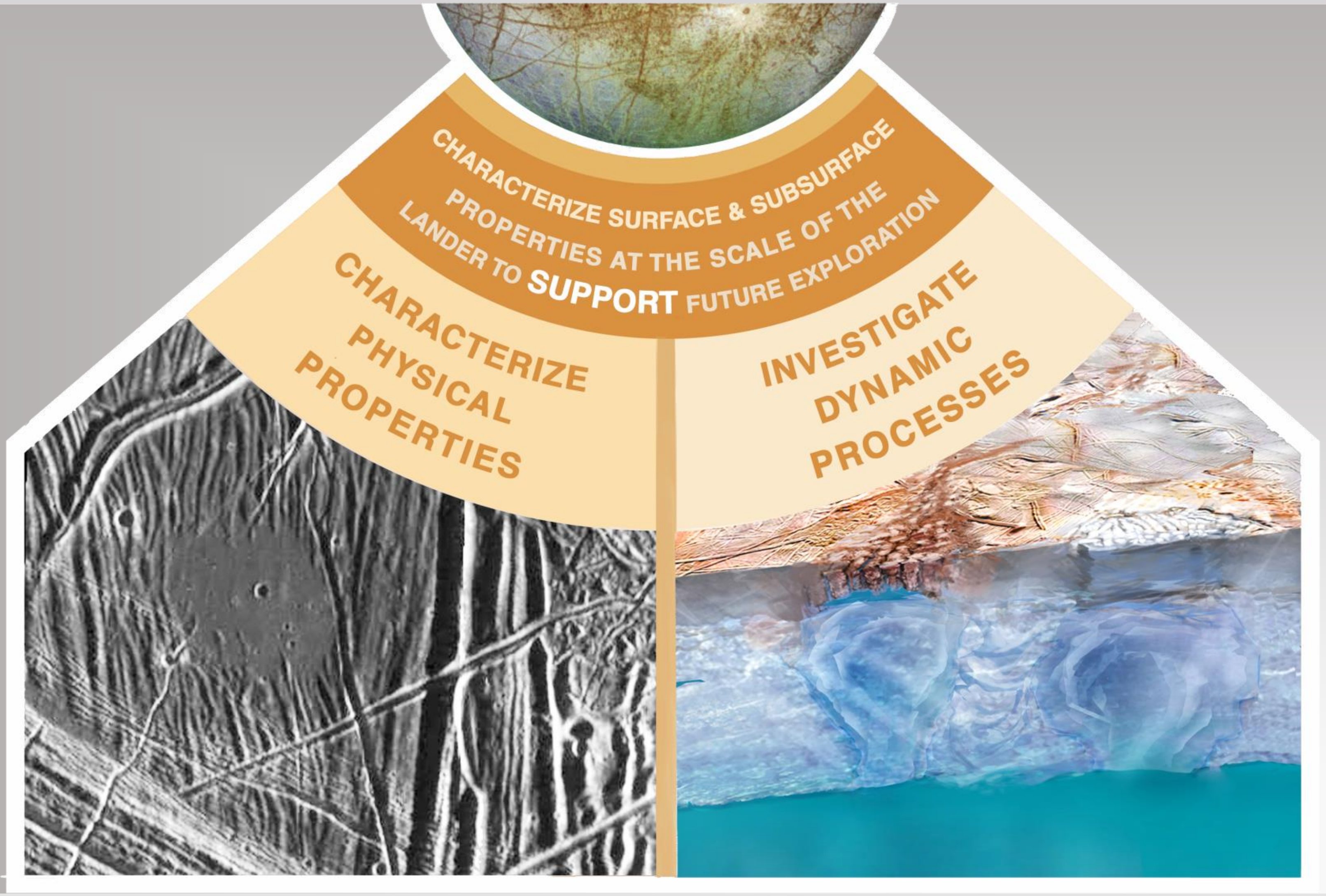
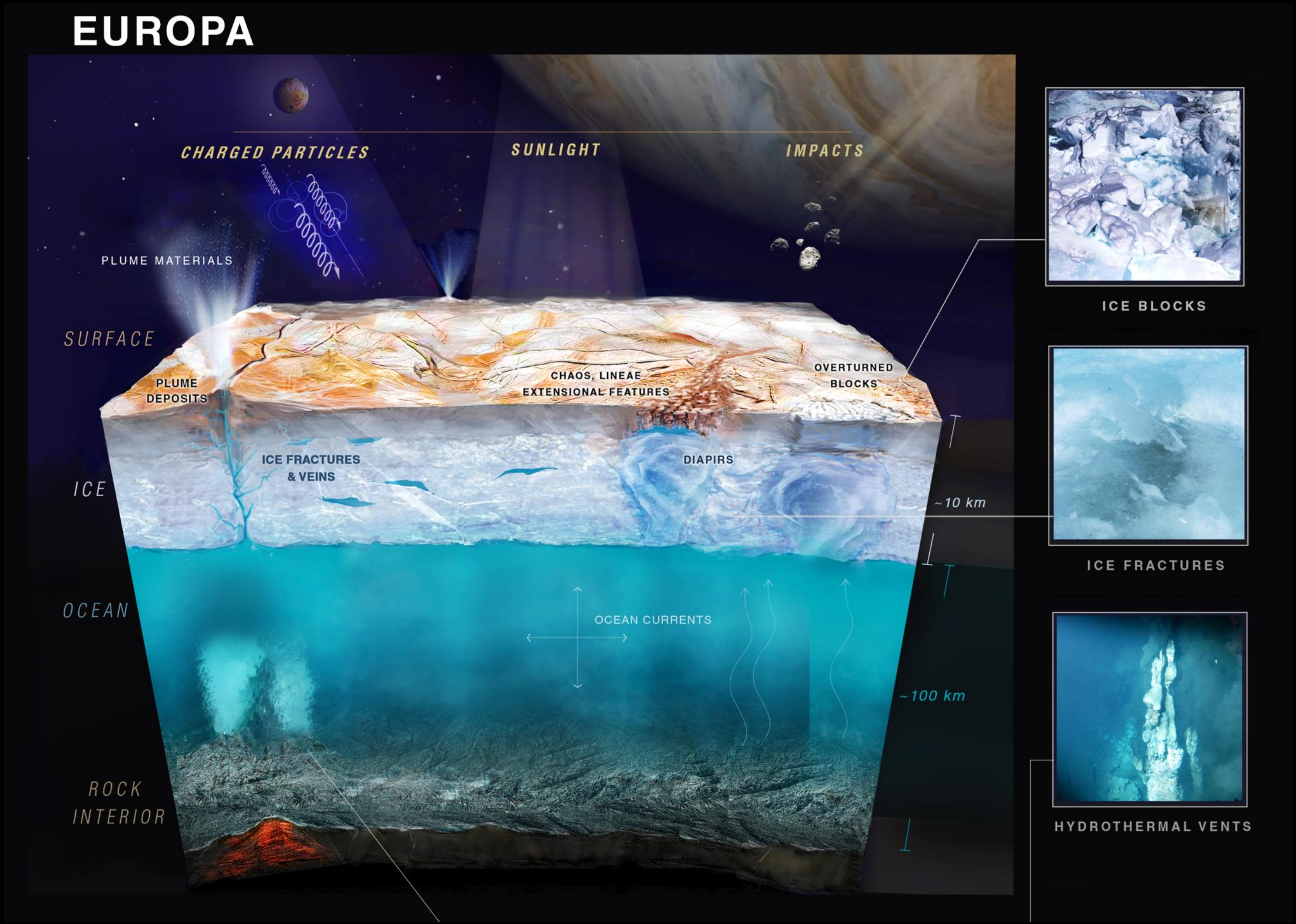

ASSESS HABITABILITY
VIA IN SITU ANALYSIS METHODS
CHARACTERIZE
NON-ICE
COMPOSITION
DETERMINE
THE PROXIMITY
TO LIQUID WATER

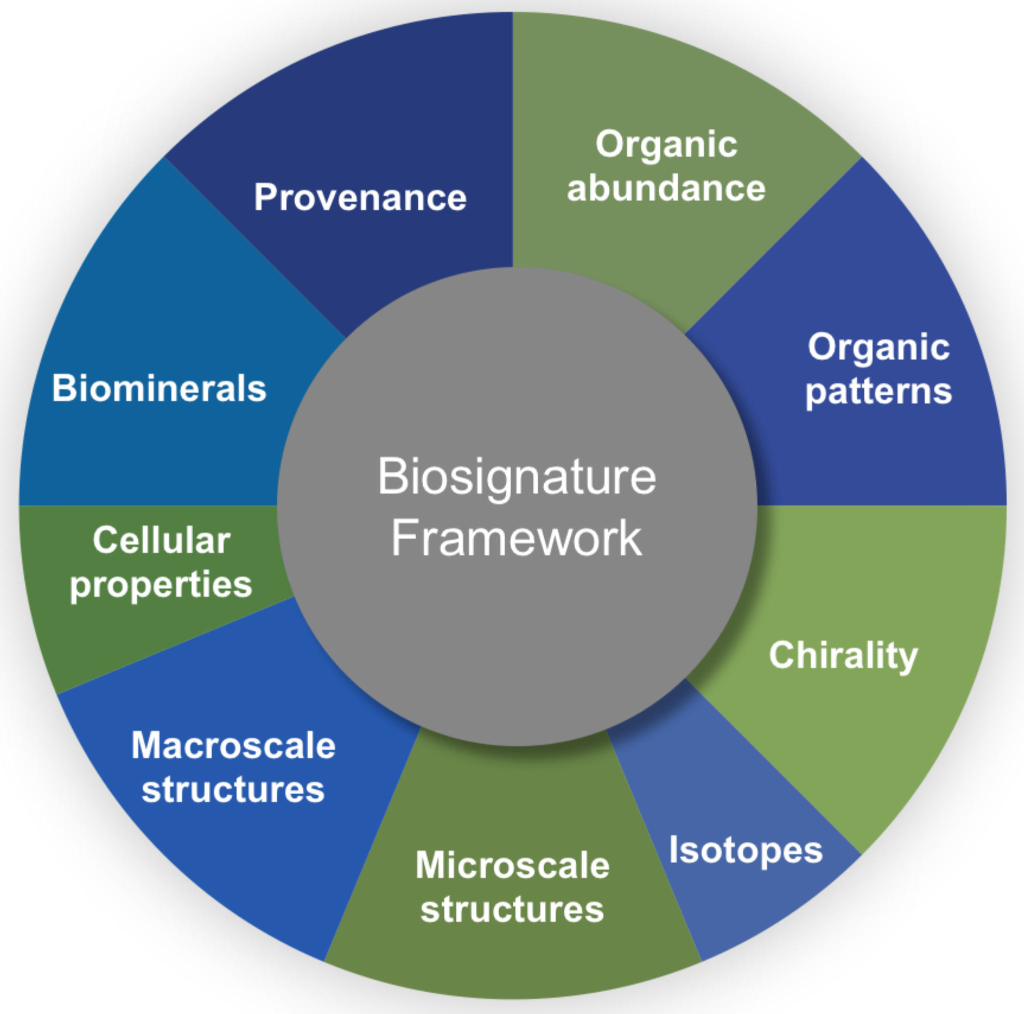
GOAL 3 CONTEXT




EUROPA
CHARGED PARTICLES
SUNLIGHT
IMPACTS
PLUME MATERIALS
SURFACE
PLUME DEPOSITS
CHAOS, LINEAE
EXTENSIONAL FEATURES
OVERTURNED BLOCKS
ICE
ICE FRACTURES & VEINS
DIAPIRS
~10 km
OCEAN
OCEAN CURRENTS
~100 km
ROCK INTERIOR
ICE BLOCKS
ICE FRACTURES
HYDROTHERMAL VENTS

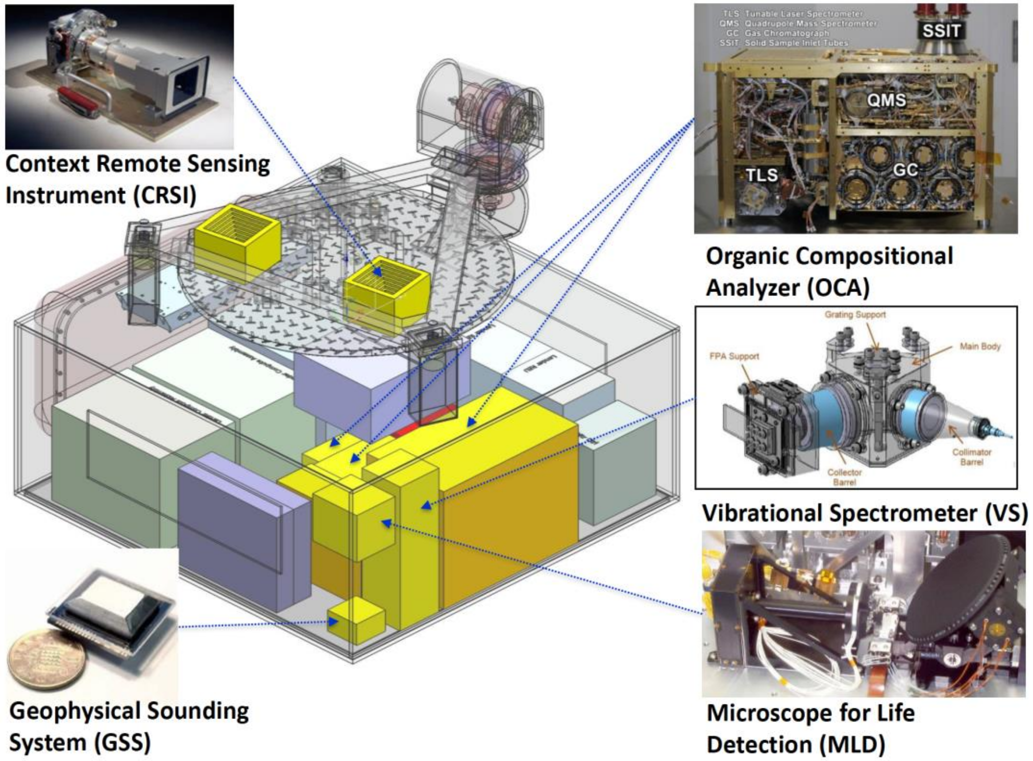
Lander Provides a Robust Biosignature Suite of Measurements

- Model payload provides a minimum of 9 lines of evidence for identifying potential biosignatures
- Biosignature Investigations are highly complementary
- Model payload ensures measurement redundancy
- Investigations yields high value science even in the absence of life.



