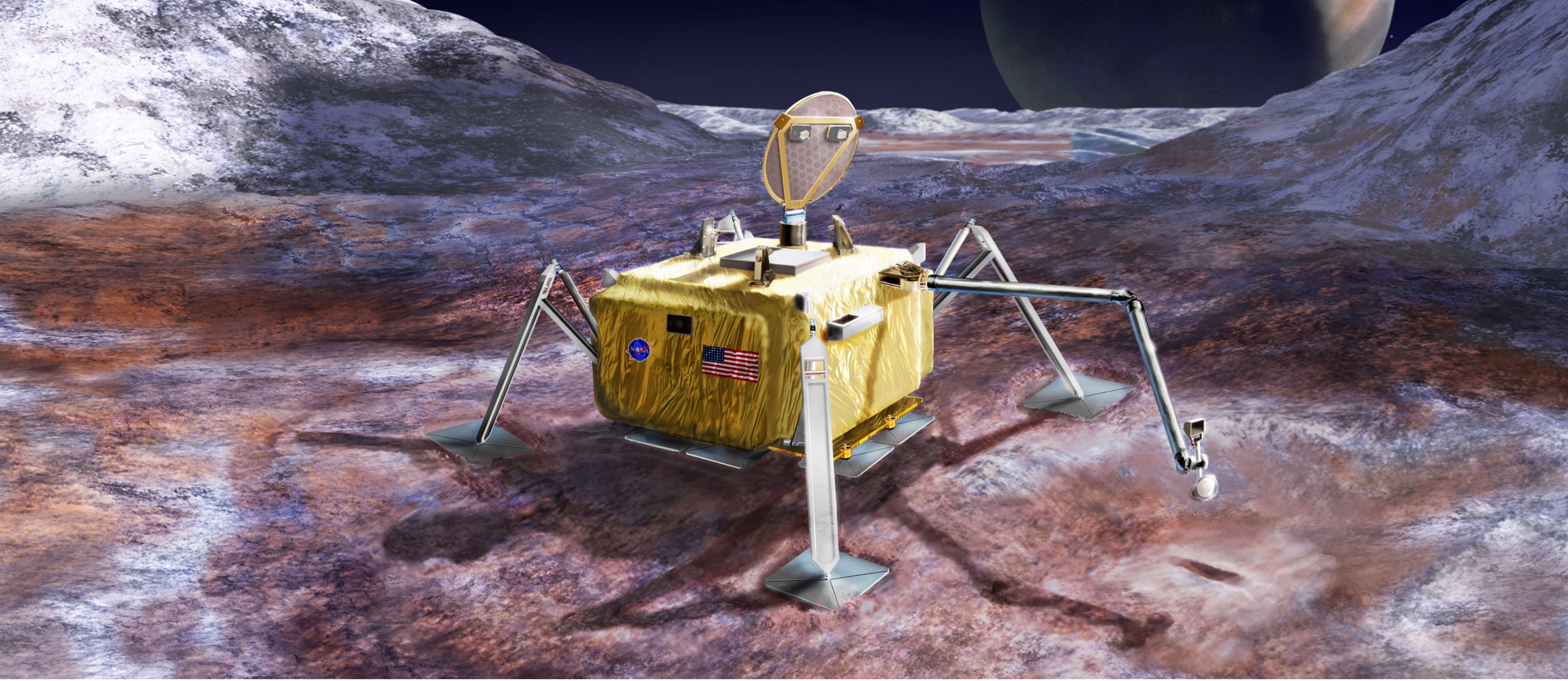
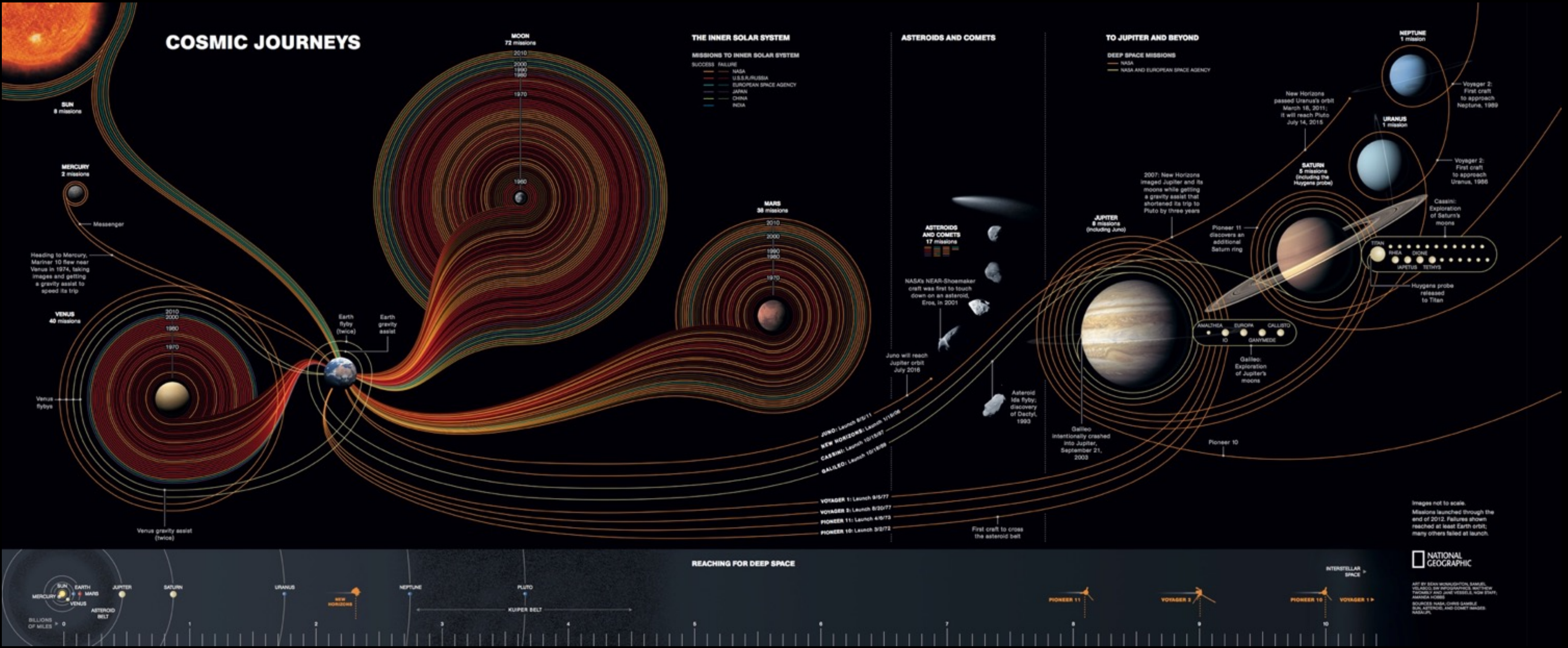


Europa Lander Mission Concept

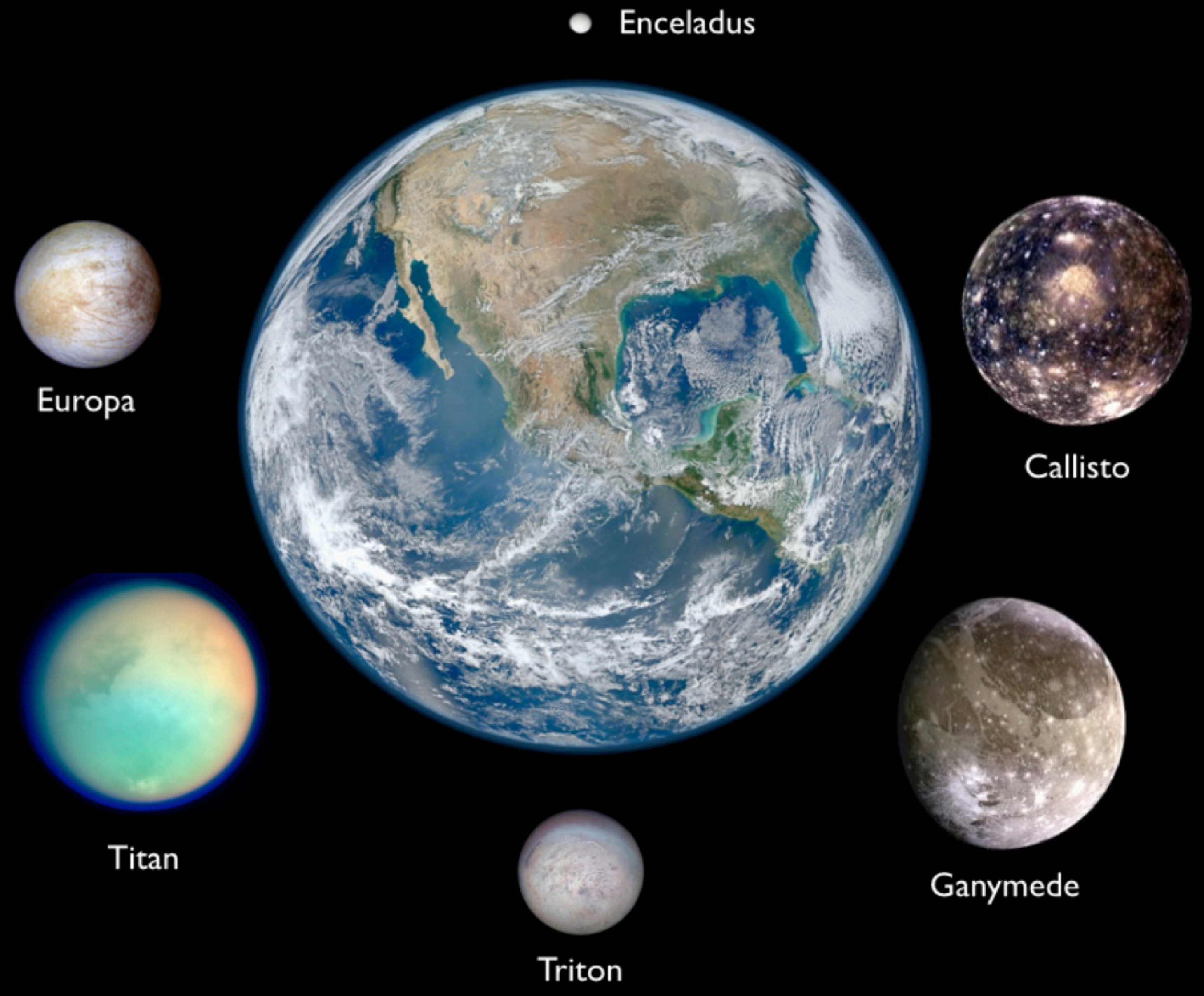
Kevin Peter Hand, JPL
Europa Lander Science Definition Team
Europa Lander Project Engineering Team