Model Payload

Instrument Class [mass allocation, unmargined], Total = 42.5 kg (with margin)	Model Payload	
	Baseline	Threshold
Context Remote Sensing Instrument (CRSI) [4.3 kg, includes shielding]	2 identical multi-filter, focusable, visible to near-infrared, stereo overlapping cameras with narrowband filters equivalent to those of the Europa Multiple Flyby Mission EIS cameras	2 identical RGB, fixed focus, stereo overlapping cameras
Microscope for Life Detection (MLD) [5.4 kg]	Deep UV resonance Raman and optical microscope with fluorescence spectrometer	Atomic Force Microscope (AFM) with optical context imager
Vibrational Spectrometer (VS) [5.4 kg]		Raman Laser Spectrometer (RLS)
Organic Compositional Analyzer (OCA) [16.4 kg]	Gas Chromatograph Mass Spectrometer (GC-MS) with Chirality Analysis and Stable Isotope Analyzer (SIA)	Gas Chromatograph Mass Spectrometer (GC-MS) with Chirality Analysis
Geophysical Sounding System (GSS) [1.2 kg]	Broad-band seismometer	3-axis geophone

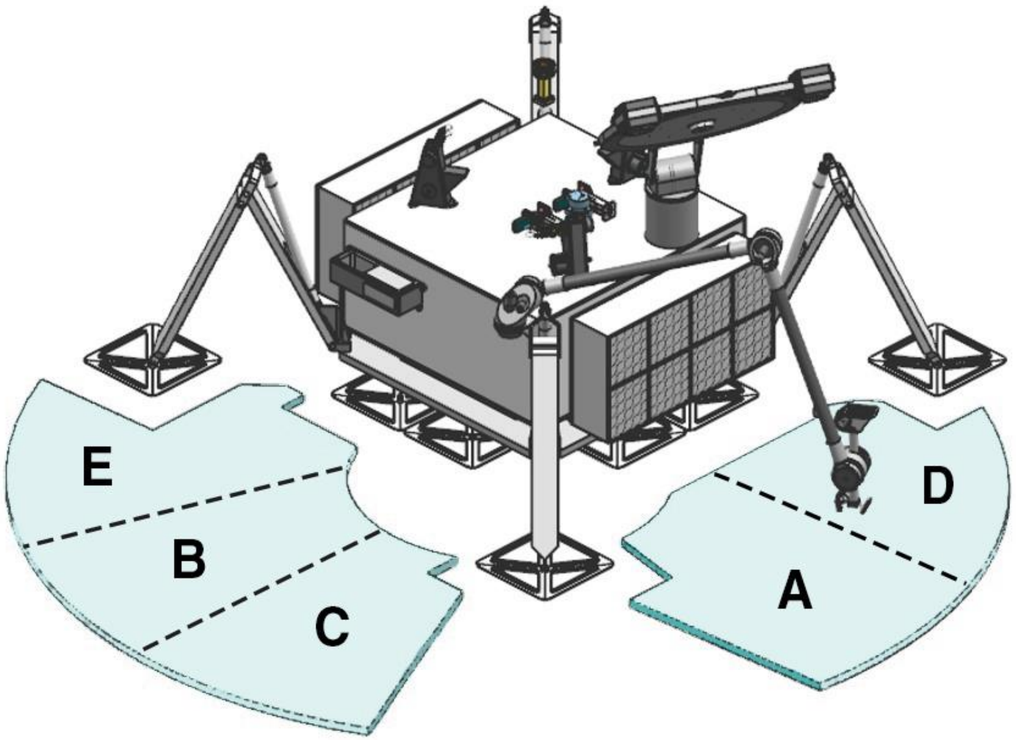


Framework for Sampling & Life Detection

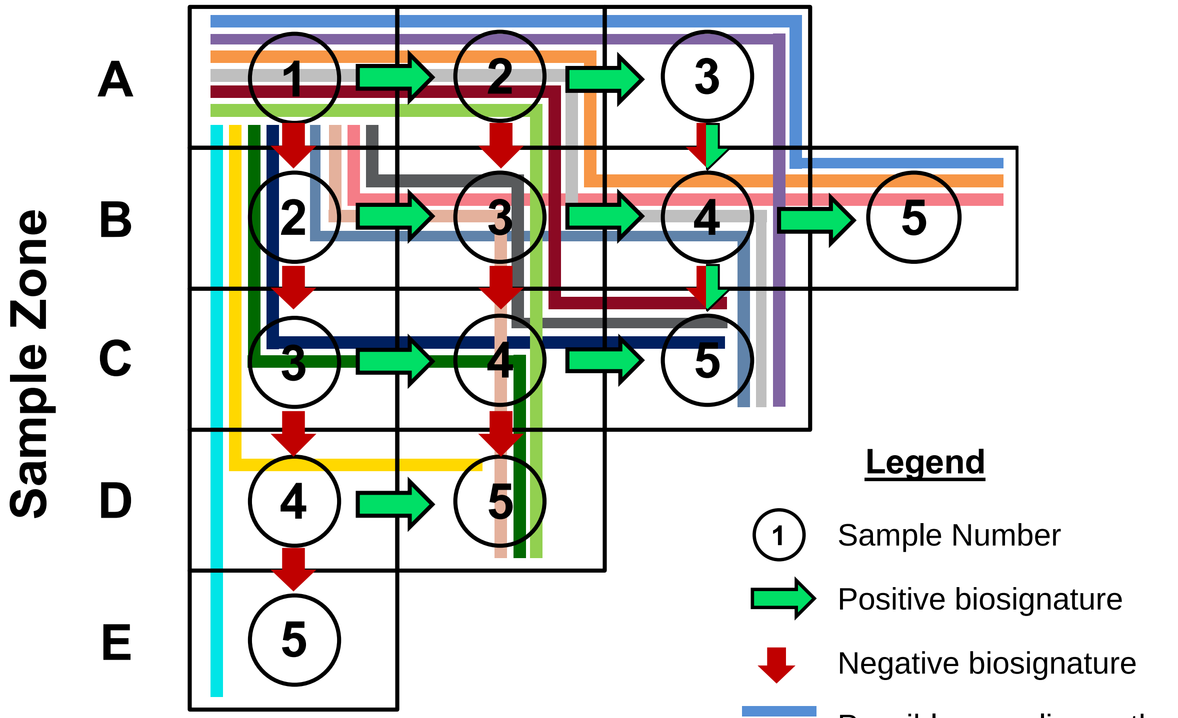
Sample Analysis Scenarios	GCMS				Microscope		Raman	Context Remote Sensing		Biosignature Result
	Abundance	Pattern	Chirality	Isotopes	Cell-like structures	Cellular properties	Biominerals	Context	Endo vs Exo	
	1	1	1	1	1	0	1	1	1	1

Surface Phase of Operations Enables Processing of at least 5 samples from 5 different sites

- 3 samples to detect and confirm any biosignatures (triplicate standard)
- Can choose up to 3 different zones, followed by 2 more samples for confirmation



Sample Zones



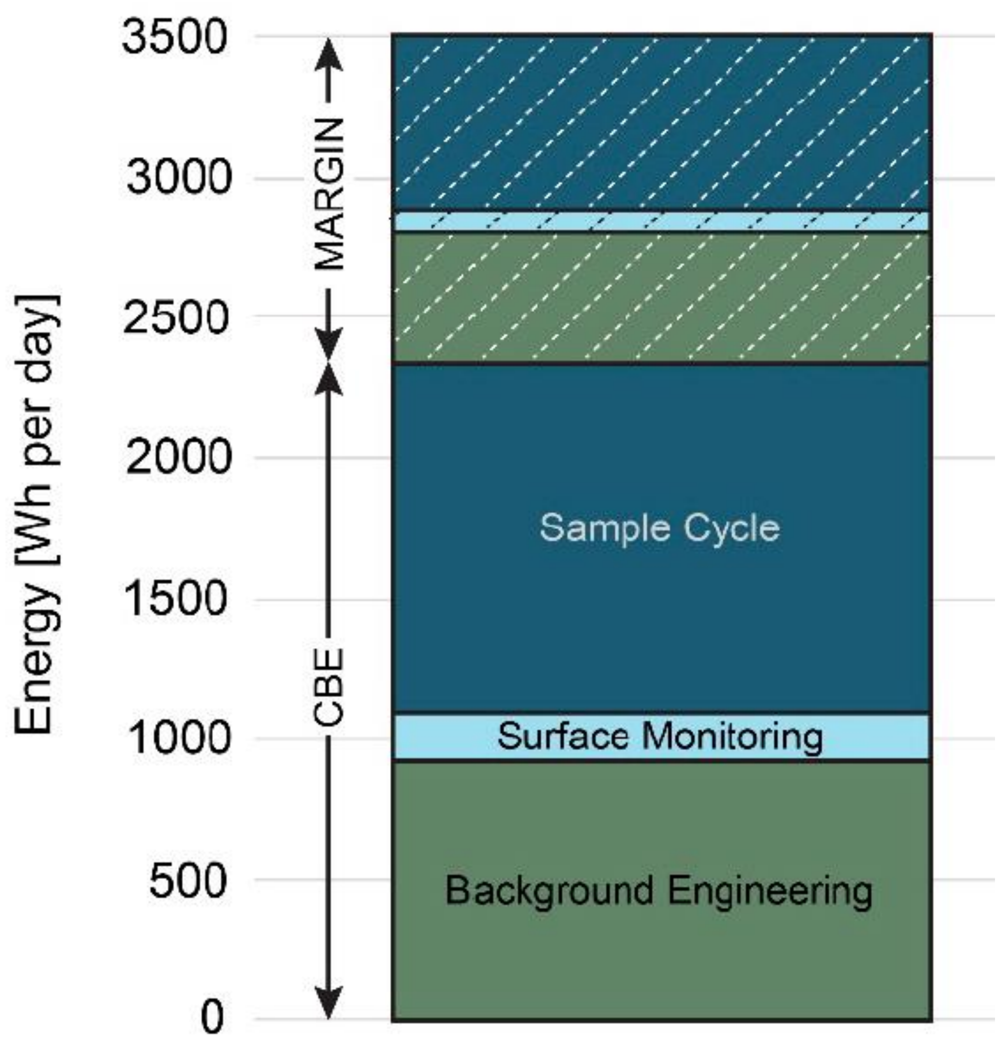
Europa 'post-Clipper' Science Scenarios

Clipper could lead to one of four scenarios:

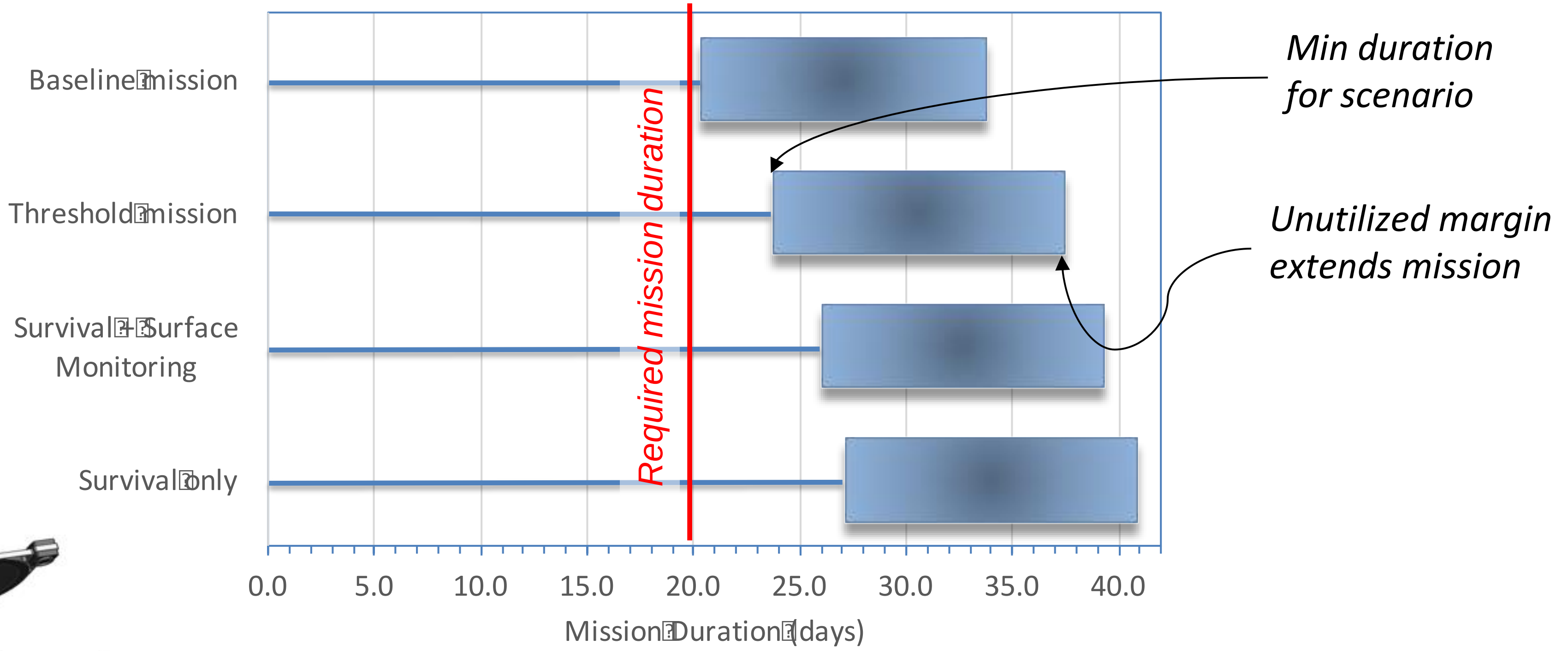
- Not Habitable
  - Europa Lander would be critical for determining why (e.g. detection limits on carbon; geological activity).
- Maybe Habitable
  - Lander critical to resolving ambiguity of remote sensing.
- Habitable
  - Lander needed to detect and characterize any potential biosignatures.
- Inhabited (*very difficult via remote sensing*)
  - Lander needed for biosignature confirmation and for surface information needed for future exploration.

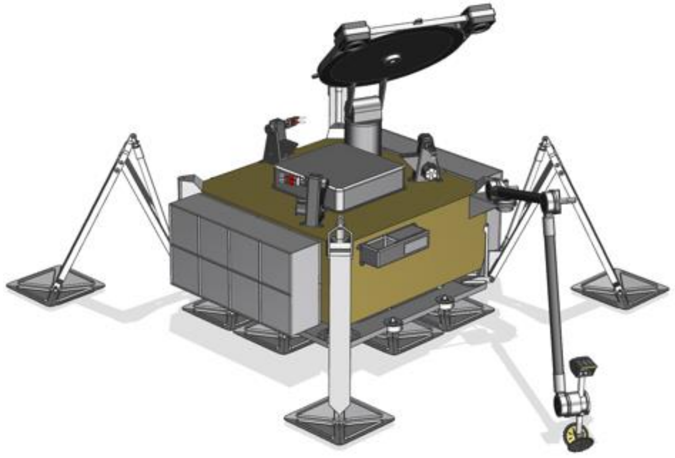
Mission Concept Enables 5+ Samples

- Primary batteries provide 45 kWh of energy for surface operations.
  - Many scenarios possible depending on how battery budget is utilized.
  - Faults put lander into survival mode with minimal draw on batteries.
- Baseline mission scenario:
  - 20 day lifetime.
  - 12 days for sampling with science team in the loop.
  - 8 additional days for sampling and decision making.



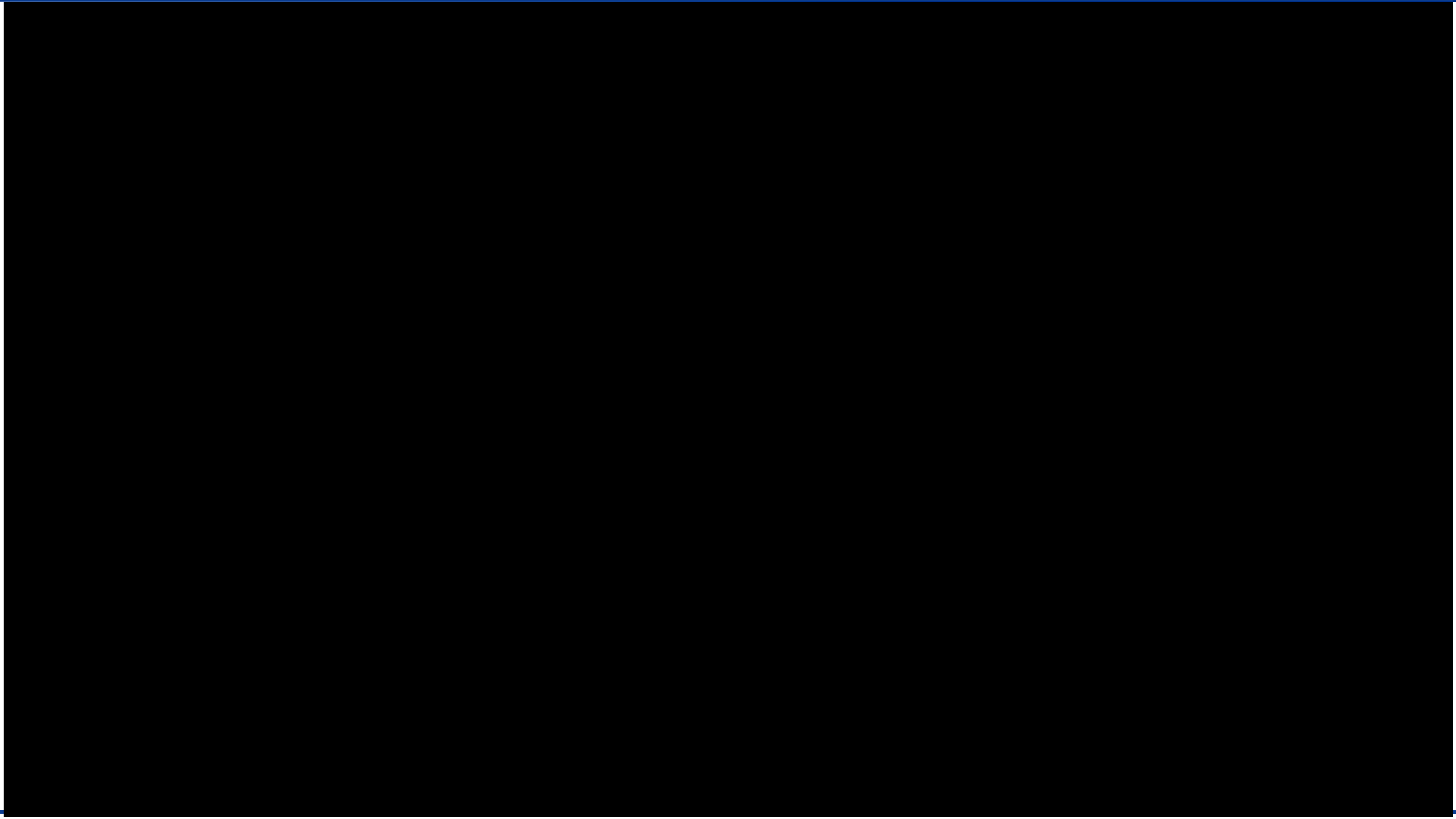
Mission Duration: 45 kWh



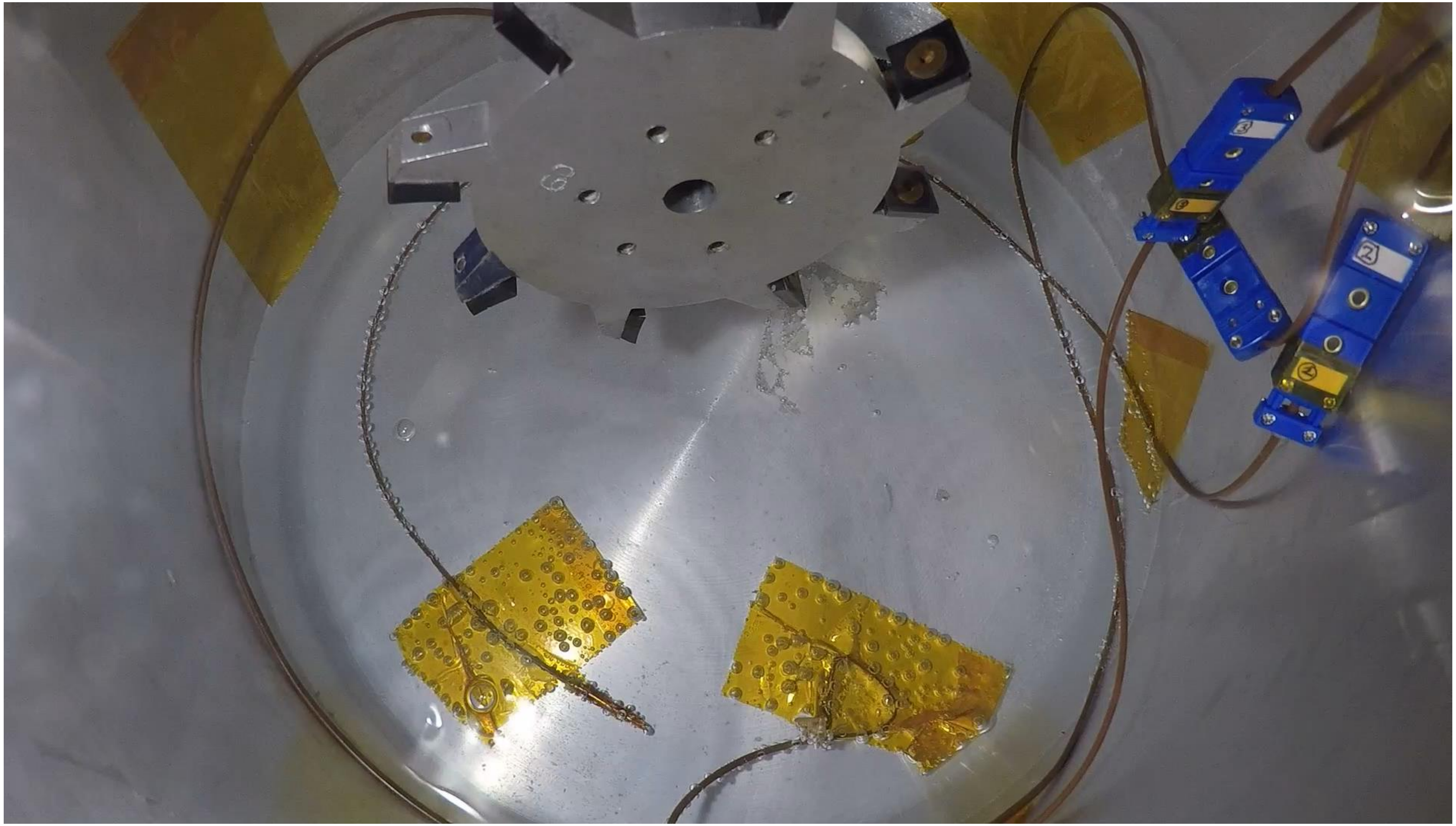


Mission scenario	# Samples	Monitoring tals	Survival tals
Baseline mission	5	continuous	0
Threshold mission	3	7	remainder
Survival + monitoring	0	continuous	0
Survival only	0	0	continuous

Europa Lander Mission Concept



Sampling: 100 K ice with $MgSO_4$ & H_2SO_4



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Relevance to NASA & the Decadal Survey

2003 Decadal Survey: Europa Lander for Astrobiology

New Frontiers in the Solar System

An Integrated Exploration Strategy

Solar System Exploration Survey

Space Studies Board

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
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- Large Initiatives:
  - Europa Geophysical Explorer
  - Titan Explorer
  - **Europa Lander** (Pathfinder or Astrobiology)
  - Neptune Orbiter
- Key Science Question: “Does (or did) life exist beyond Earth?”
  - **Europa Lander**
  - Mars Sample Return

2011 Vision & Voyages Decadal Survey

Planetary Habitats Theme:

"Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?"

Relevance to 2011 Decadal Survey

Europa Lander			Decadal Survey	
Goals		Objectives	Themes/Goals	Questions/Objectives
BIOSIGNATURES	**1. Search for evidence of life on Europa.**	**1a.** Detect and characterize any organic indicators of past or present life.	**Crosscutting Theme 2:** Planetary Habitats	**Priority Question 6:** Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now? … *"a lander will probably be required to fully characterize organics on the surface of Europa "*
			Satellite Science Goal 1: What determines the abundance and composition of satellite volatiles?	**Objective 2:** What determines the abundance and composition of satellite volatiles? **Question 2:** Are volatiles present at the surface or in the ice shell of Europa that are indicative of internal processing or resurfacing? *"Investigations … include determination of the volatile composition of the ices, the stable isotope ratios of carbon, hydrogen, oxygen, and nitrogen"*
		1b. Identify and characterize morphological, textural or other indicators of life.	**Satellite Science Goal 3:** What are the processes that result in habitable environments?	**Objective 4:** Is there evidence for life on the satellites? **Question 1.** Does (or did) life exist below the surface of Europa or Enceladus? *"A key future investigation of the possibility of life on the outer planet satellites is to analyze organics from the interior of Europa. Such analysis requires […] a lander …." "Studies of the plume of Enceladus and any organics on the surface of Europa (or in potential Europa plumes) may provide evidence of biological complexity even if the organisms themselves are no longer present or viable."*
		1c. Detect and characterize any inorganic indicators of past or present life.		
		1d. Determine the provenance of sampled material.	**Satellite Science Goal 3:** What are the processes that result in habitable environments?	**Objective 2:** What are the sources, sinks, and evolution of organic material? **Question 3:** Are organics present on the surface of Europa, and if so, what is their provenance?

Relevance to 2011 Decadal Survey

Europa Lander			Decadal Survey	
	Goals	Objectives	Themes/Goals	Questions/Objectives
SURFACE HABITABILITY	**2. Assess the habitability of Europa via in situ techniques uniquely available to a lander mission.**	**2a.** Characterize the non-ice composition of Europa's near-surface material to determine whether there are indicators of chemical disequilibria and other environmental factors essential for life.	**Crosscutting Theme 2**: Planetary Habitats	**Priority Question 4:** What were the primordial sources of organic matter, and where does organic synthesis continue today?
			Satellite Science Goal 3: What are the processes that result in habitable environments?	**Objective 3:** What energy sources are available to sustain life? **Question 1:** What is the nature of any biologically relevant energy sources on Europa? *"Important directions for future investigations …include (1) measurement of the oxidant content."*
		2b. Determine the proximity to liquid water and recently erupted materials at the lander's location.	**Satellite Science Goal 1:** How did the satellites of the outer solar system form and evolve?	**Objective 3:** How are satellite thermal and orbital evolution and internal structure related? **Question 8:** What is the thickness of Europa's outer ice shell and the depth of its ocean?
				Objective 4: What is the diversity of geologic activity and how has it changed over time? **Question 5:** Has material from a subsurface Europa ocean been transported to the surface, and if so, how? *"…in situ measurements from the surface would provide additional information on the surface composition and environment and the subsurface structure"*
			Satellite Science Goal 3: What are the processes that result in habitable environments?	**Objective 1:** Where are subsurface bodies of liquid water located, and what are their characteristics and histories? **Question 1:** What are the depths below the surface, the thickness, and the conductivities of the subsurface oceans of the Galilean satellites?

Relevance to 2011 Decadal Survey

<table>
<tr><th colspan="3">Europa Lander</th><th colspan="2">Decadal Survey</th></tr>
<tr><th colspan="2">Goals</th><th>Objectives</th><th>Themes/Goals</th><th>Questions/Objectives</th></tr>
<tr><td rowspan="4">SURFACE PROPERTIES AND DYNAMICS</td><td rowspan="4">3. Characterize surface and subsurface properties at the scale of the lander to support future exploration.</td><td rowspan="2">3a. Observe the properties of surface materials and sub-meter-scale landing hazards at the landing site, including the sampled area. Connect local properties with those seen from flyby remote sensing.</td><td>Crosscutting Theme 3: Workings of Solar Systems</td><td>Priority Question 10: How have the myriad chemical and physical processes that shape the solar system operated, interacted, and evolved over time?</td></tr>
<tr><td>Satellite Science Goal 2: What processes control the present-day behavior of these bodies?</td><td>Objective 3: How do exogenic processes modify these bodies?
Question 4: How are potential Europa surface biomarkers from the ocean-surface exchange degraded by the radiation environment?</td></tr>
<tr><td rowspan="2">3b. Characterize dynamic processes of Europa's surface and ice shell over the mission duration to understand exogenous and endogenous effects on the physicochemical properties of surface material.</td><td>Satellite Science Goal 1: How did the satellites of the outer solar system form and evolve?</td><td>Objective 4: What is the diversity of geologic activity and how has it changed over time?
Question 5: Has material from a subsurface Europa ocean been transported to the surface, and if so, how?</td></tr>
<tr><td>Satellite Science Goal 2: What processes control the present-day behavior of these bodies?</td><td>Objective 1: How do active endogenic processes shape the satellites’ surfaces and influence their interiors?
Objective 3: How do exogenic processes modify these bodies?</td></tr>
</table>

Measurement Approach is Well-Established

Life Detection Strategy
NRC 2000 Signs of Life Report

- Morphology
- Organic Chemistry & Biochemistry
- Inorganic Chemistry
- Isotopic Analyses
- Environmental Measurements

Signs of Life

A Report Based on the April 2000
Workshop on Life Detection Techniques

Committee on the Origins and Evolution of Life

Space Studies Board
Division on Engineering and Physical Sciences

Board on Life Sciences
Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
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Searching for Signs of Life: Lessons from Viking

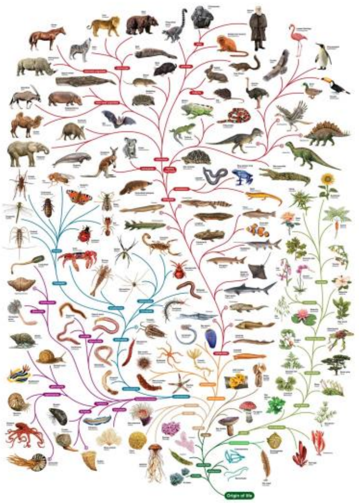
- If the payload permits, conduct experiments that assume contrasting definitions for life.
- **Given limited payload, the biochemical definition of life deserves priority**.
- Establishing the geological and chemical context of the environment is critical.
- **Life-detection experiments should provide valuable information regardless of the biology results**.
- Exploration need not, and often cannot, be hypothesis testing. Planetary missions are often missions of exploration; and therefore, the above guidelines must be put in the context of exploration and discovery driven science.