January 16, 2018



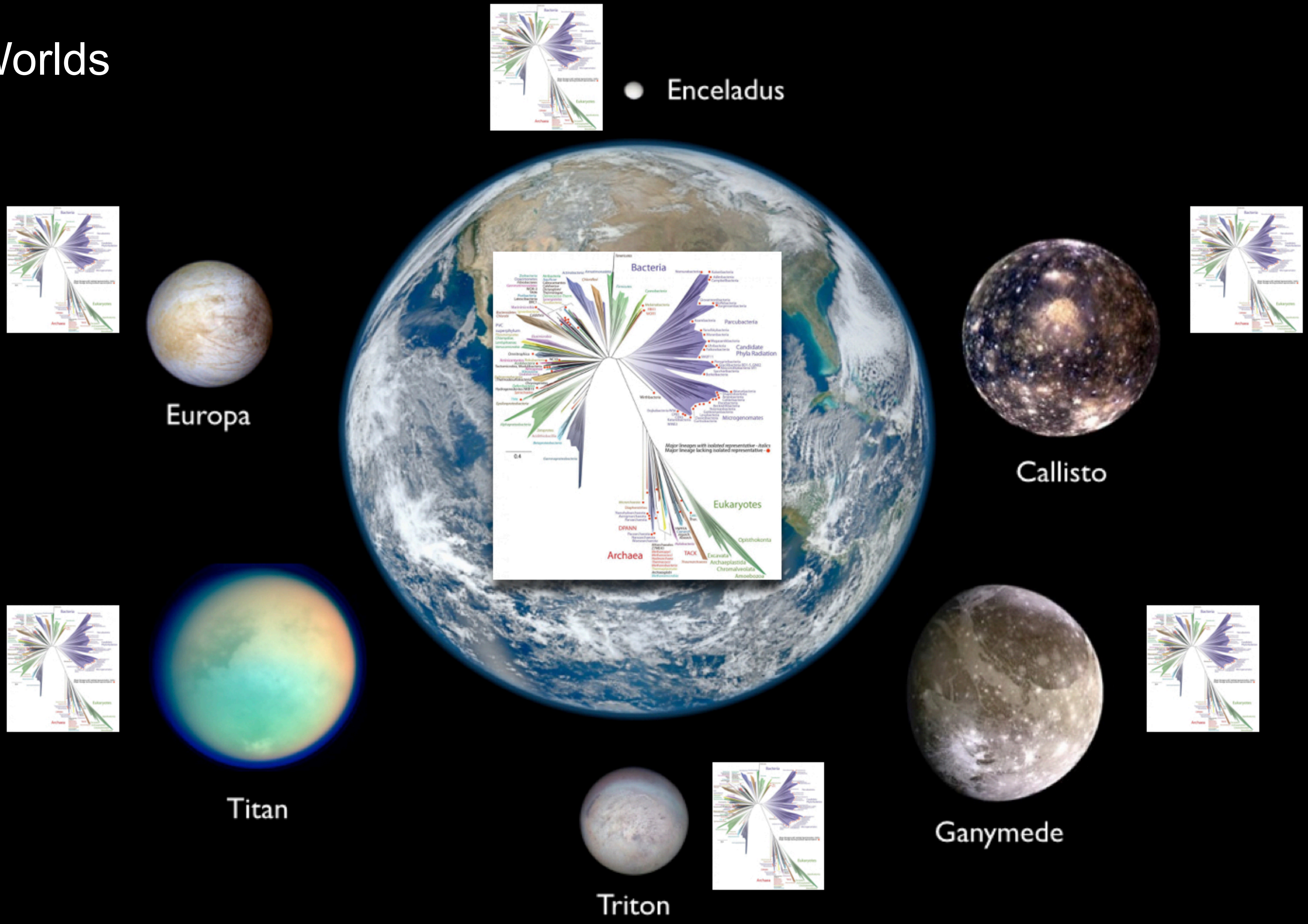
COSMIC JOURNEYS
SUN
8 missions
MERCURY
2 missions
Messenger
Heading to Mercury, Mariner 10 flew near Venus in 1974, taking images and getting a gravity assist to speed its trip
VENUS
40 missions
Venus flybys
Venus gravity assist (twice)
MOON
72 missions
Earth flyby (twice)
Earth gravity assist
MARS
38 missions
THE INNER SOLAR SYSTEM
MISSIONS TO INNER SOLAR SYSTEM
SUCCESS FAILURE
NASA
U.S.S.R./RUSSIA
EUROPEAN SPACE AGENCY
JAPAN
CHINA
INDIA
ASTEROIDS AND COMETS
ASTEROIDS AND COMETS
17 missions
NASA's NEAR-Shoemaker craft was first to touch down on an asteroid, Eros, in 2001
Juno will reach Jupiter orbit July 2016
Asteroid Ida flyby; discovery of Dactyl, 1993
First craft to cross the asteroid belt
JUNO: Launch 8/5/11
NEW HORIZONS: Launch 1/19/06
CASSINI: Launch 10/15/97
GALILEO: Launch 10/18/89
VOYAGER 1: Launch 9/5/77
VOYAGER 2: Launch 8/20/77
PIONEER 11: Launch 4/6/73
PIONEER 10: Launch 3/2/72
TO JUPITER AND BEYOND
DEEP SPACE MISSIONS
NASA
NASA AND EUROPEAN SPACE AGENCY
JUPITER
8 missions
(including Juno)
2007: New Horizons imaged Jupiter and its moons while getting a gravity assist that shortened its trip to Pluto by three years
AMALTHEA
IO
EUROPA
GANYMEDE
CALLISTO
Galileo: Exploration of Jupiter's moons
Galileo intentionally crashed into Jupiter, September 21, 2003
Pioneer 10
SATURN
5 missions
(including the Huygens probe)
Pioneer 11 discovers an additional Saturn ring
Cassini: Exploration of Saturn's moons
TITAN
RHEA
DIONE
IAPETUS
TETHYS
Huygens probe released to Titan
URANUS
1 mission
Voyager 2: First craft to approach Uranus, 1986
NEPTUNE
1 mission
Voyager 2: First craft to approach Neptune, 1989
New Horizons passed Uranus's orbit March 18, 2011; it will reach Pluto July 14, 2015
Images not to scale.
Missions launched through the end of 2012. Failures shown reached at least Earth orbit; many others failed at launch.
REACHING FOR DEEP SPACE
SUN
MERCURY
VENUS
EARTH
MARS
ASTEROID BELT
JUPITER
SATURN
URANUS
NEW HORIZONS
NEPTUNE
PLUTO
KUIPER BELT
PIONEER 11
VOYAGER 2
PIONEER 10
VOYAGER 1
INTERSTELLAR SPACE
BILLIONS OF MILES
0
1
2
3
4
5
6
7
8
9
10
NATIONAL GEOGRAPHIC

Ocean Worlds



Shown to scale

Ocean Worlds

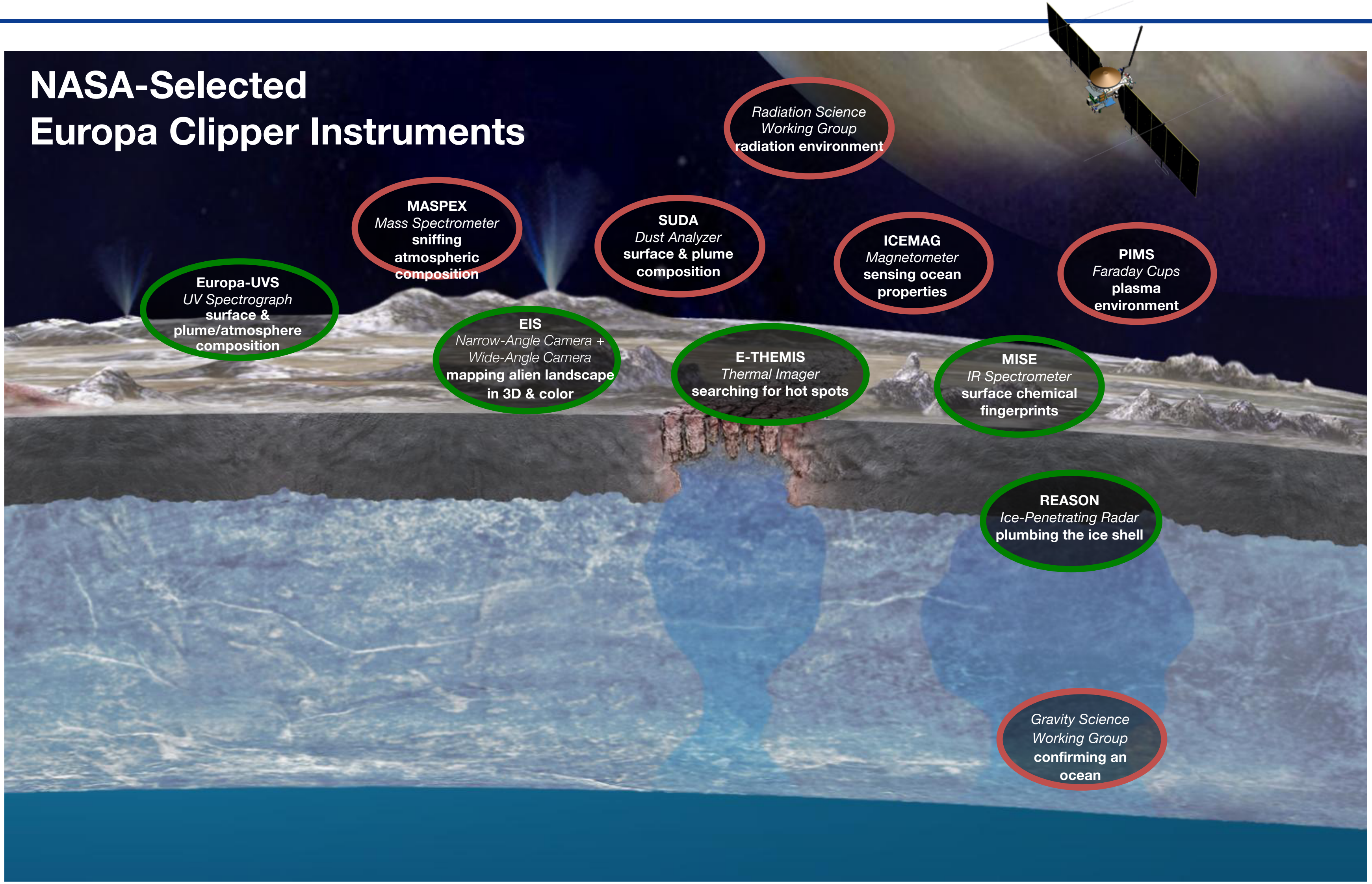


Shown to scale

Does *biology* work beyond Earth?