NRC 2000; Chyba and Phillips (2001)

We are ready to resume the direct search for life beyond Earth

DNA discovered

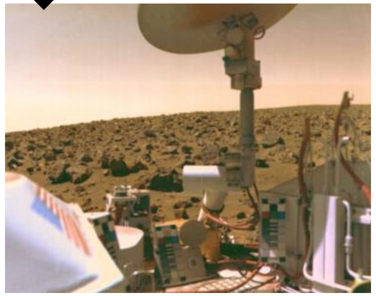
1953



Tree of Life Then…

Hydrothermal vents discovered

1976



Viking Landers

1977

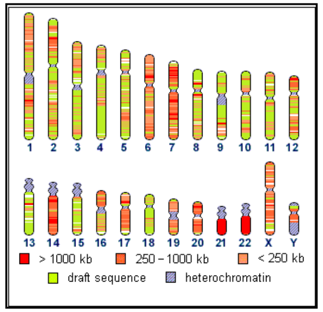
Archaea discovered (3rd domain of life)

Cryptoendoliths in Antarctica discovered

PCR Invented

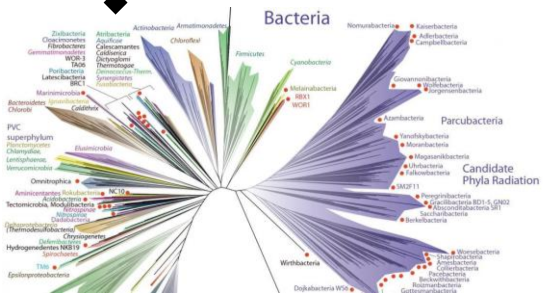
1983

2003



Human genome sequenced

2016



…Tree of Life Now.

Europa Lander SDT Report

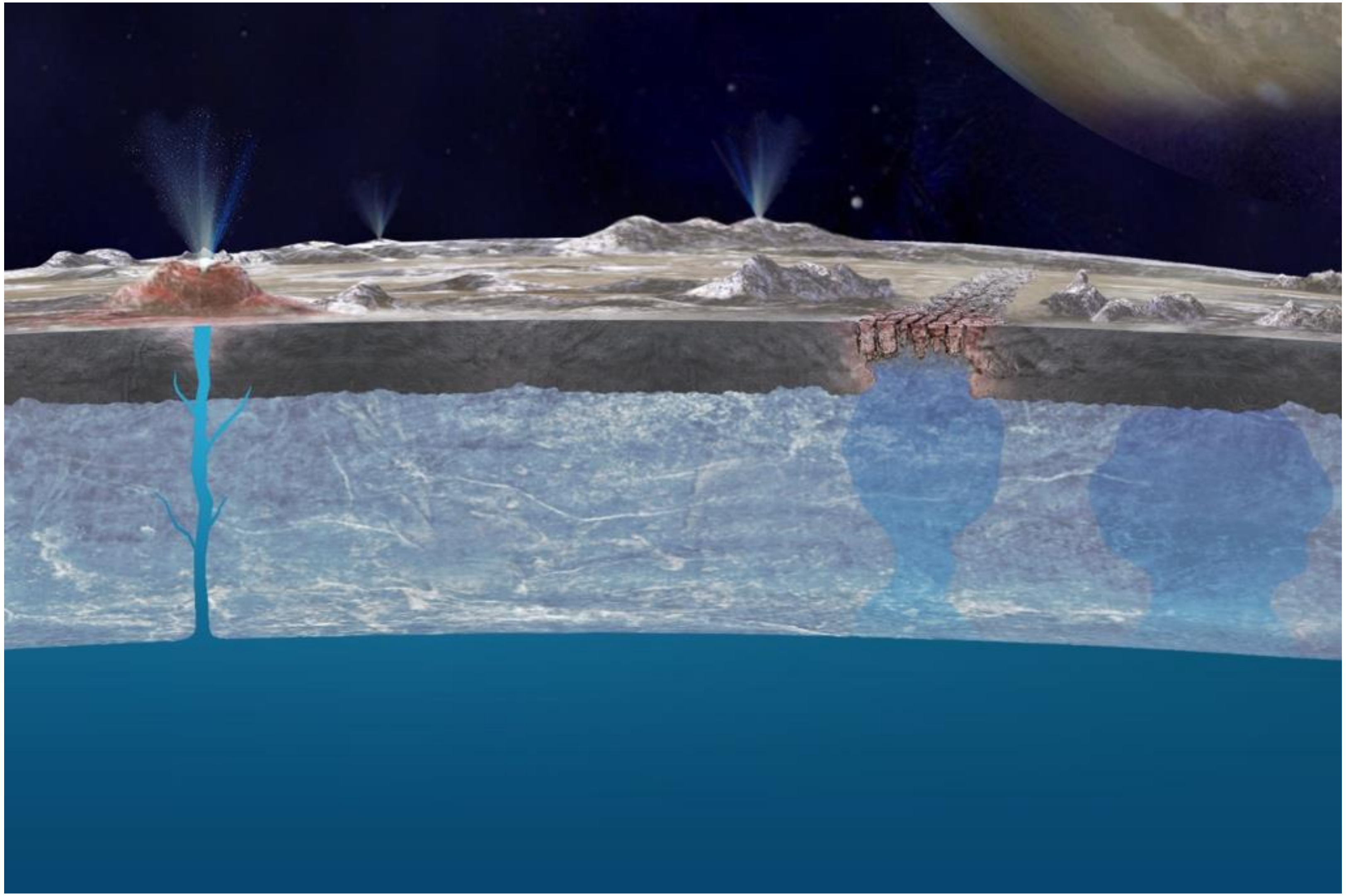
2017

Backup

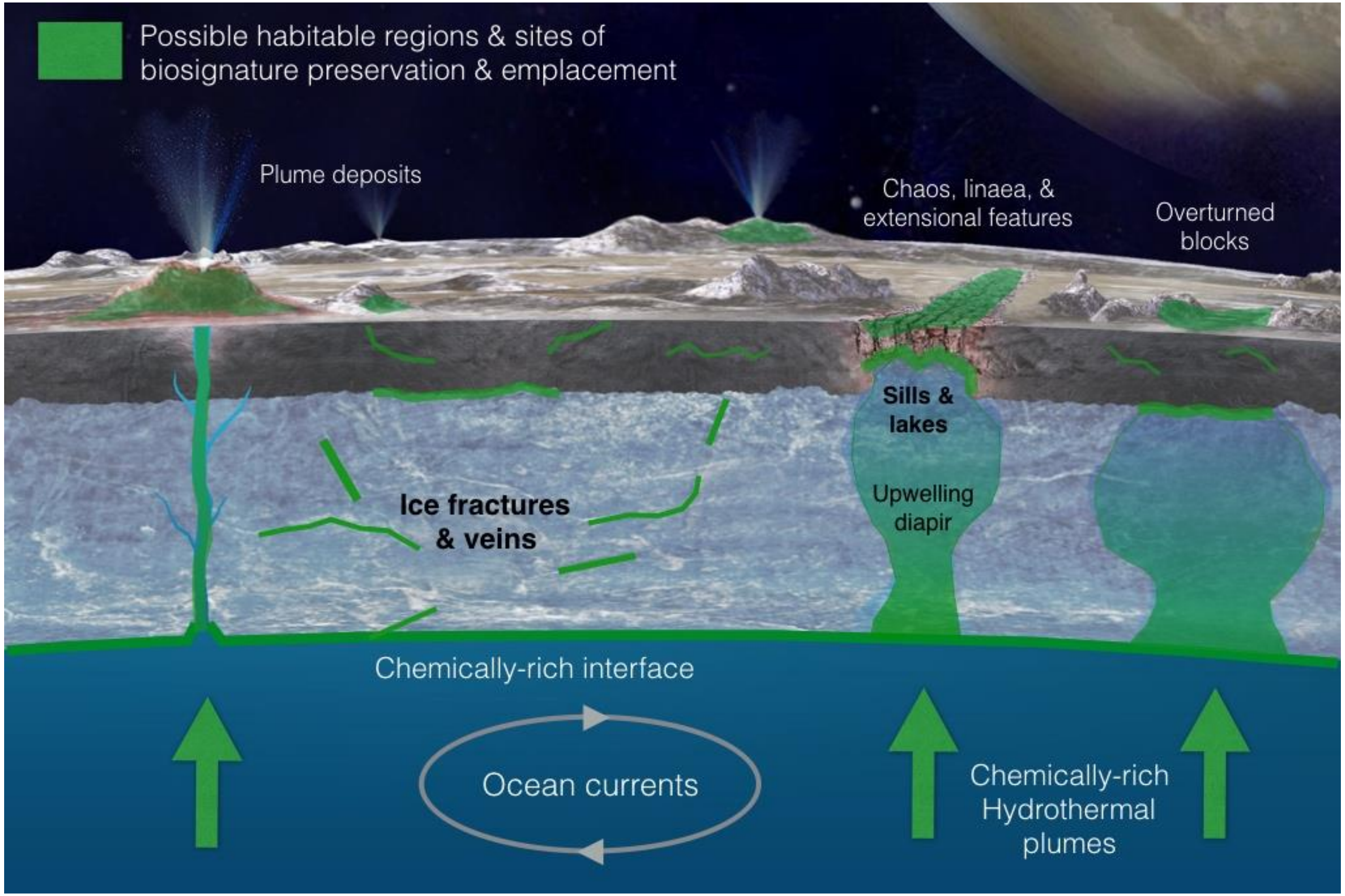
Europa Lander Surface Lifetime: Trades & Considerations

- Lander was required to bring a relay for data uplink/downlink to Earth
  - Carrier Relay Orbiter (CRO) lifetime limited by radiation environment (~30 days).
  - EMFM could only be used for backup.
  - Options with Direct-to-Earth (DTE) as primary link are too massive.
  - ESA JUICE relay not permitted.
- Radioactive Power Source (RPS) option
  - Added lifetime difficult to justify given CRO lifetime limit.
  - RPS options too massive and complex.
  - Planetary Protection becomes significantly more challenging.
- Primary Battery option
  - Optimizes operations and minimizes complexity (i.e., energy as needed, when needed, and e.g., thermal management and mechanical configuration).
  - Easily 'quantized' and scaled.
  - Provides radiation shielding around vault.
  - Right 'knee-in-the-curve' for stationary, pathfinding lander.

Provenance



Provenance

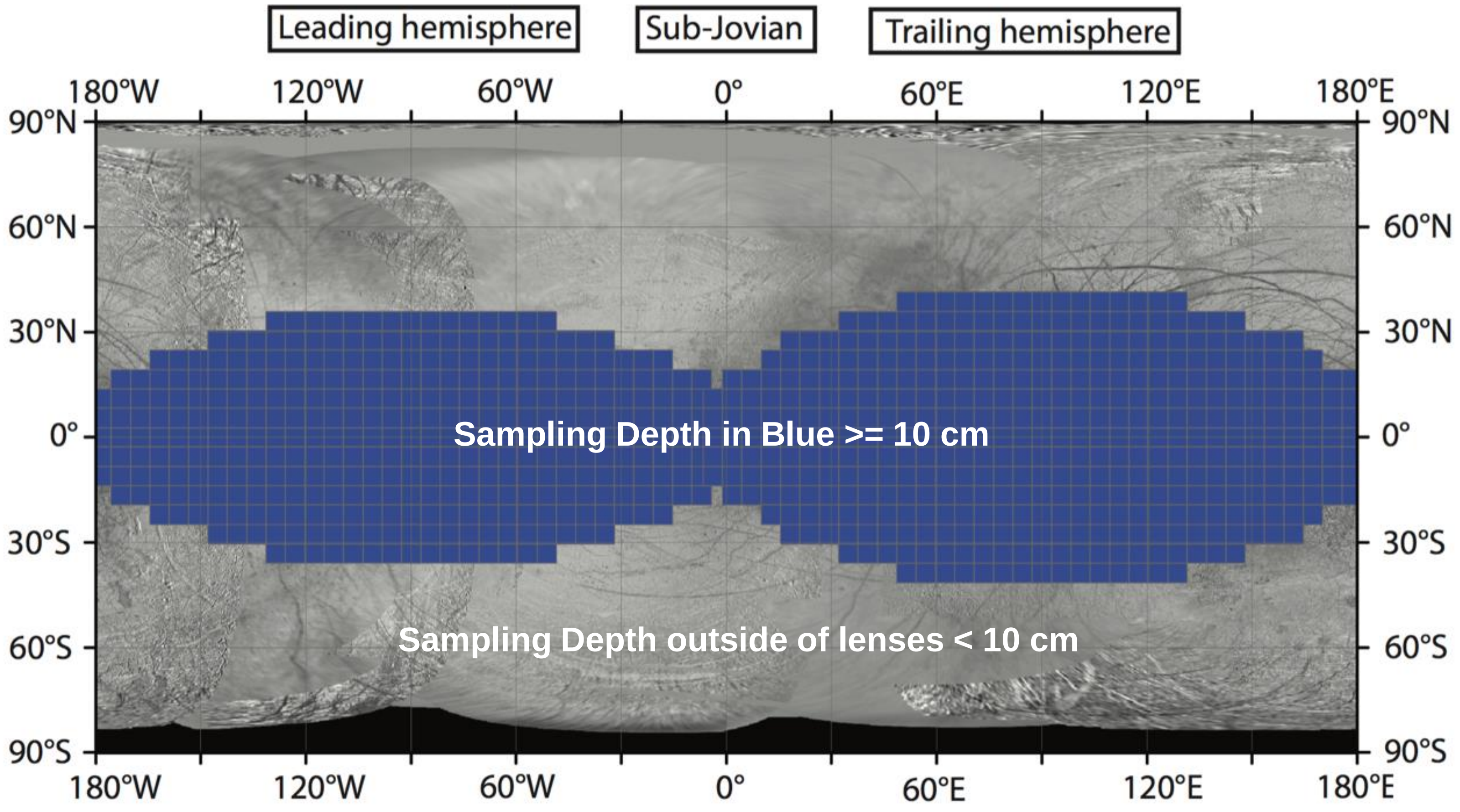


Possible habitable regions & sites of biosignature preservation & emplacement
Plume deposits
Chaos, linaea, & extensional features
Overturned blocks
Sills & lakes
Ice fractures & veins
Upwelling diapir
Chemically-rich interface
Ocean currents
Chemically-rich Hydrothermal plumes

Organics & Radiation Processing

- Accessing a ‘pristine’ samples
  - Target young surfaces
  - Geography is a key driver of radiation processing (stay out of the lenses, if possible).
  - Target dense materials (e.g. salt vs water)
    - Avoid radicals
- ‘Pristine’ samples are not *essential* to the detection of potential biosignatures
  - Archean rocks on Earth.
  - Radiation processing experiments.
  - Remote sensing of organics will serve as a guide.

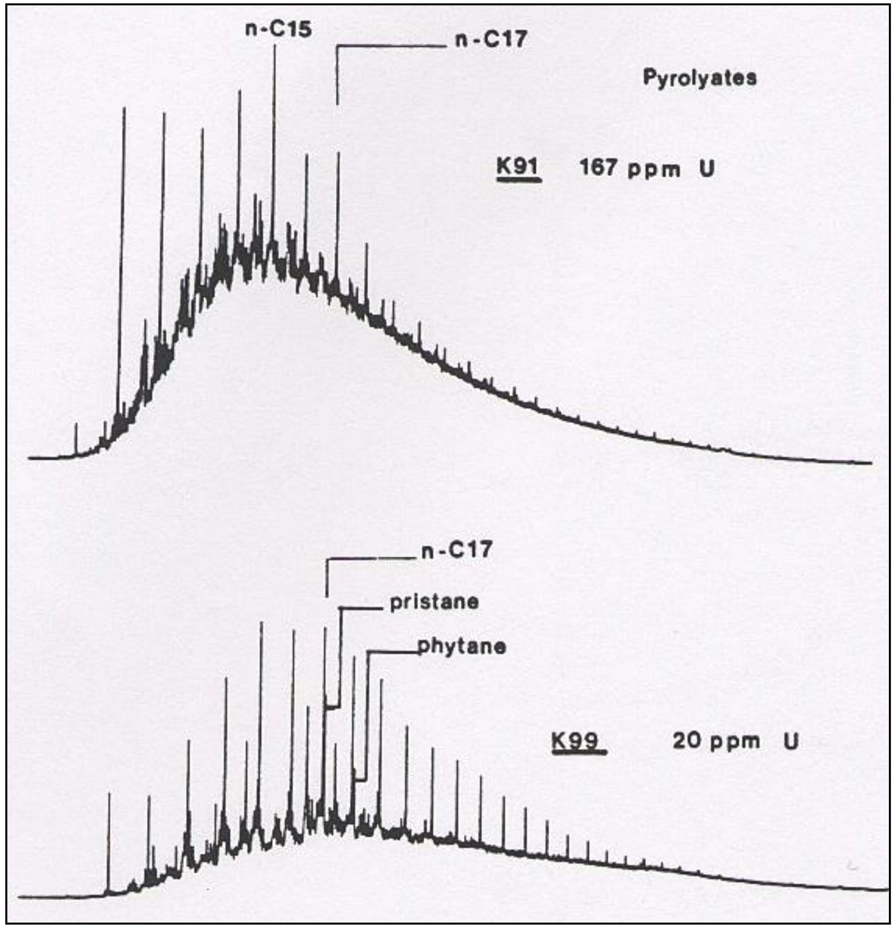
Radiation processing: Sampling depth



For a 10^7 yr average surface age, a pure water ice surface would be radiation processed to a 60 Grad dose (100 eV/16-amu) down to 10 cm.

Radiolytic Alteration of Biosignatures

- Europan surface worst case is 60 Grad at 10 cm depth.
- Useful points of comparison:
  - Mars: Total dose ranges from 80 Grad near the surface to 20 Grad at 1 meter depth.
  - Earth: Archean rocks and diagenetic processing provide parallels to radiolytic modification.
  - Comets & Asteroids: >100 Grad dose for surface and near-surface material.



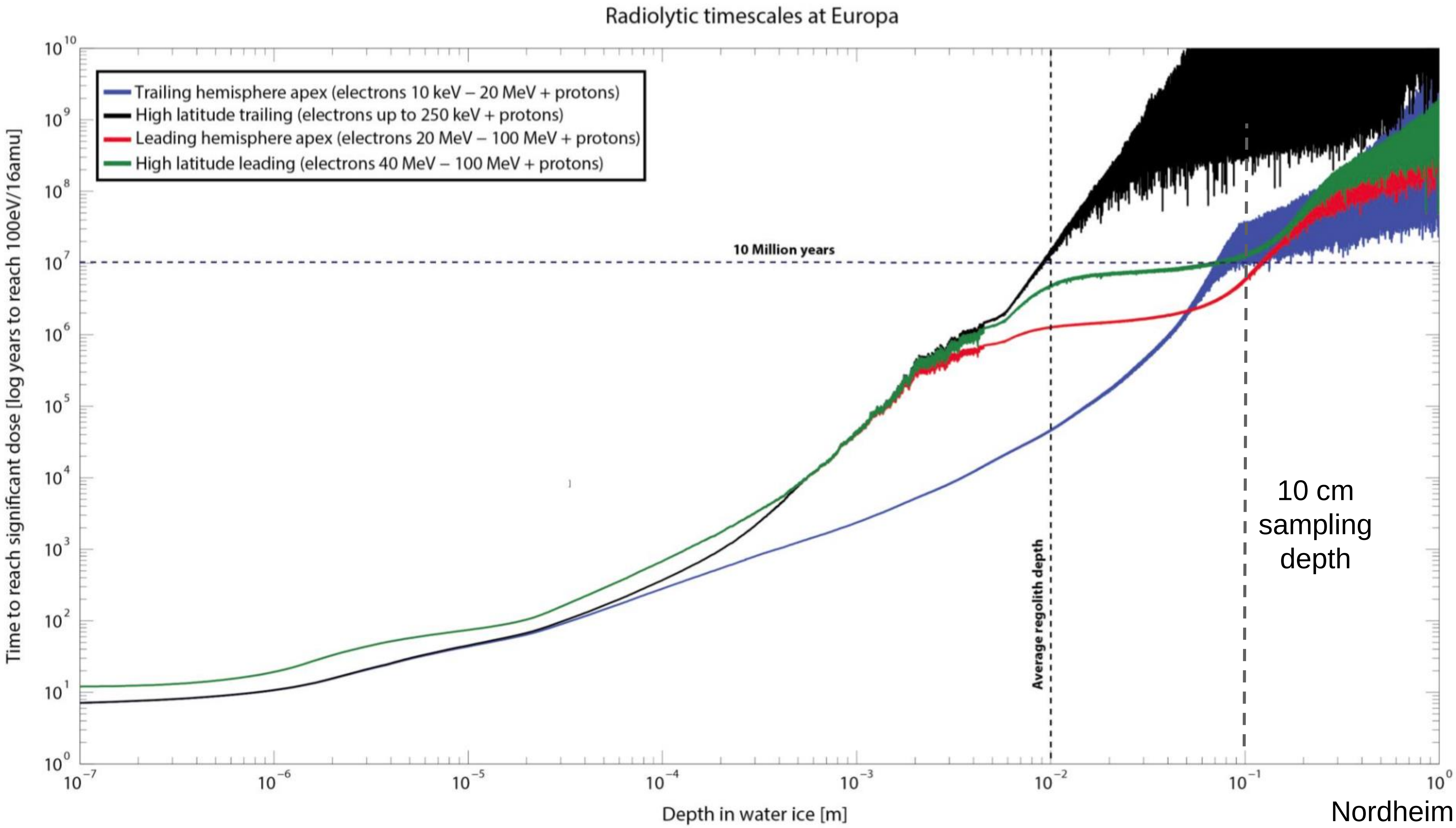
Sundararaman and Dahl (1993), Hand et al. (2009)

Radiolytic Alteration of Biosignatures

- Radiolytic Processing of Organics:
  - 100 eV/16 amu (60 Grad) is more than enough energy to break every bond several times (a few to 10 eV/bond).
  - Just because a bind *CAN* break does not mean that it *WILL* break (e.g. nitrile bond and aromatics).
  - Aliphatic hydrocarbons transform into aromatic hydrocarbons.
  - Oxidation forms phenols, ketones, aldehydes, and carboxylic acids.
  - H/C ratio decreases.
  - Formation of functionalized aromatic compounds.

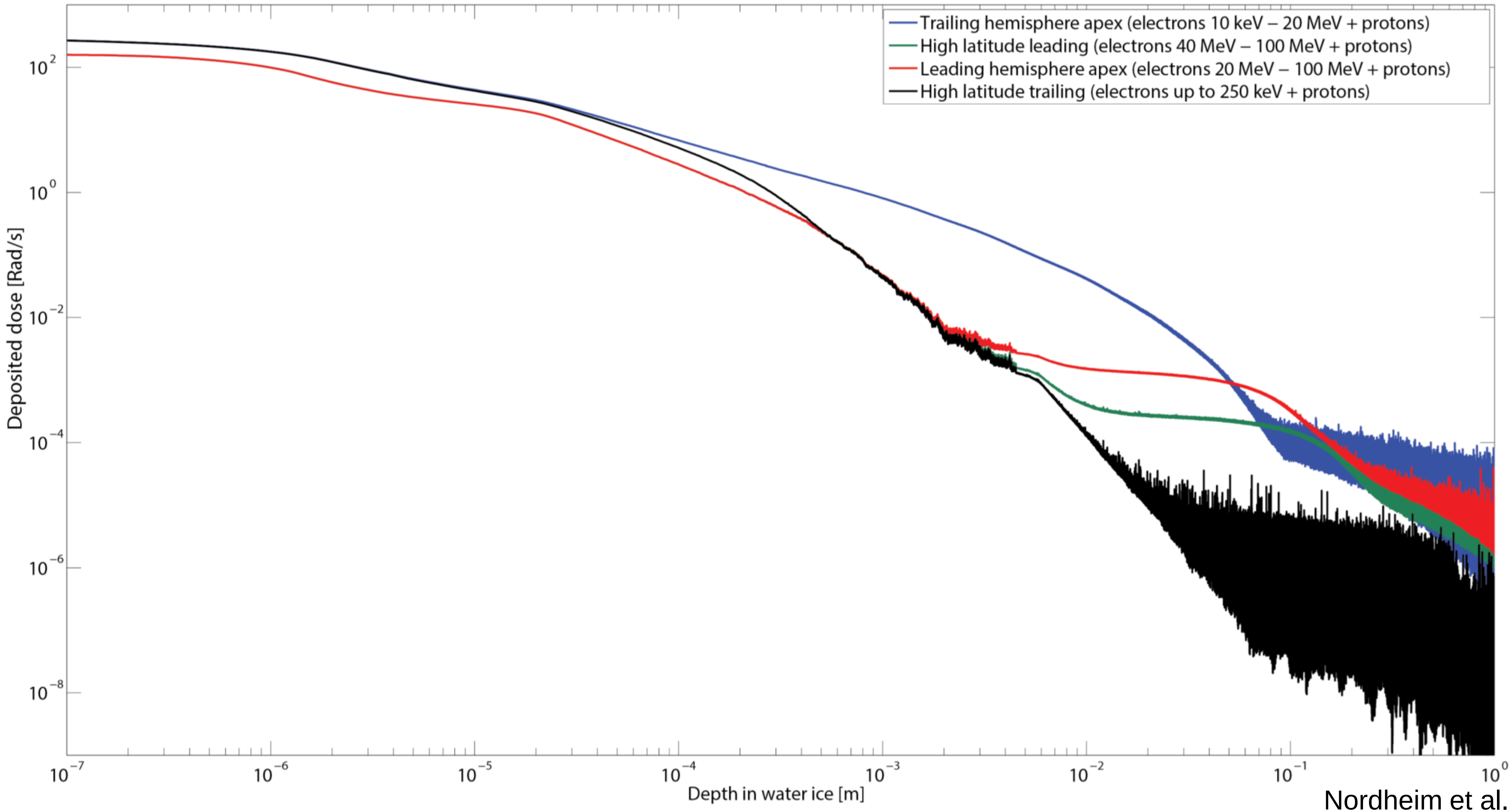
Court et al. (2006)

Radiation processing: Sampling depth



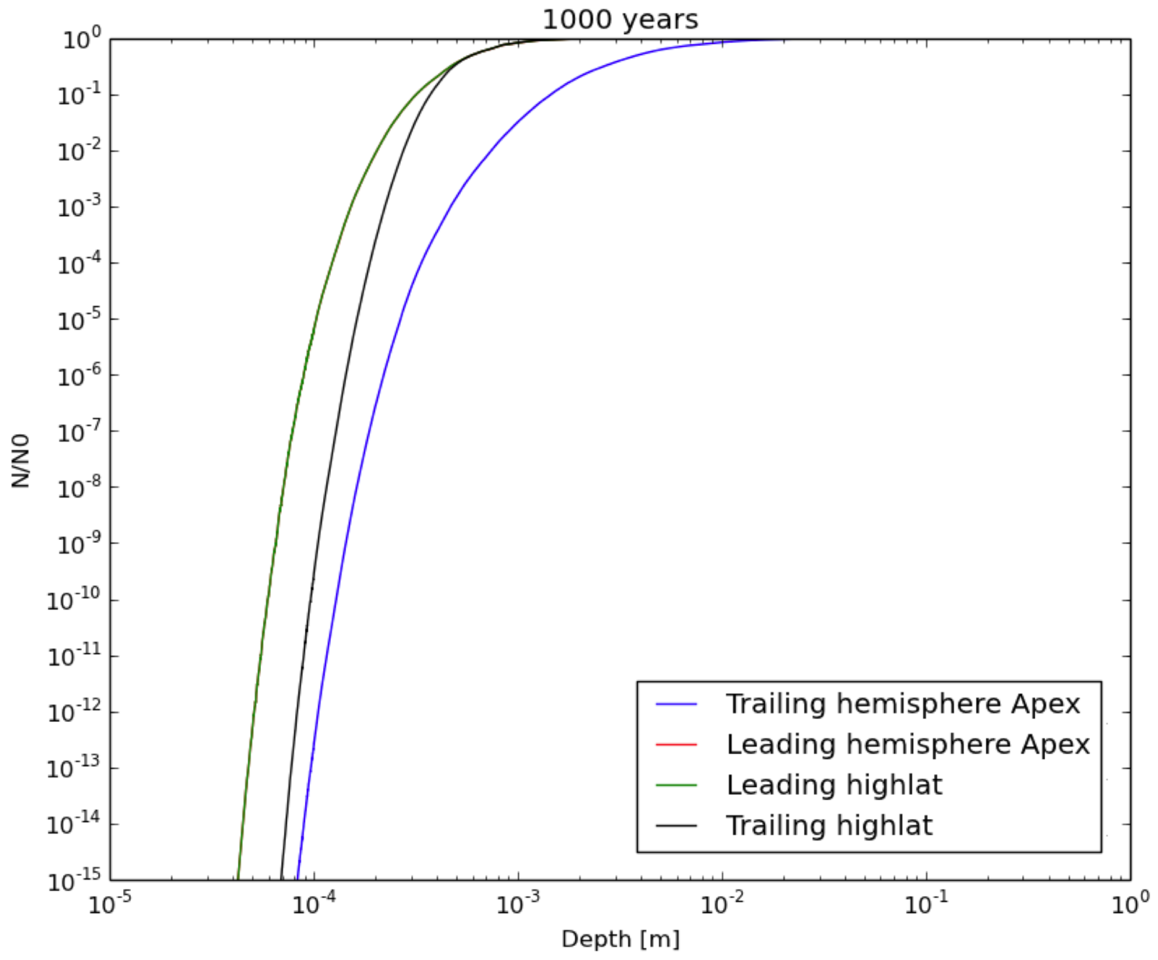
Nordheim et al. (in prep)