Europa Clipper Mission Science Overview

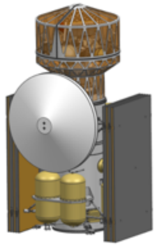
Mission Goal:
Explore Europa to investigate its habitability

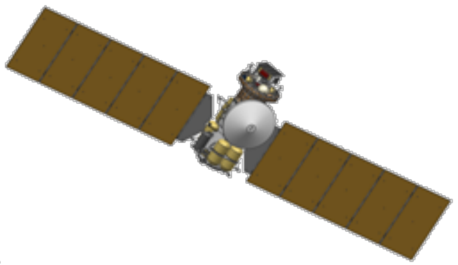


Slide removed

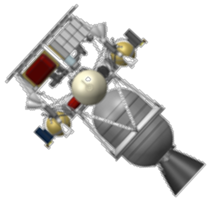
Video removed

Europa Lander Mission Concept

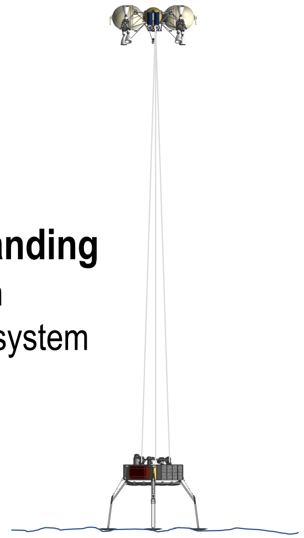


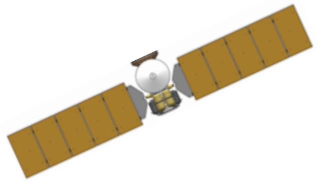


Cruise/Jovian Tour
- Jupiter orbit insertion Apr 2030
- Earliest landing on Europa: Dec 2031

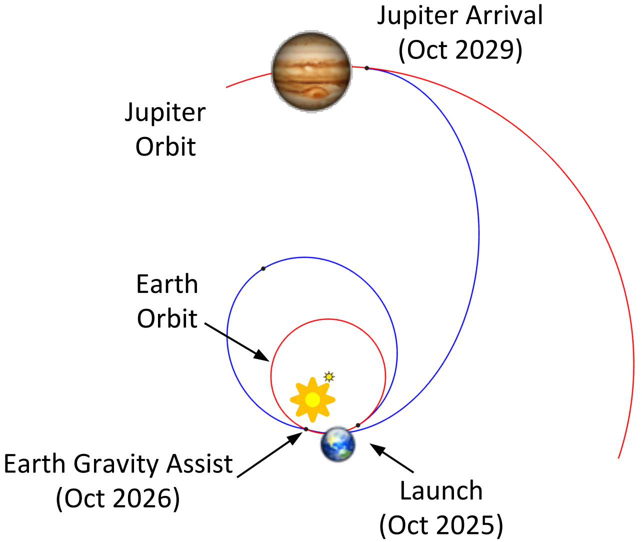


Deorbit, Decent, Landing
- Guided deorbit burn
- Sky Crane landing system
- 100-m accuracy



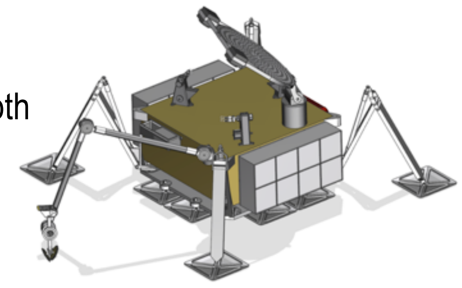


Carrier Relay Orbit
- 24 hour period
- >10 hours continuous coverage per orbit
- 2.0 Mrad radiation exposure



Launch
- SLS Block 1B
- Oct. 2025 earliest

Surface Mission
- 20+ days
- 42.5 kg payload allocation
- 5 samples, 7 cc each, >=10 cm depth
- Relay comm through Carrier or Clipper (backup)
- 3–4 Gbit data return
- 45 kWh battery
- 1.5 Mrad radiation exposure



Science Definition Team

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

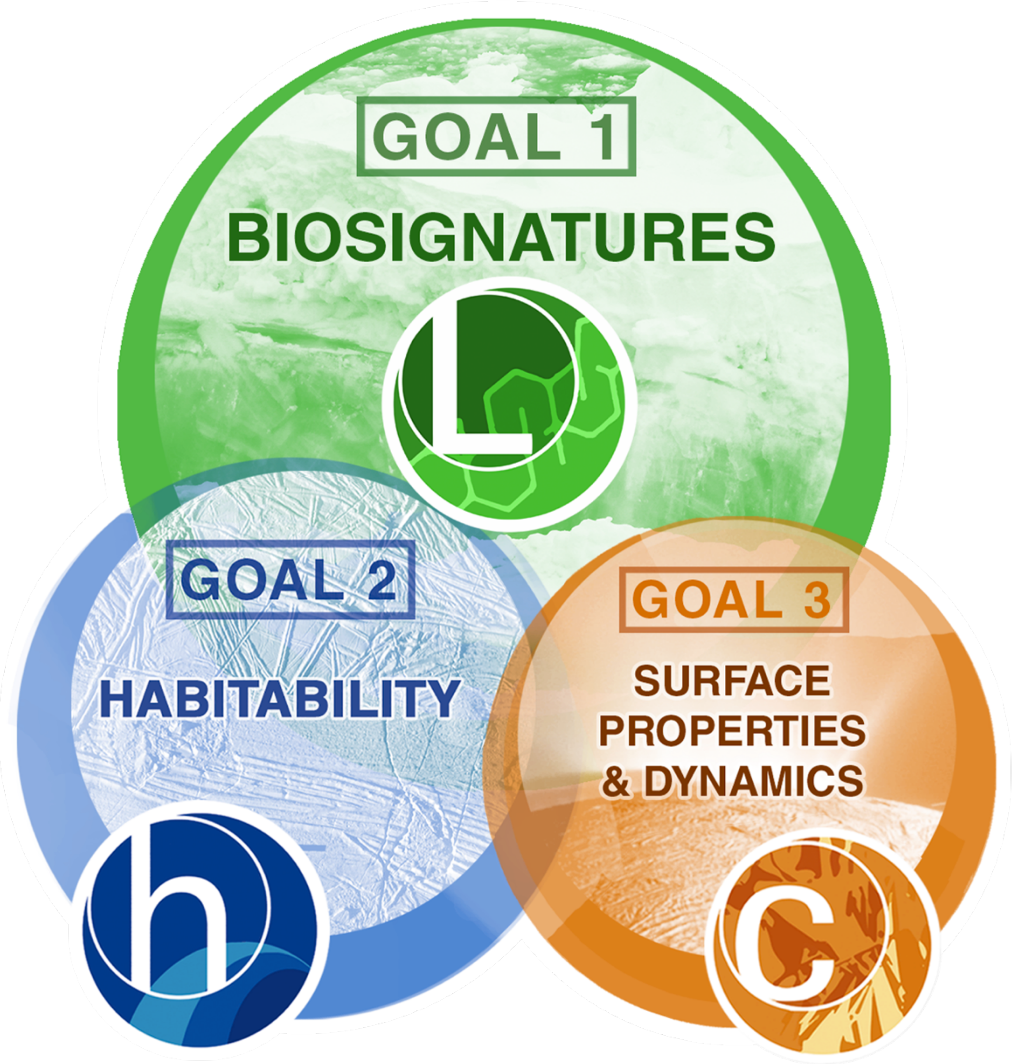
- Ken Edgett, MSSS
- Bethany Ehlmann, Caltech
- Jonathan Lunine, Cornell
- Alyssa Rhoden, ASU
- Will Brinkerhoff, GSFC
- Alexis Templeton, CU Boulder
- Michael Russell, JPL
- Tori Hoehler, NASA Ames
- Ken Nealson, USC
- Sarah Horst, JHU
- Peter Willis, JPL
- Alex Hayes, Cornell
- Brent Christner, Univ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

Planetary scientists, Microbiologists, Geochemists

Presentations to, and Feedback from, the Scientific Community, Review Boards, & HQ

- Town Hall #1: Lunar & Planetary Sciences Conference, February 2017.
  - Approximately 6 hours of presentations and Q&A with HQ assembled committee and LPSC attendees (and open to public).
- Town Hall #2: Astrobiology Science Conference, March 2017.
  - Approximately 6 hours of presentations and Q&A with HQ assembled committee and AbSciCon attendees (and open to public)
  - 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.
  - Update briefing Summer 2017
- Committee on Astrobiology & Planetary Sciences (NRC CAPS)
  - Progress report presentation, Fall 2016.
  - Full report out-brief March, 2017.
- Seven presentations, total of >16 hours of briefing and Q&A.
- Town Hall Executive Committee feedback addressed through response letter to NASA.
- **Mission Concept Review, June 19-22nd, 2017. Chair: Prof. B. Braun.**
- Post-MCR direction from HQ (7/28/2017) addressed through external board assembled by Braun.
- Report out to HQ by Braun was provided Oct. 2017.
- Direction letter from HQ received (12/7/2017).

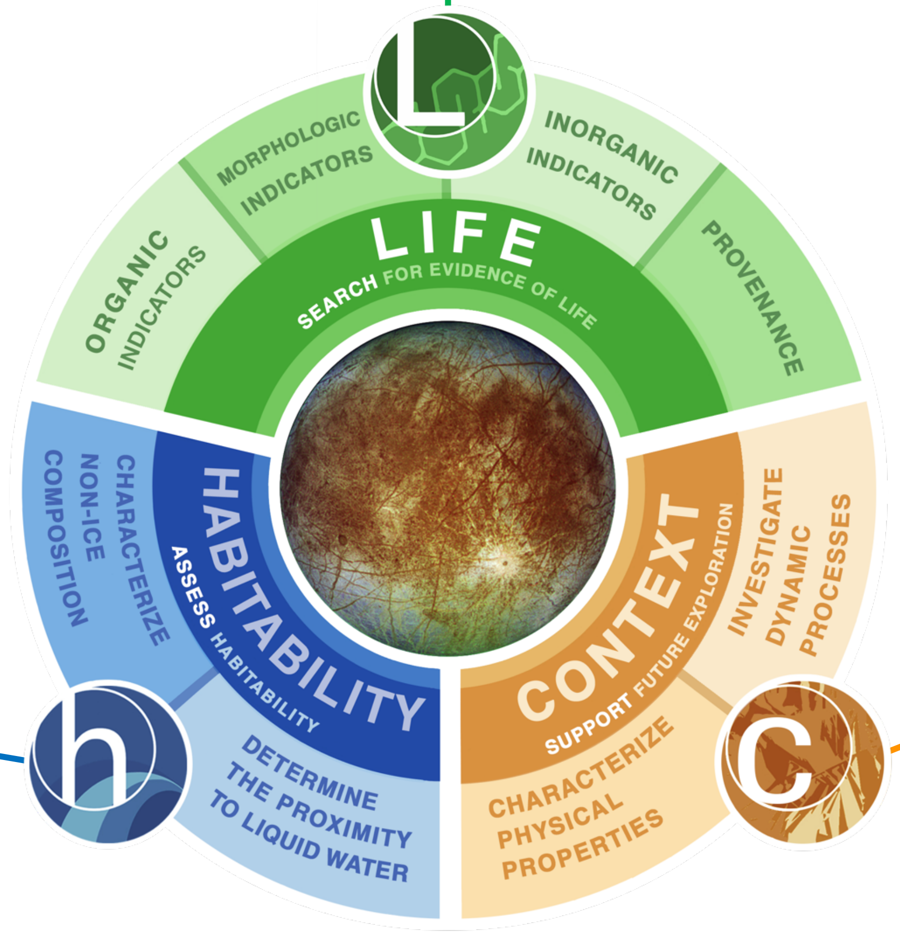
Europa Lander Goals:
A Robust Approach to Searching for Signs of Life