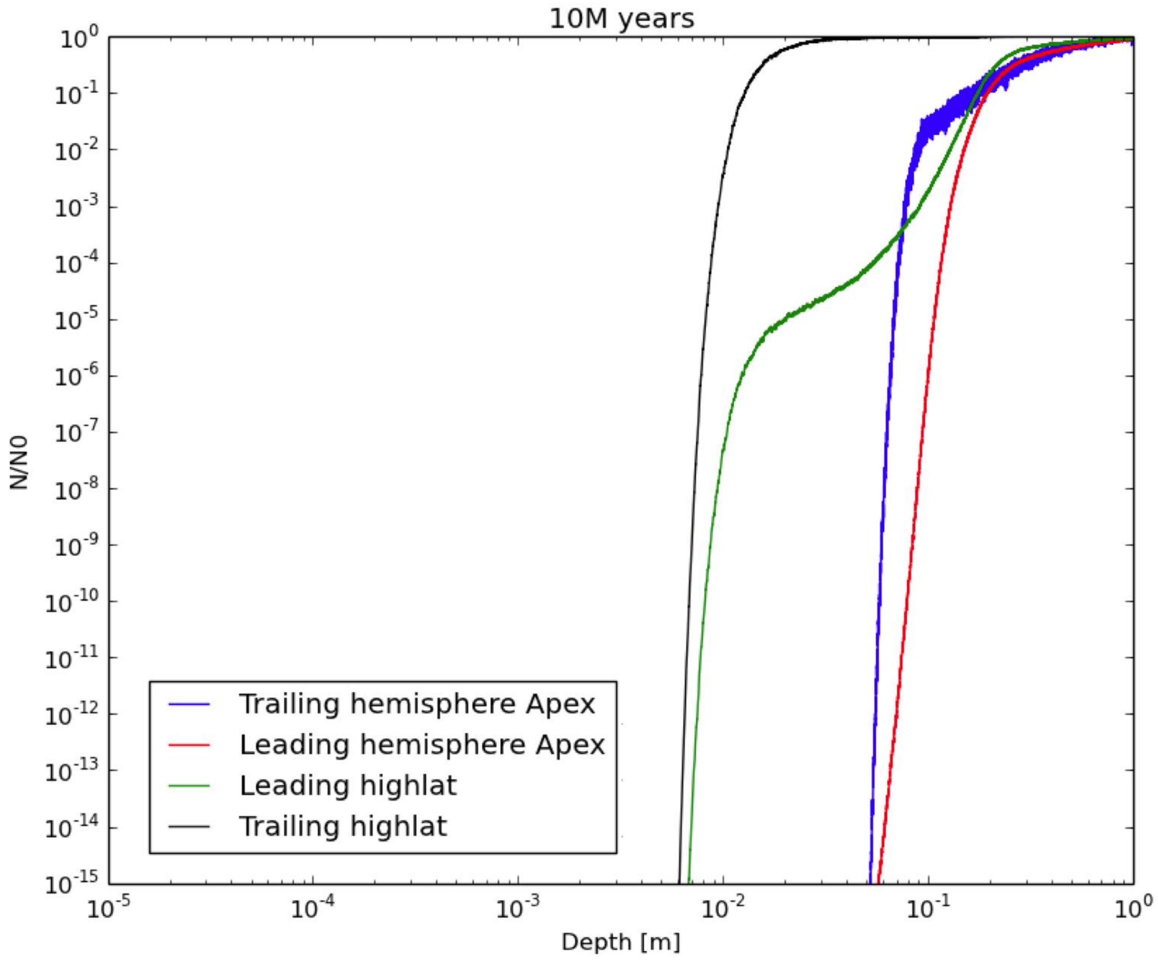
Radiation processing: Deposited Dose



Nordheim et al. (in prep)

Radiation Processing & Amino Acid Survival





Nordheim et al. (in prep)

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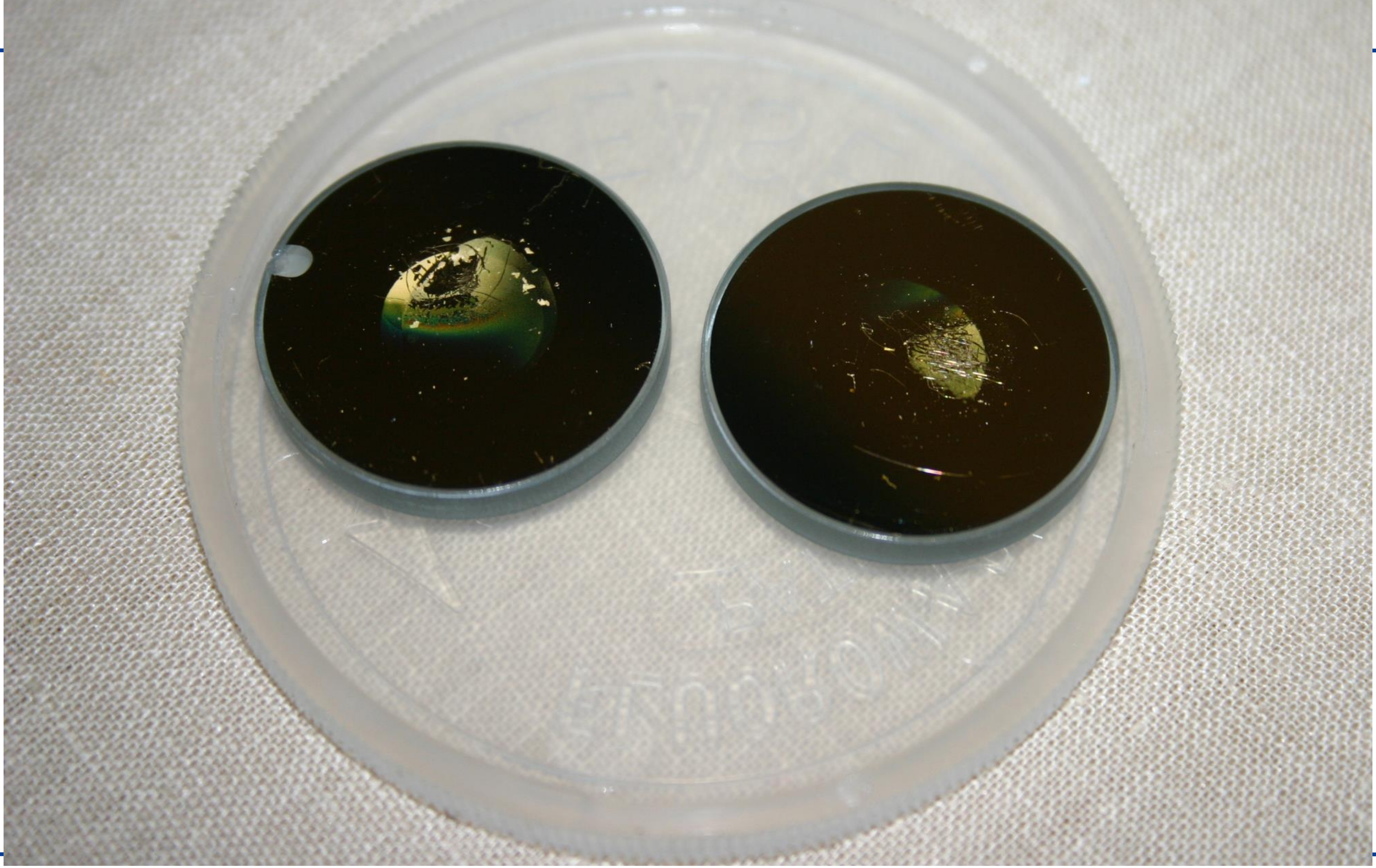
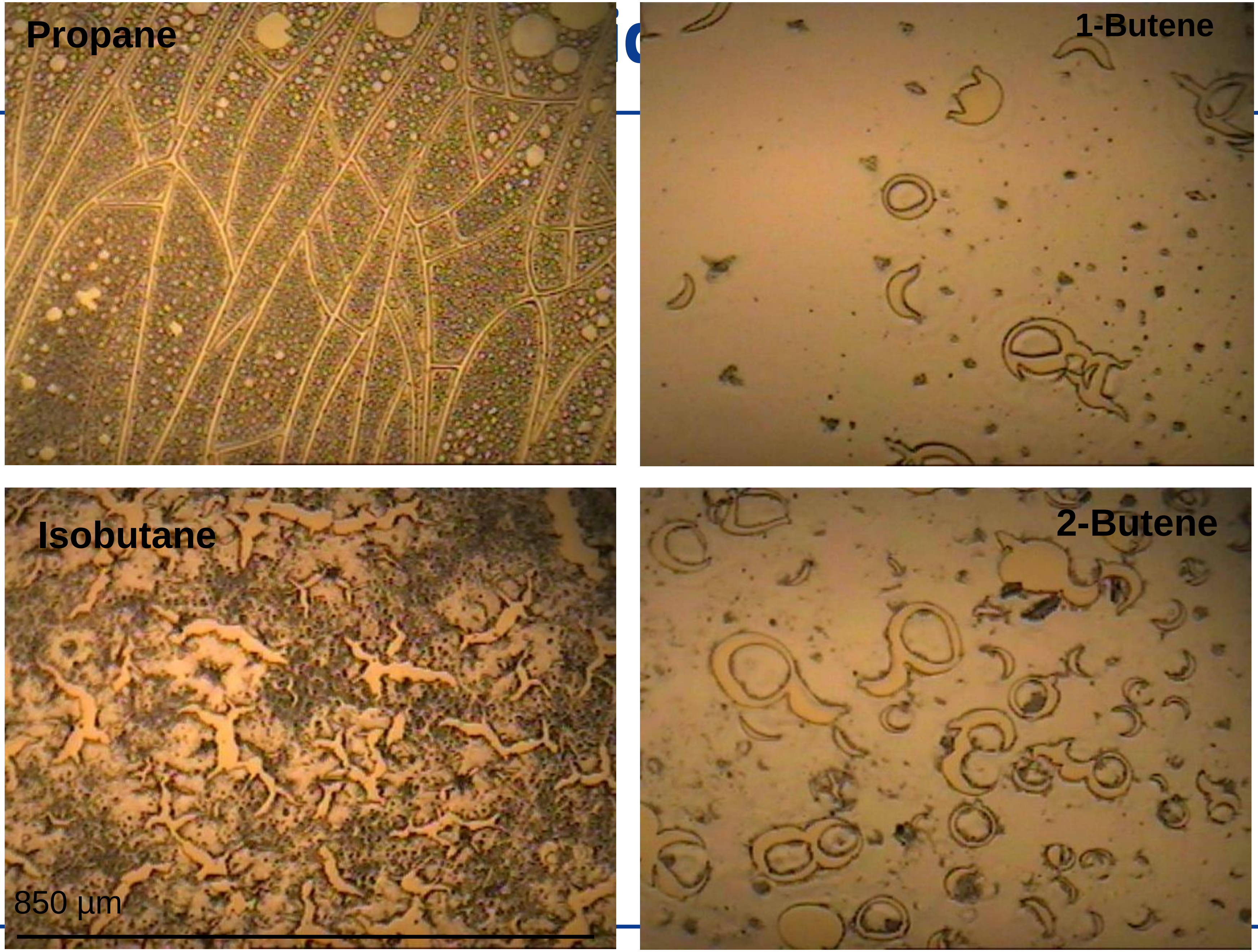
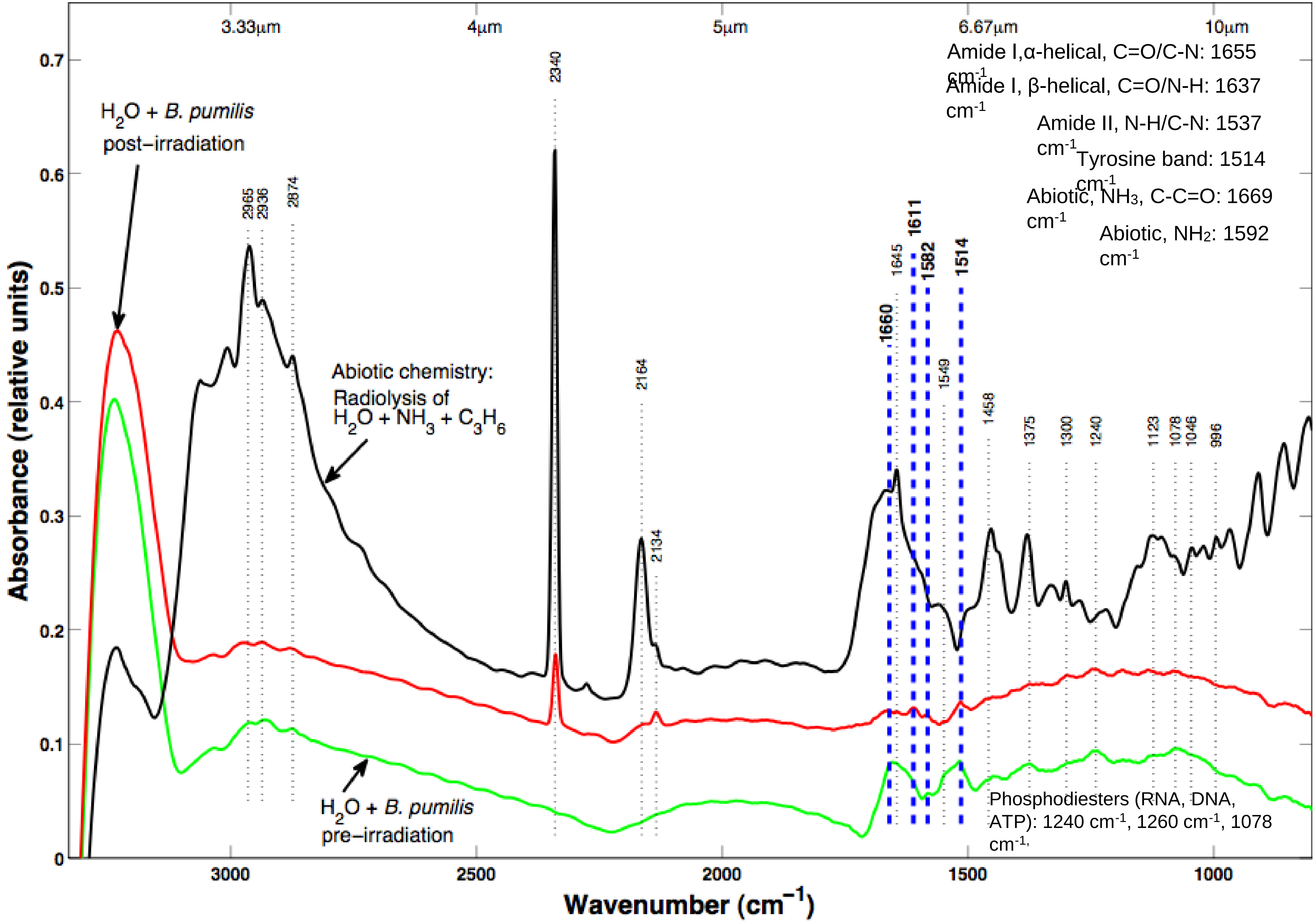
Gold mirrors ~ 1 cm spot size with e$^-$ beam