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

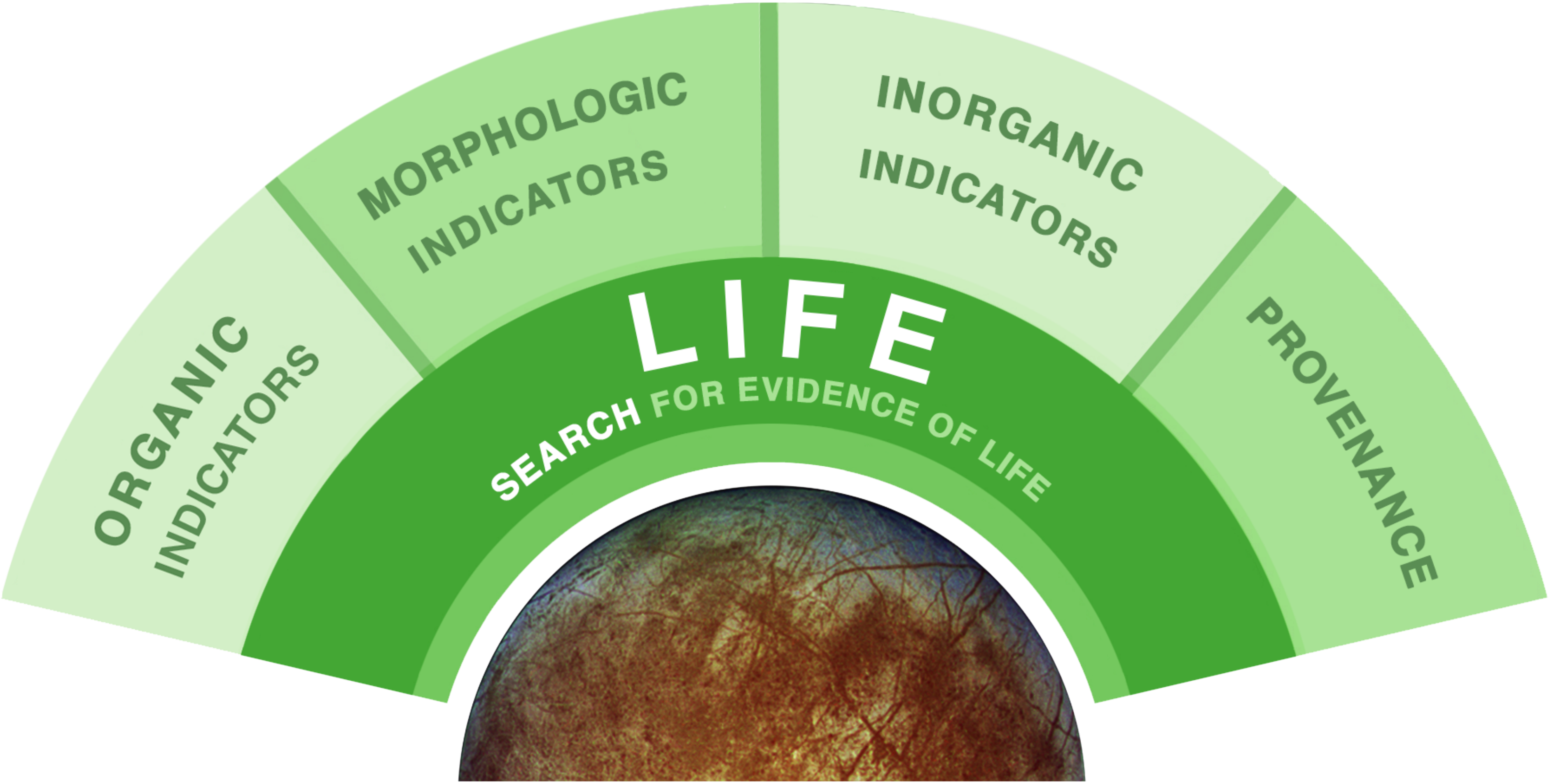
GC-MS | Microscope | Raman spectrometer | Context cameras

Raman spectrometer
GC-MS
Context cameras
Geophone



Raman spectrometer
Microscope
GC-MS
Context cameras
Geophone

Goal 1: Search for Evidence of Life



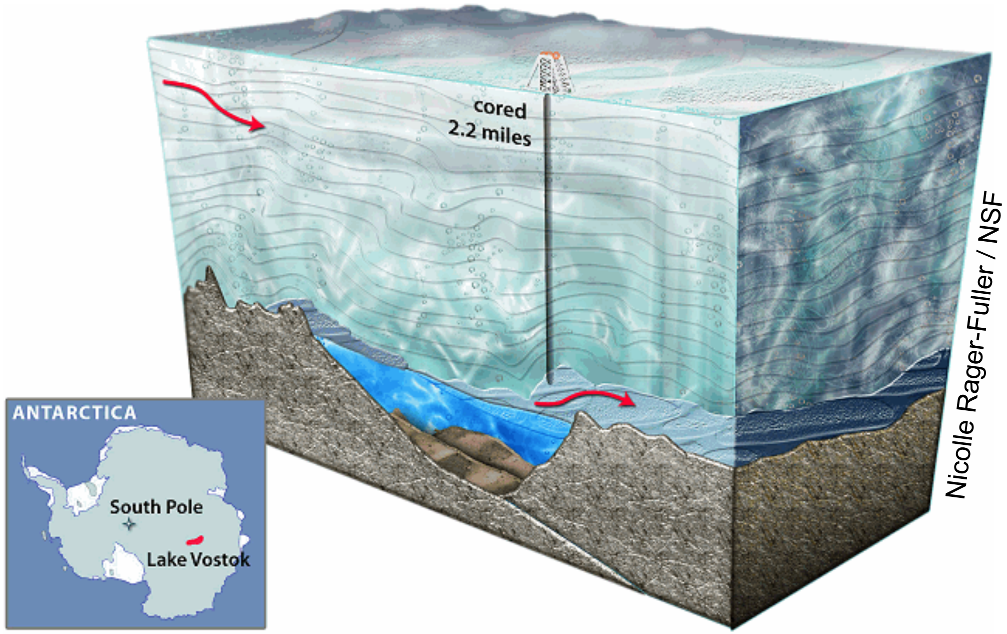
Benchmark environments for Biosignatures

What biosignatures exist?

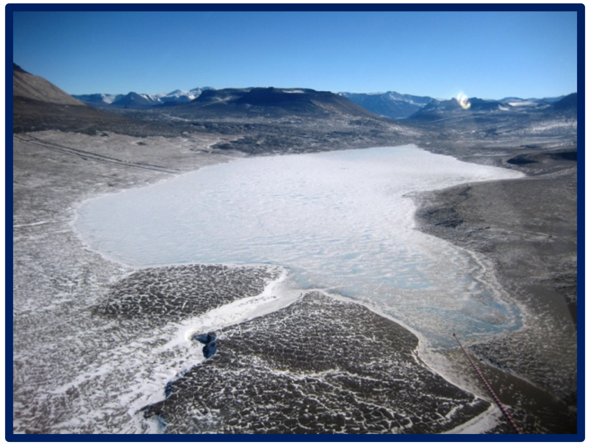
What limits are needed for detecting signs of life?

Signs of life

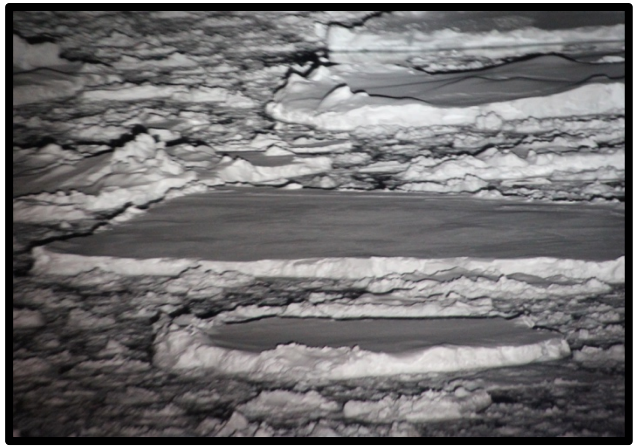
- Chemical indicators
  - Organic abundance
  - Organic composition
- Physical indicators
  - Size and shape
  - Abundance
  - Properties



Nicolle Rager-Fuller / NSF



H Dugan/UIC

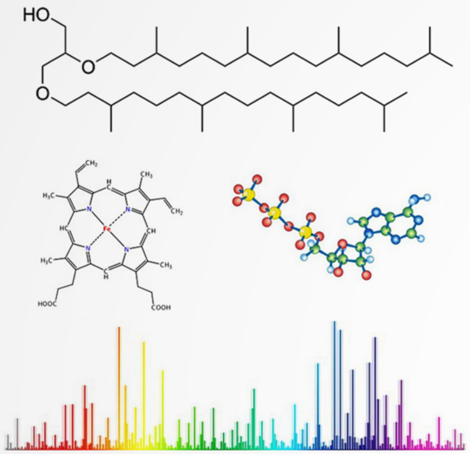


AE Murray /DRI

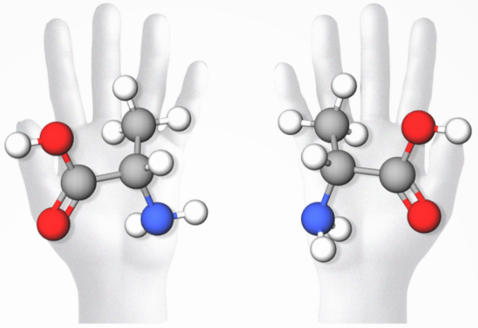
Detection Limits & Measurement Requirements: Earth Environments as a Benchmark for Life Detection

	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**

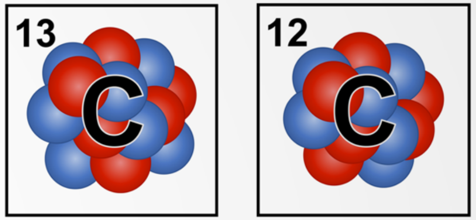
GOAL 1 ORGANIC INDICATORS



ORGANIC DETECTION, CHARACTERIZATION, COMPOSITION



ENANTIOMERIC EXCESS



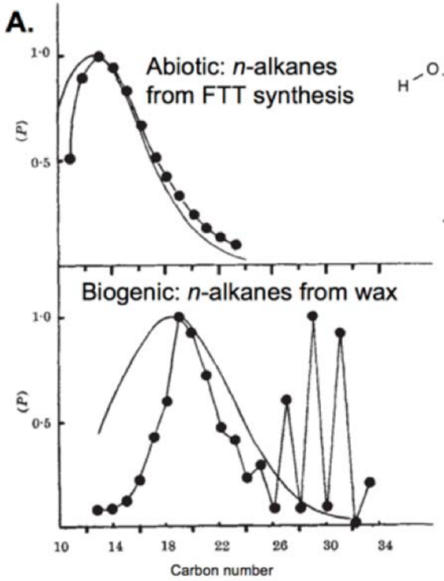
carbon–13	carbon–12
6 protons	6 protons
7 neutrons	6 neutrons
1.07% of all C	98.93% of all C
HEAVY	*LIGHT*

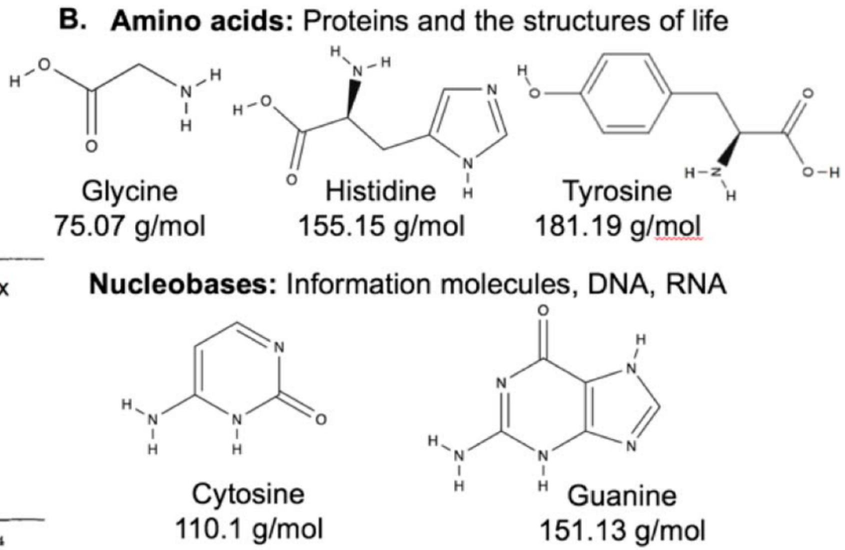
ISOTOPIC INDICATORS

Organic Detection & Characterization

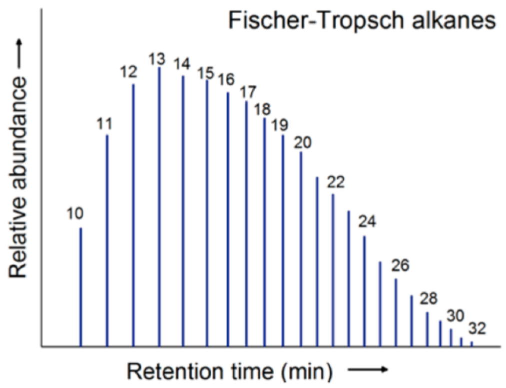
- Determine the presence, identities, and relative abundances of amino acids, carboxylic acids, lipids, and other molecules of potential biological origin (biomolecules and metabolic products) at compound concentrations as low as 1 picomole in a 1 gram sample of europan surface material.

- 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.

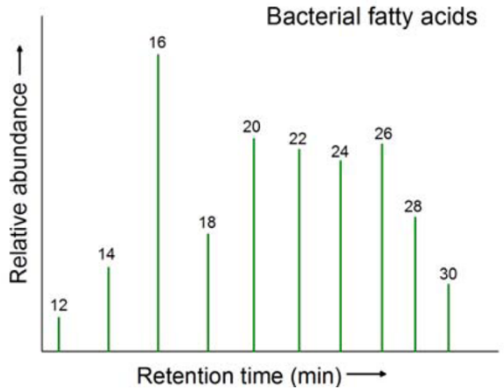




Abiotic organic synthesis
- Low specificity



Biological organic synthesis
- High specificity



Lovelock (1965), 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

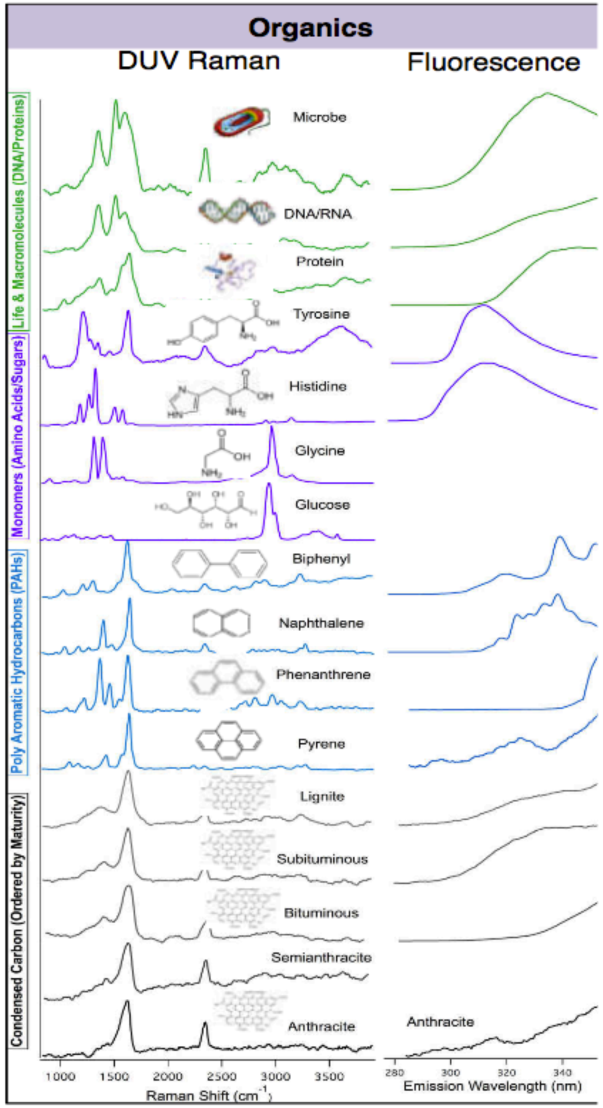
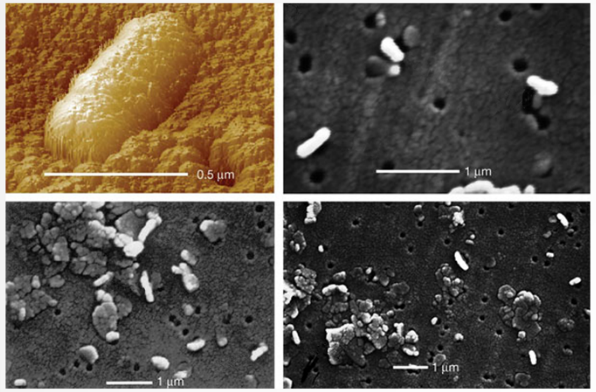


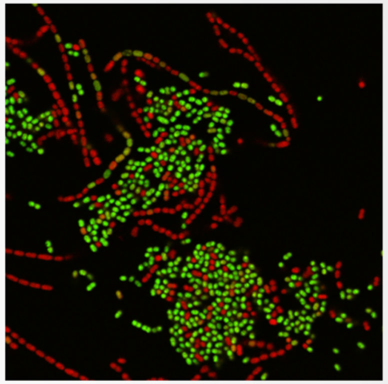
Image courtesy Beegle et al.

GOAL 1 MORPHOLOGIC INDICATORS



MICROSCALE STRUCTURES

MACROSCALE STRUCTURES

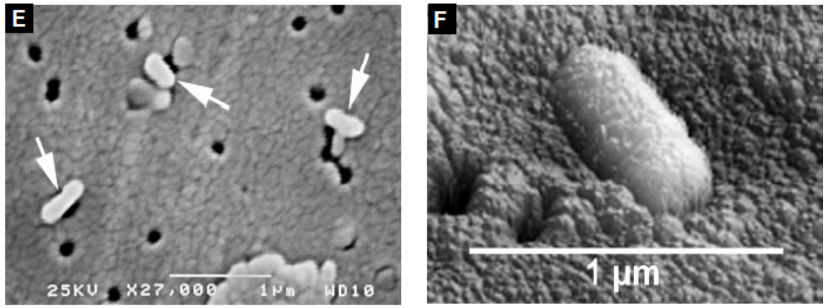


CELLULAR PROPERTIES

Microscale & Macroscale Structures

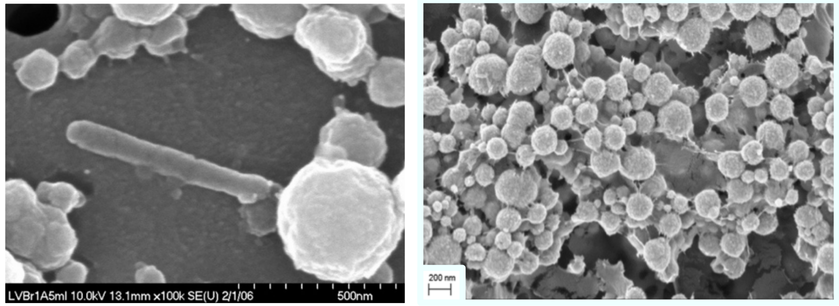
Micro:

Lake Vostok Accretion ice



Priscu et al. 1999, Science.