Propane
1-Butene
Isobutane
2-Butene
850 µm



3.33µm
4µm
5µm
6.67µm
10µm
Amide I,α-helical, C=O/C-N: 1655 cm-1
Amide I, β-helical, C=O/N-H: 1637 cm-1
Amide II, N-H/C-N: 1537 cm-1
Tyrosine band: 1514 cm-1
Abiotic, NH3, C-C=O: 1669 cm-1
Abiotic, NH2: 1592 cm-1
H2O + B. pumilis post−irradiation
Abiotic chemistry: Radiolysis of H2O + NH3 + C3H6
H2O + B. pumilis pre−irradiation
Phosphodiesters (RNA, DNA, ATP): 1240 cm-1, 1260 cm-1, 1078 cm-1,
2965
2936
2874
2340
2164
2134
1660
1645
1611
1582
1549
1514
1458
1375
1300
1240
1123
1078
1046
996
Absorbance (relative units)
Wavenumber (cm−1)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
3000
2500
2000
1500
1000

SDT and Project Engineering Optimization of Science Return

- Iterations on Science Goals and measurement requirements resulted in 42.5 kg allocation for instruments (up from ~25 kg when SDT was assembled).
- Mission lifetime increased to 20+ days to enable Science Ground-In-The-Loop for sample acquisition during Surface Phase (up from ~10 days when SDT was assembled).
- Number of samples increased to a Baseline of 5 samples (up from 3 when SDT was assembled).
- Data return link now capable of >5 Gb of data returned from the lander (up from ~1 Gb with Clipper only link).

Candidate L1 Baseline Science Requirements

Level 1 Science Requirements	
Search for evidence of life on Europa.	The Europa Lander Mission shall detect and characterize any existing organic, inorganic, morphological, textural and/or other indicators of past or present life.
Assess the habitability of Europa.	The Europa Lander Mission shall determine the composition of Europa's non-ice, near-surface material; search for indicators of chemical disequilibria and other environmental factors essential for life; and search for liquid water and recently erupted materials in proximity to the lander's location.
Characterize surface and subsurface properties at the scale of the lander.	The Europa Lander Mission shall observe the physical properties of surface materials at the landing site and characterize the dynamic processes of Europa's ice shell at the scale of the landing site over mission duration.
Number of Samples	The Europa Lander Mission shall be capable of collecting 5 in situ samples for analysis by the payload during the prime mission.

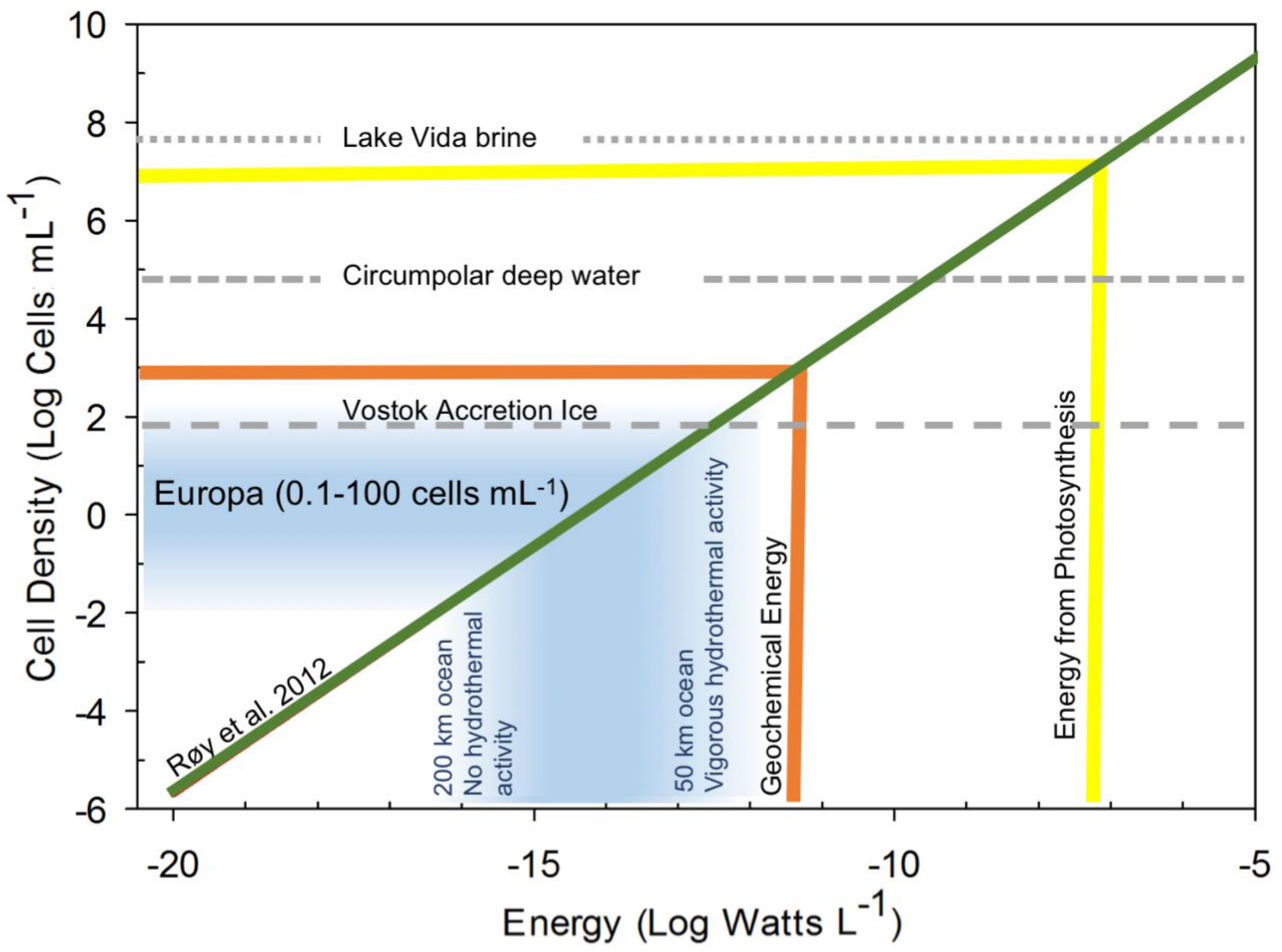
- Candidate L1 Baseline Science requirements based on the SDT report been drafted and reviewed at HQ and JPL program office.
- Descope options and L1 Threshold Science requirements to be assessed after payload selection

Qualitative L1 Science requirements are appropriate for a first landed mission.

Key Feedback from Town Hall Executive Committees

- Ranged from science comments (e.g. the team makes a basic assumption that the mission is searching for 'life as we know it') to the need to consider a back-up sampler.
- A few key science and project level suggestions:
  - Consideration should be given to back-up sampling (e.g. a gas inlet for passive sampling with the mass spectrometer).
  - Greater consideration should be given to contamination control and accommodating a sample blank(s).
  - Given the challenges of sample acquisition, processing, and delivery, a thorough test campaign should be developed.
  - Greater consideration should be given to the radiation processing depth in the surface regolith.

Relationship between cell density and energy in benchmark environments



Relationship (green) based on on cell-specific maintenance energy requirements reported for energy-poor deep ocean sediments; Europa energy flux estimated in Hand et al. 2009, Vance et al. 2016.

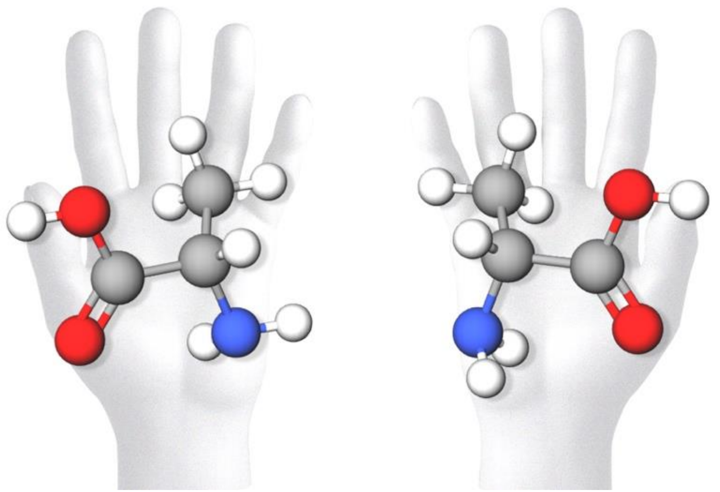
Baseline & Threshold Model Payload

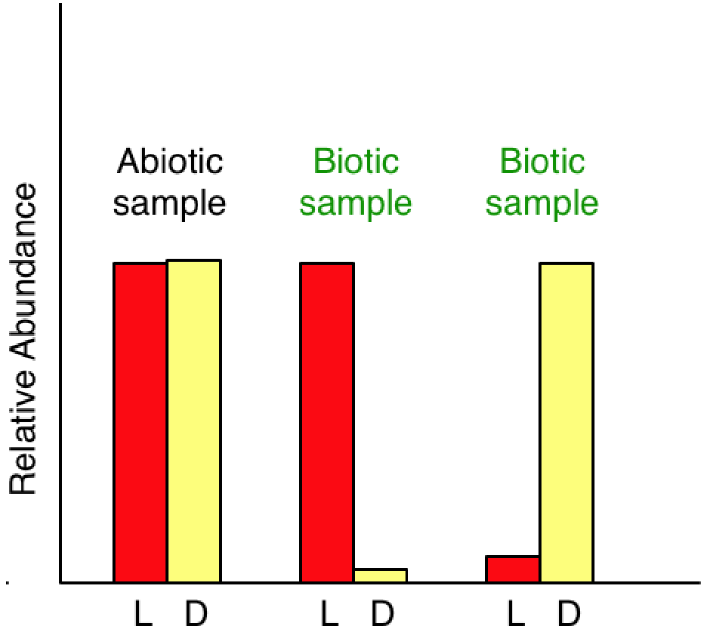
Instrument Class	Baseline Model Payload		
	Model Instrument	Characteristics	Similar Instruments*
Context Remote Sensing Instrument (CSRI)	• Two identical multi-filter, focusable, visible to near-infrared, stereo overlapping cameras with narrowband filters equivalent to those of the EIS cameras on the EMFM	• Multispectral filter wheel spanning the 350–1050 nm range • 34-mm fixed focal length, f/8 lenses with 21° x 15° FOV • Camera heads: ○ Mounted on the HGA, ≥1 m above the local europan surface ○ Spaced ≥20 cm apart with 2.5° toe-in • Camera resolution: ○ Minimum of 500 microns per pixel at distance of 2 m or more	• Mastcam-34 or -100 on MSL • Mastcam-Z on Mars 2020 • ChemCam on MSL • SuperCam on Mars 2020
Microscope for Life Detection (MLD) **+** **Vibrational Spectrometer (VS)** *[combined instrumentation]*	• Deep UV resonance Raman and optical microscope with fluorescence spectrometer	• Optical microscope (OM): ○ Resolution appropriate to provide context imaging of samples ○ FOV: 100 microns x 100 microns ○ Co-boresighted to spectrometer • Spectrometer ○ Adjustable optical focus (depth of field ±12.5 mm) ○ Rastered mapping of area co-registered with OM ○ Raman shift: 150–3800 cm^{-1} ▪ Sufficient range for minerals and organics ○ Resolution: ~6 cm^{-1}	• Context imager: ○ WATSON on Mars 2020 • Spectrometer: ○ SHERLOC on Mars 2020 ○ MicrOmega on the ExoMars 2020 rover
Organic Compositional Analyzer (OCA)	• Gas Chromatograph Mass Spectrometer (GC-MS) with both chirality analysis and Stable Isotope Analyzer (SIA)	• Quadrupole mass spectrometer (QMS) ○ Electron ionization source ○ Mass-to-charge (m/z) range: 2–550 Da ○ Mass resolution: Δm ≤1 Da across m/z range ○ Abundance sensitivity: >10^6 ○ LOD (for organics): 1 pmol g^{-1} • Sample oven max temperature: ≥600°C • Stable Isotope Analyzer (SIA): ○ LOD (for C1 compound at 1 pmol g^{-1}): 10 fmol g^{-1}	• QMS and GC from the Sample Analysis at Mars (SAM) suite on MSL
Geophysical Sounding System (GSS)	• Broad-band seismometer	• Frequency range: 0.1 to >100 Hz • 3-axis arrival information	• SP seismometer from SEIS on InSight

Instrument Class	Threshold Model Payload		
	Model Instrument	Characteristics	Similar Instruments*
Context Remote Sensing Instrument (CSRI)	• Two identical RGB, fixed focus, stereo overlapping cameras	• RGB Bayer pattern CMOS detectors • 14.7-mm fixed focal length, f/12 lenses with 45° x 45° FOV • Camera heads: ○ Mounted on the HGA, ≥1 m above the local europan surface ○ Spaced ≥20 cm apart with 2.5° toe-in • Camera resolution: ○ Minimum of 500 microns per pixel at distance of 2 m or more	• Navcam on MSL • EECAM for Mars 2020
Microscope for Life Detection (MLD)	• Atomic Force Microscope (AFM) with optical context imager	• Optical context imager: ○ Fixed focus with 6x magnification ○ FOV: 2 mm x 1 mm • Atomic Force Microscope ○ Scan area: 65 microns x 65 microns ○ Resolution (x, y, z): 50 nm	• OM-AFM of the Phoenix Mars Lander MECA system • Aspects of the MIDAS-AFM on Rosetta
Vibrational Spectrometer (VS)	• Raman Laser Spectrometer (RLS)	• Raman infrared point spectrometer ○ Adjustable optical focus (depth of field: ±1 mm) ○ Raman shift: 150–3800 cm^{-1} ▪ Sufficient range for minerals and organics ○ Resolution: ~6 cm^{-1}	• RLS on the ESA ExoMars 2020 rover • VNIR+SWIR for SuperCam on Mars 2020
Organic Compositional Analyzer (OCA)	• Gas Chromatograph Mass Spectrometer (GC-MS) with chirality analysis	• Quadrupole mass spectrometer (QMS) ○ Electron ionization source ○ Mass-to-charge (m/z) range: 2–550 Da ○ Mass resolution: Δm ≤1 Da across m/z range ○ Abundance sensitivity: >10^6 ○ LOD (for organics): 1 pmol g^{-1} • Sample oven max temperature: ≥600°C	• QMS and GC from the Sample Analysis at Mars (SAM) suite on MSL
Geophysical Sounding System (GSS)	• 3-axis geophone	• Frequency range: 0.1–100 Hz • 3-axis arrival information	• SISMO seismometer from the OPTIMISM instrument on the Russian Mars 96 spacecraft

Chirality and Life's little twist

- Life's Legos consist of almost exclusively one enantiomer (i.e. one hand)
  - Earth: L-amino acids and D-sugars
- Abiotic processes produce racemic mixtures*
- Enantiomeric excess may be a 'universal principle' for building carbon-based life.