Lake Vida Brine

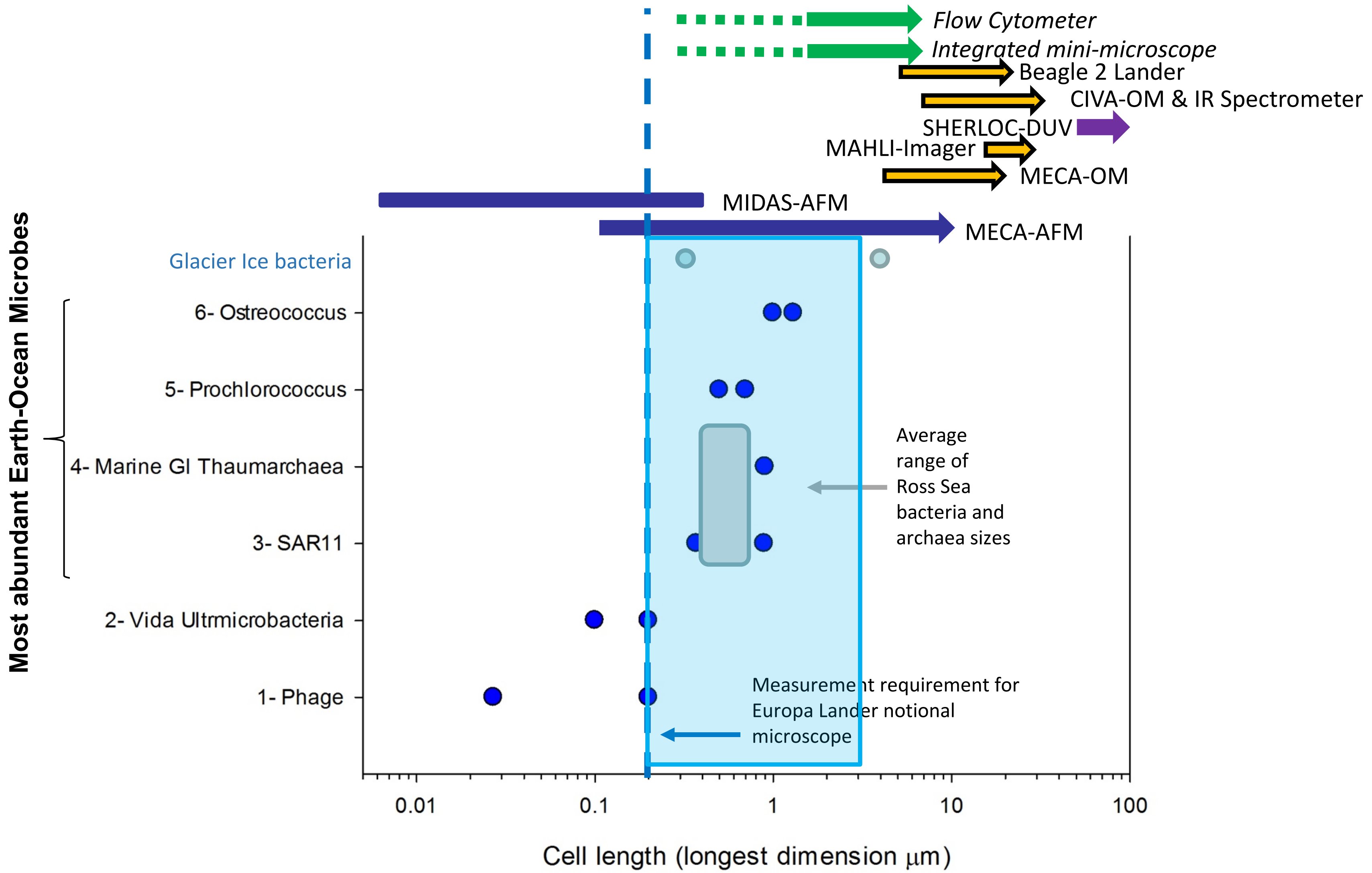


Murray et al. 2012 PNAS.

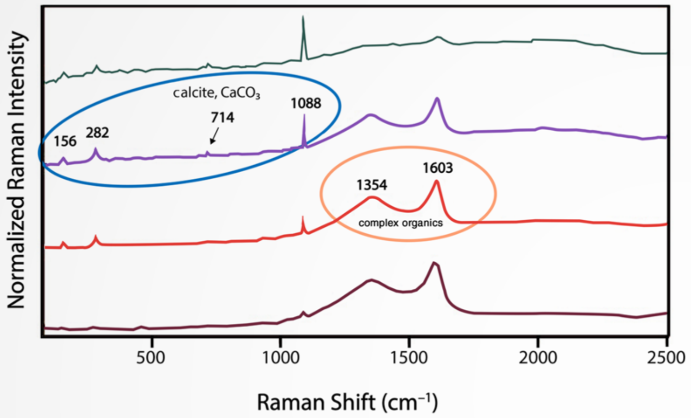
Macro:

- Pigments
- Filamentous aggregations
- Biomineral structures

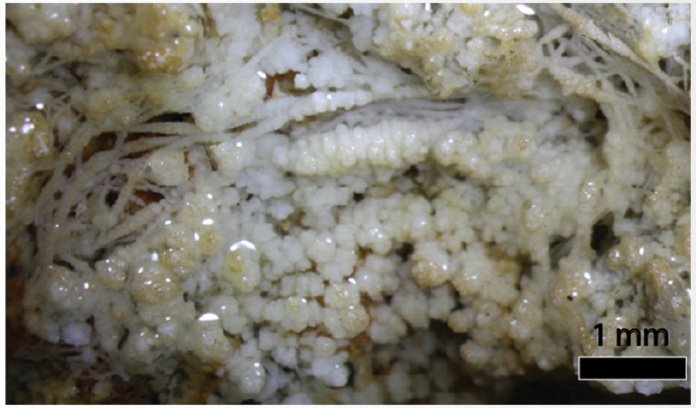
Earth Benchmarks: Size ranges of microbial life



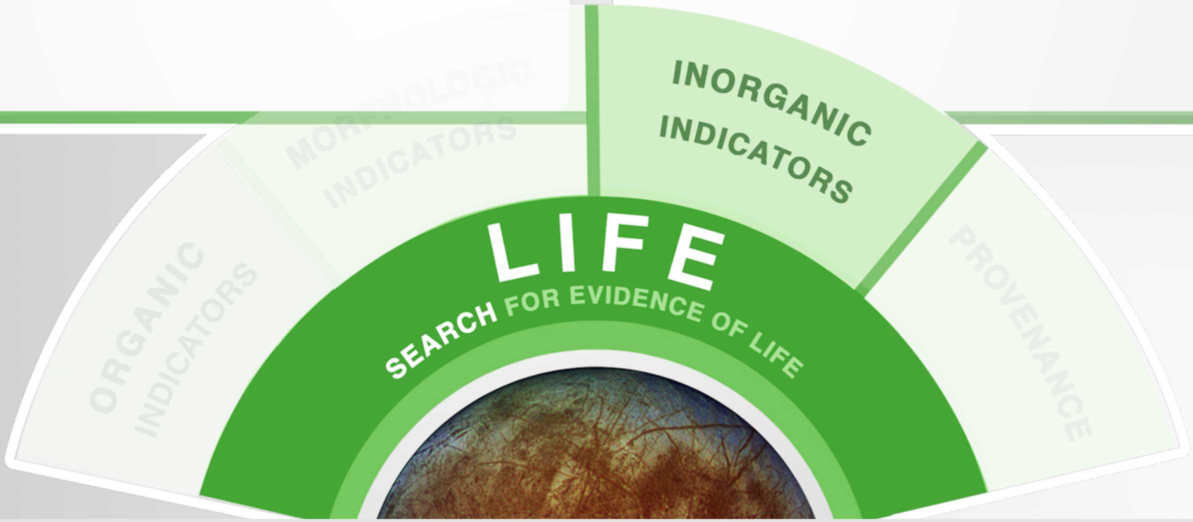
GOAL 1 INORGANIC INDICATORS



INORGANIC COMPOSITION

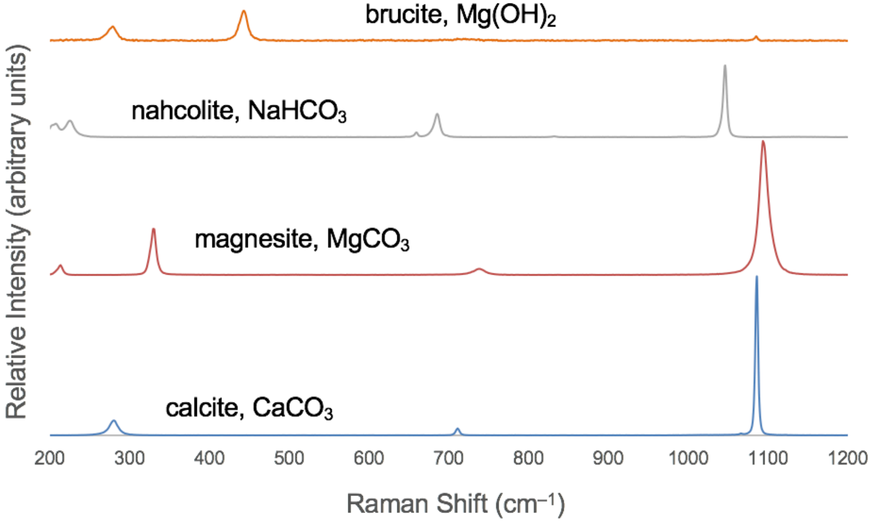


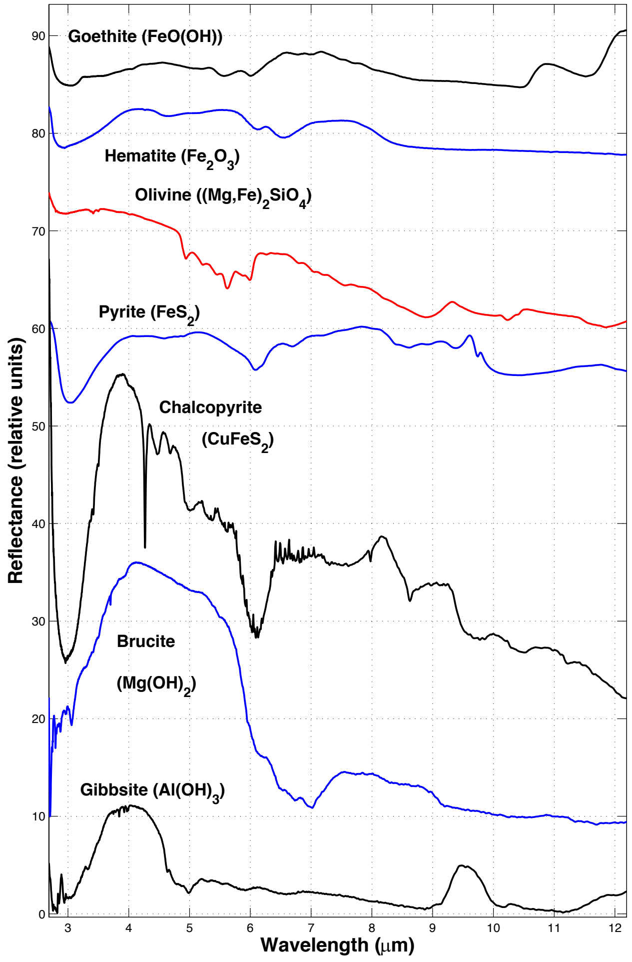
BIOMINERALS



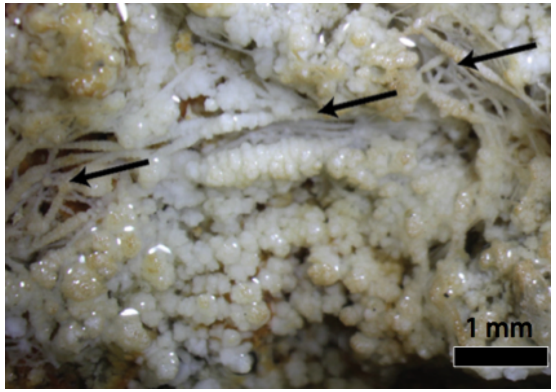
Inorganic Indicators of Life

- 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.



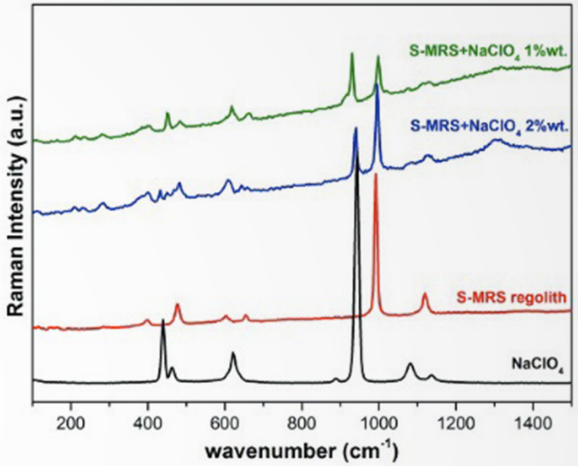


Priscu et al. (1999)



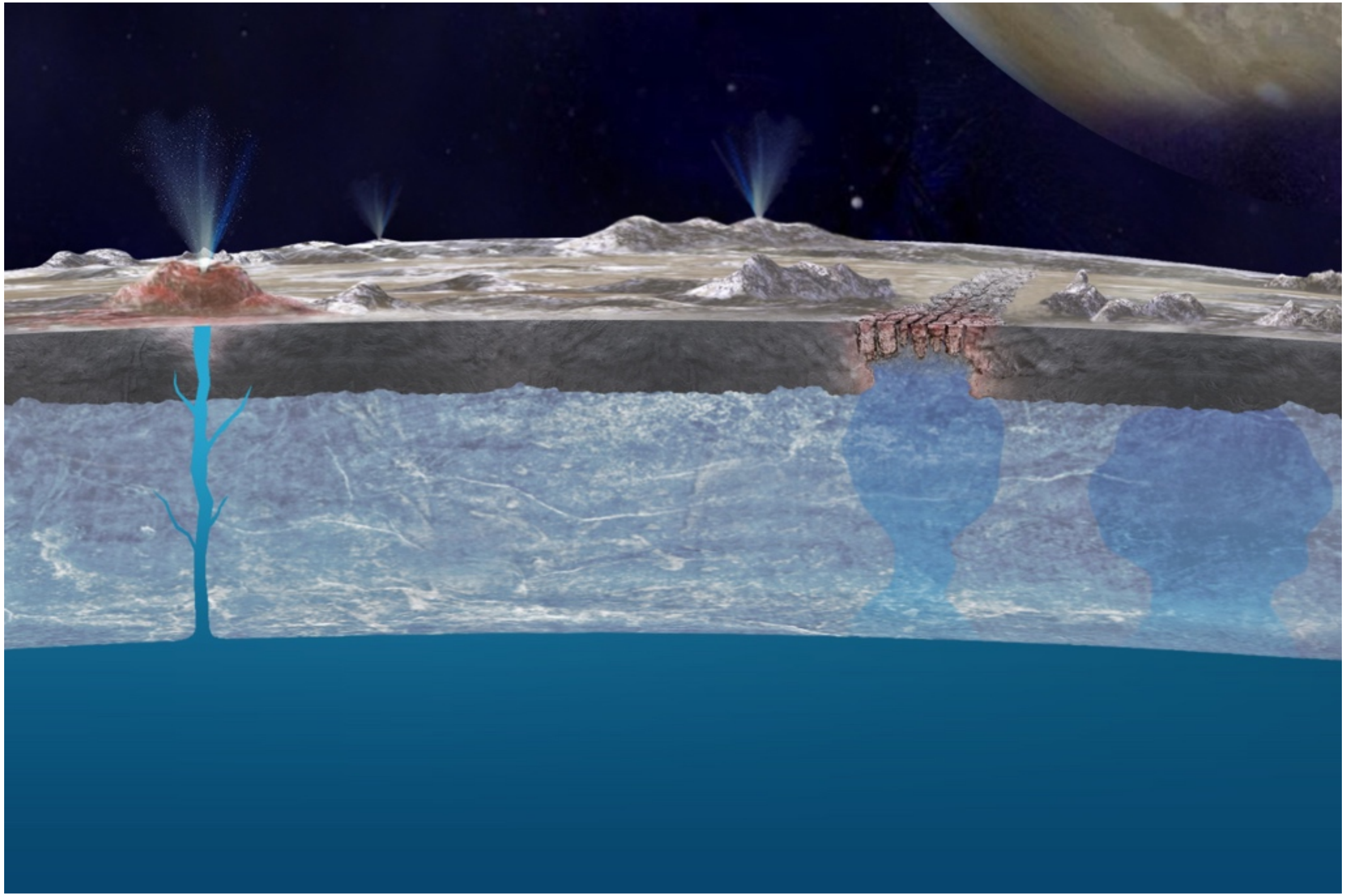
GOAL 1 PROVENANCE

GEOLOGICAL CONTEXT

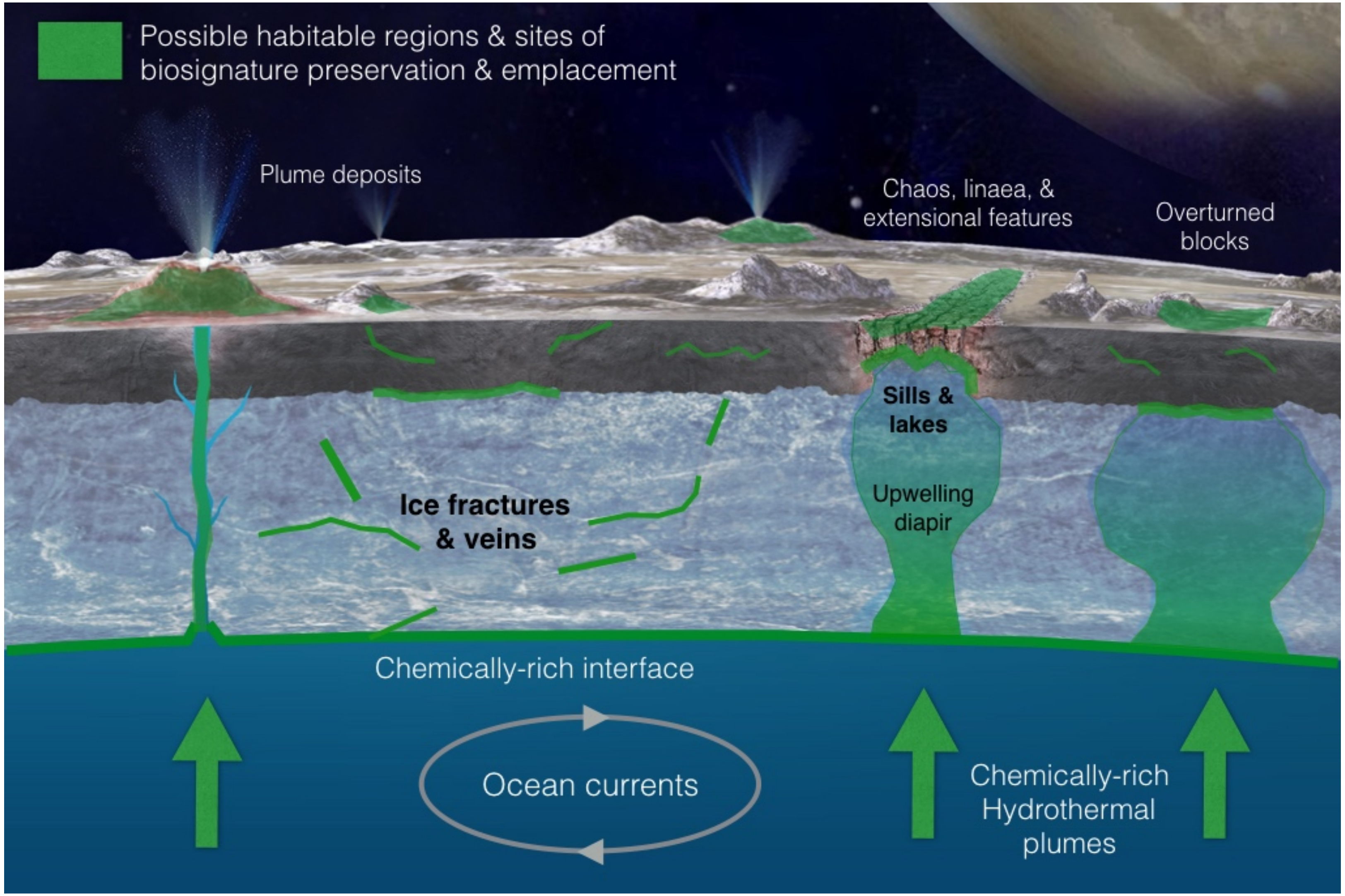


ENDOGENOUS vs. EXOGENOUS ORIGINS AND PROCESSING

Provenance



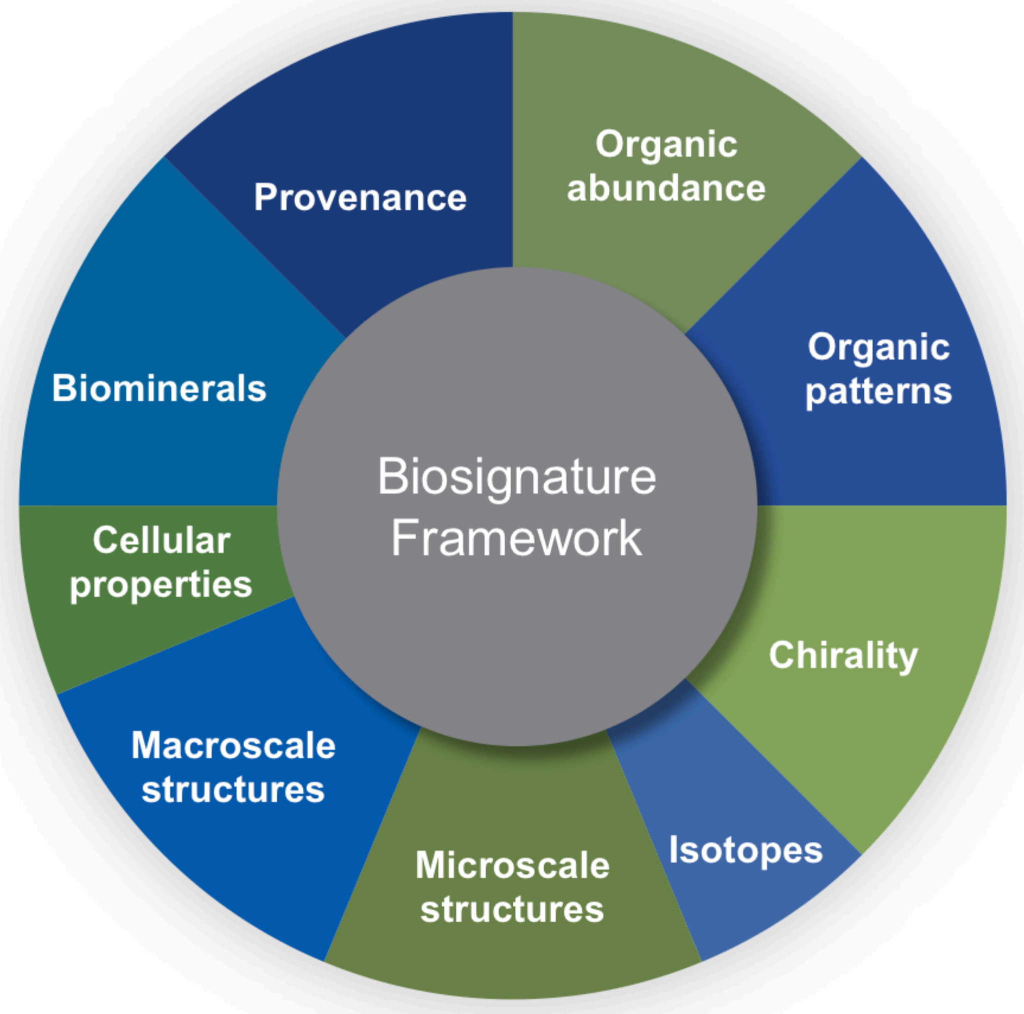
Provenance



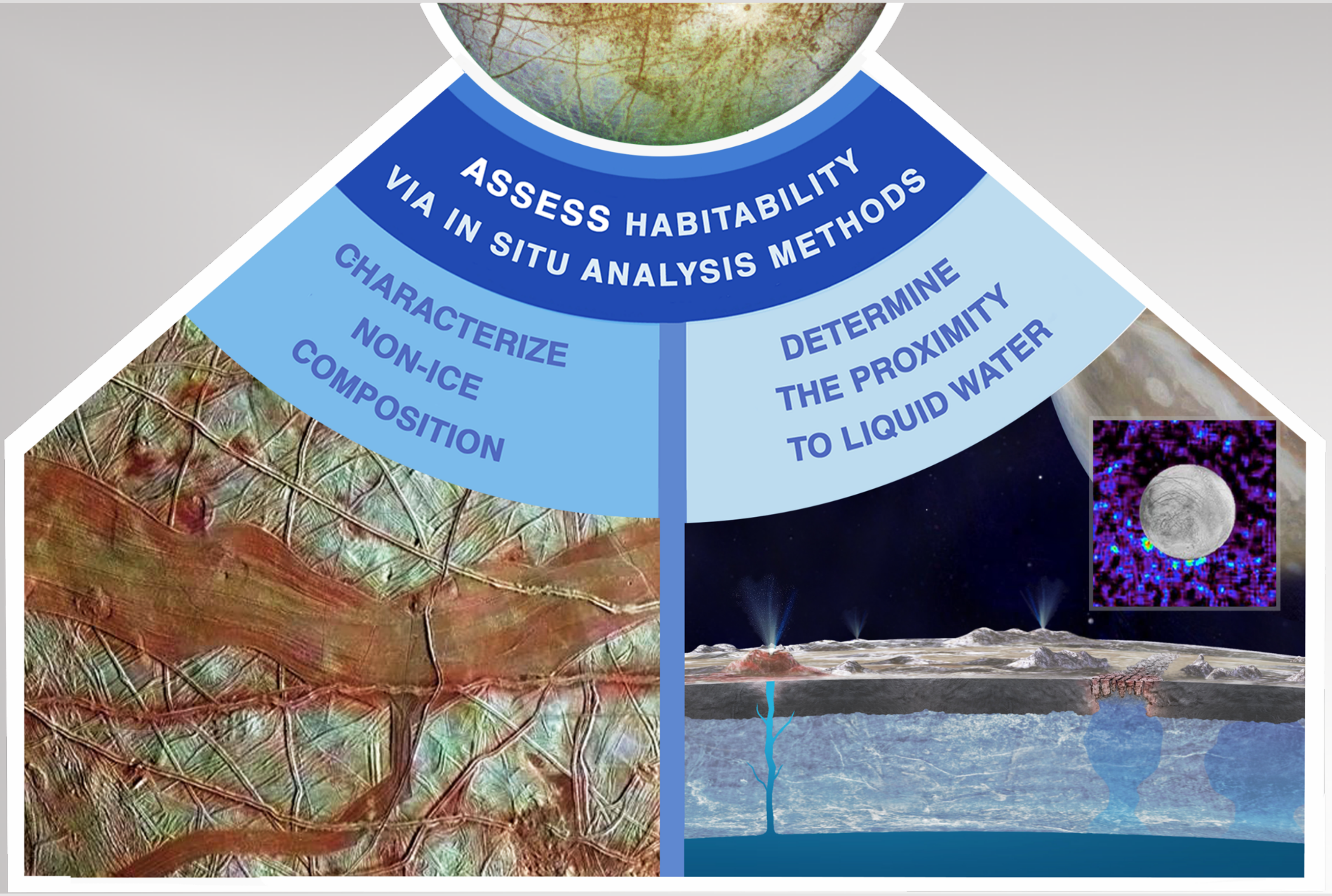
Possible habitable regions & sites of biosignature preservation & emplacement
Plume deposits
Chaos, linaea, &
extensional features
Overturned
blocks
Sills &
lakes
Upwelling
diapir
Ice fractures
& veins
Chemically-rich interface
Ocean currents
Chemically-rich
Hydrothermal
plumes

Lander Provides a Robust Suite of Biosignature 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 yield high value science even in the absence of any potential biosignatures.**