*Pure circularly polarized light can yield enantiomeric excess

Meteoritic Abiotic Benchmarks

- How much of an enantiomeric excess do we need to implicate biological processes?

~18% EE detected in some amino acids in Murchison meteorite – an 'abiotic benchmark'.

SDT set an EE 'biogenic' threshold of 20%.

Measurement Requirement:
Quantify Enantiomeric Excess (chirality) to an accuracy of <5%

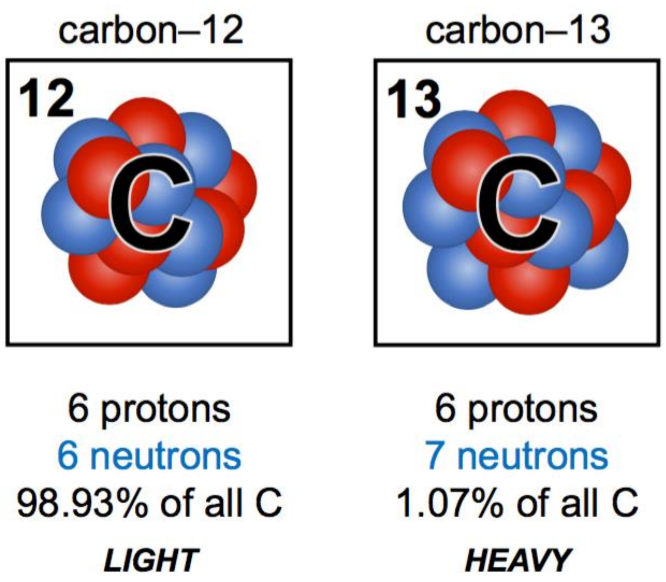
TABLE 7.1 Enantiomeric Enrichments for Amino Acids in the Murchison and Murray Meteorites

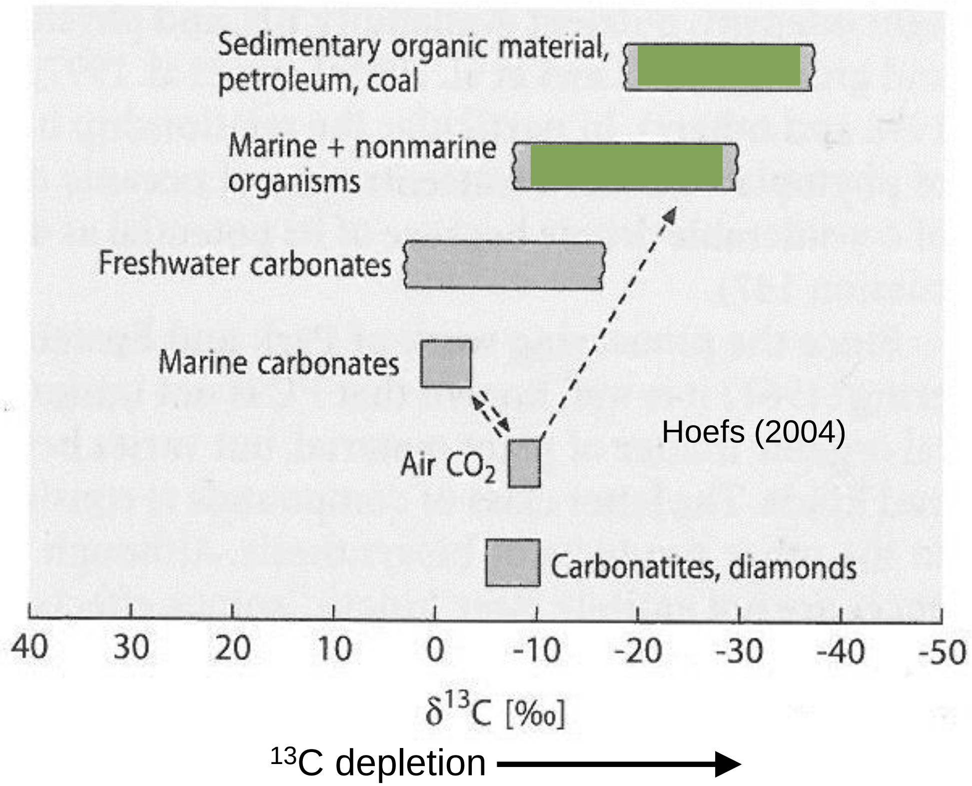
Compound	On Earth[a]	Enantiomeric Enrichment (%)	
		Murchison	Murray
2-Amino-2,3-dimethyl-pentanoic acid			
2S,3S/2R,3R	Unknown	7.6	1.0
2S,3S/2R,3S	Unknown	9.2	2.2
α-Methylnorleucine	Unknown	4.4	1.8
α-Methylnorvaline	Unknown	2.8	1.4
α-Methylvaline	Unknown	2.8	1.0
Isovaline	Rare	8.4	6.0
Norvaline	Rare	0.4	0.8
α-amino-n-butyric acid	Common	0.4	−0.4
Valine	Ubiquitous	2.2	−0.4
Alanine	Ubiquitous	1.2	0.4

[a]Natural abundance of the amino acid in Earth's biosphere.
SOURCE: Data from Pizzarello, S., and Cronin, J.R. 2000. Non-racemic amino acids in the Murray and Murchison meteorites. *Geochim. Cosmochim. Acta* 64:329-338.

Carbon isotopes indicate 'Life is Enlightened'

- Biological processes preferentially exclude carbon's stable heavy (^{13}C) isotope.
- Radiation processing preferentially sputters and releases ^{12}C.
- Not definitive, but an important contextual measurement for understanding carbon reservoirs on any world.





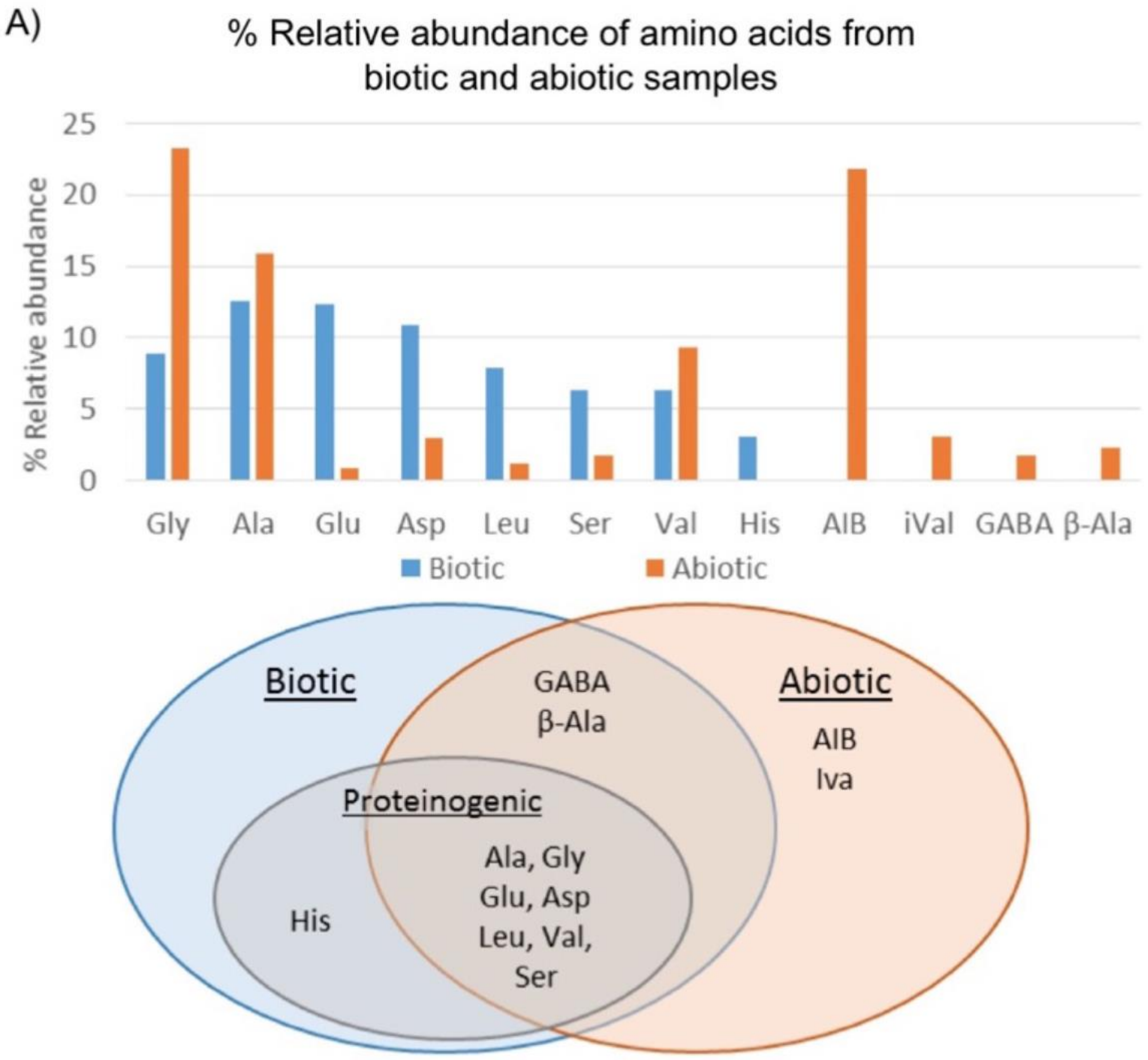
Organic Detection & Characterization: Amino acids

Amino Acid Relative Abundance

Abundances of the 12 amino acids found in highest abundance in biotic (*E. coli*) and abiotic (meteoritic) samples:

Eight chiral amino acids:
Ala, Asp, Glu, Ser, Val, Leu, His, Iva

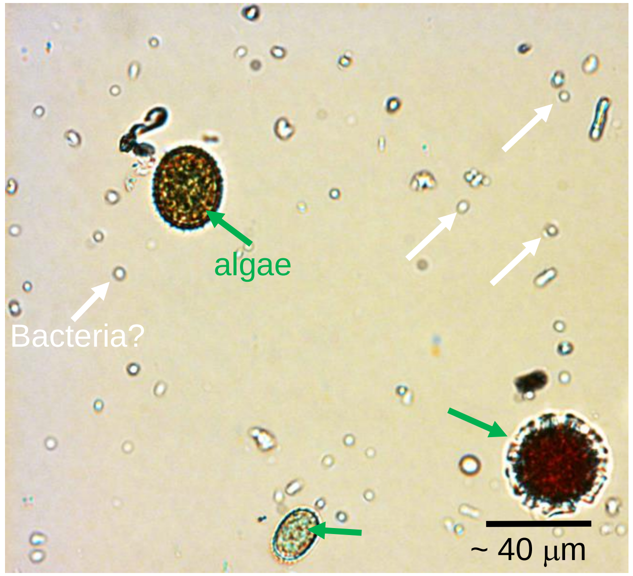
Four achiral amino acids:
Gly, β-Ala, GABA, and AIB



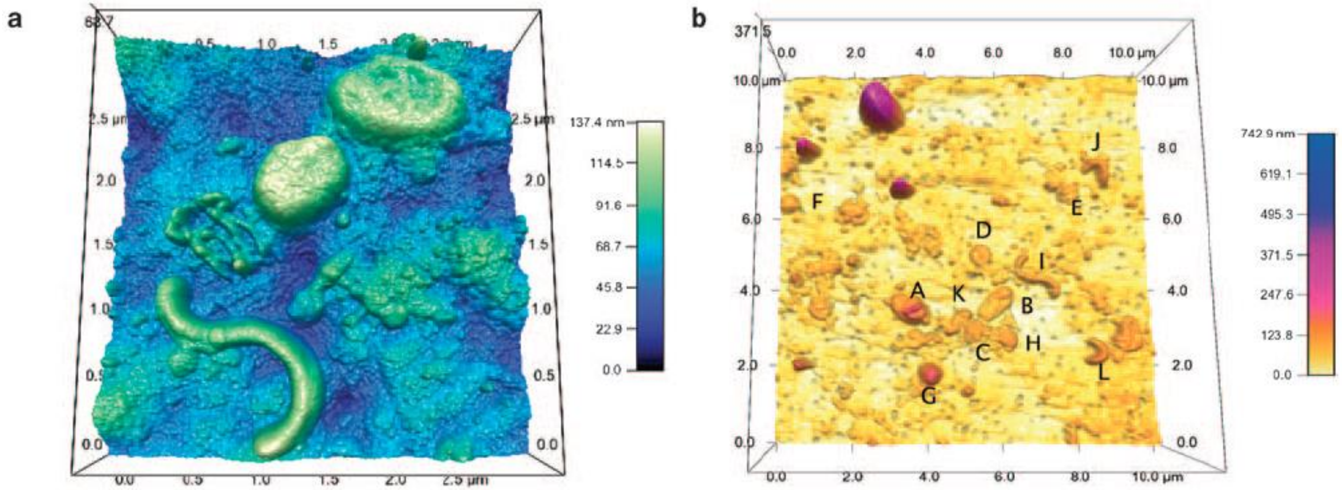
Creamer et al., (2017)

Microscopic Capabilities

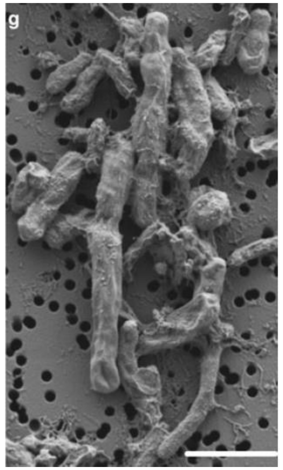
Light Microscopy (400X mag):
Snow microbiota



Atomic force microscopy: Marine bacteria



Scanning electron microscopy:
Glacial ice bacteria



Fluorescence microscopy:
Antarctic marine bacteria with
DNA-binding stain