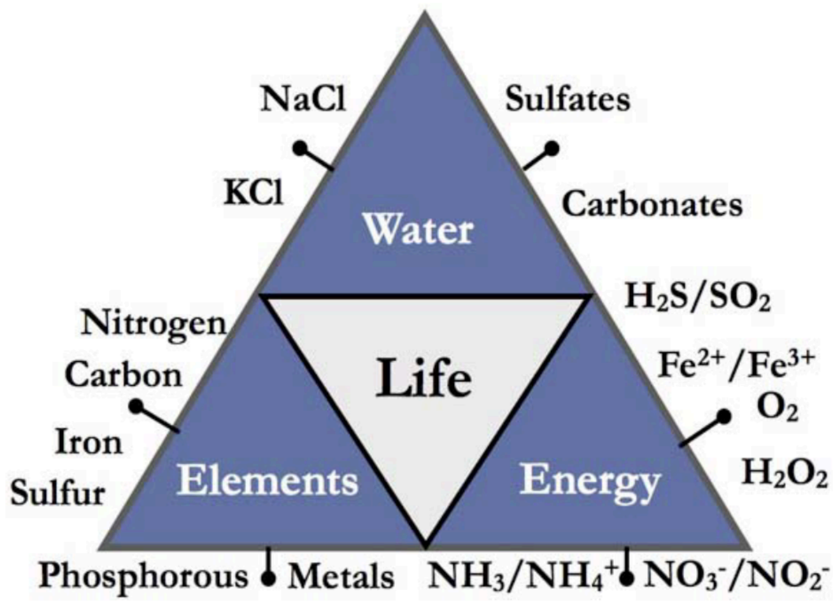


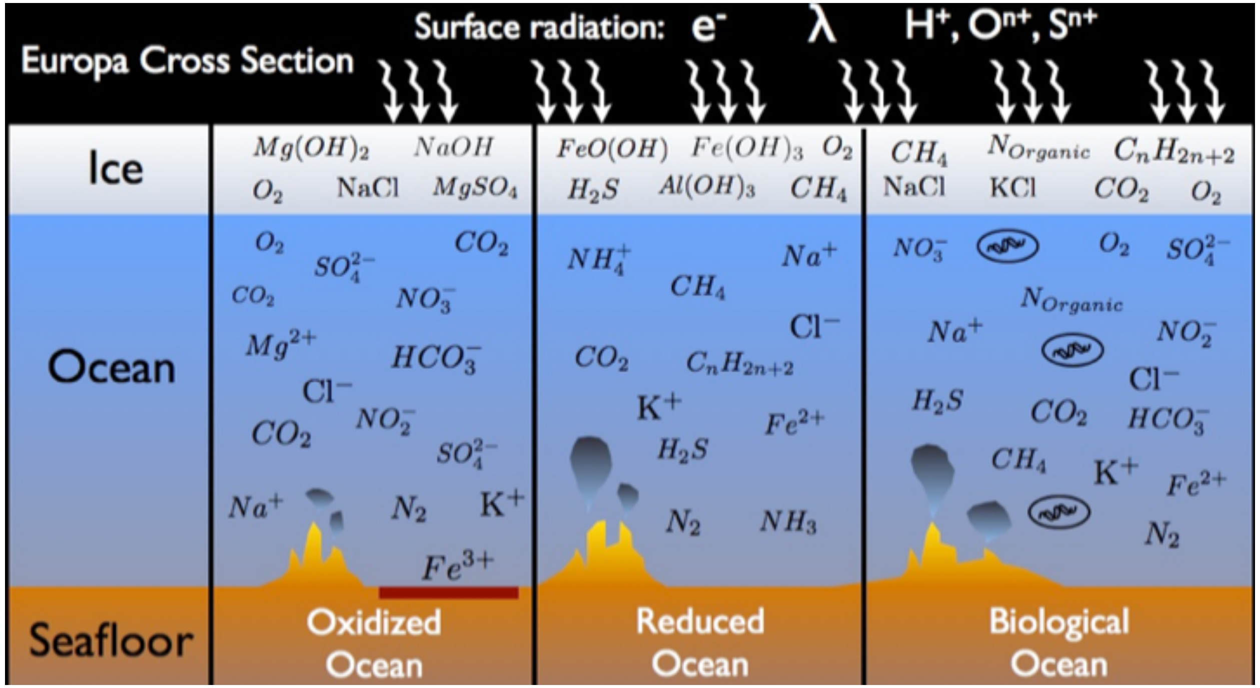
GOAL 2 HABITABILITY



Goal 2: Habitability

- **Objective 2A: Characterize the non-ice composition of Europa's near-subsurface material to determine whether there are indicators of chemical disequilibria and other environmental factors essential for life.**
  - **Investigation 2A1**: Determine the extent to which the habitability of Europa's ocean and liquid water environments can be inferred from surface non-ice materials as sampled and imaged.
  - **Investigation 2A2**: Identify patterns of spatial variability (textural, compositional) that may relate to habitability, and inform sample collection (Baseline only).

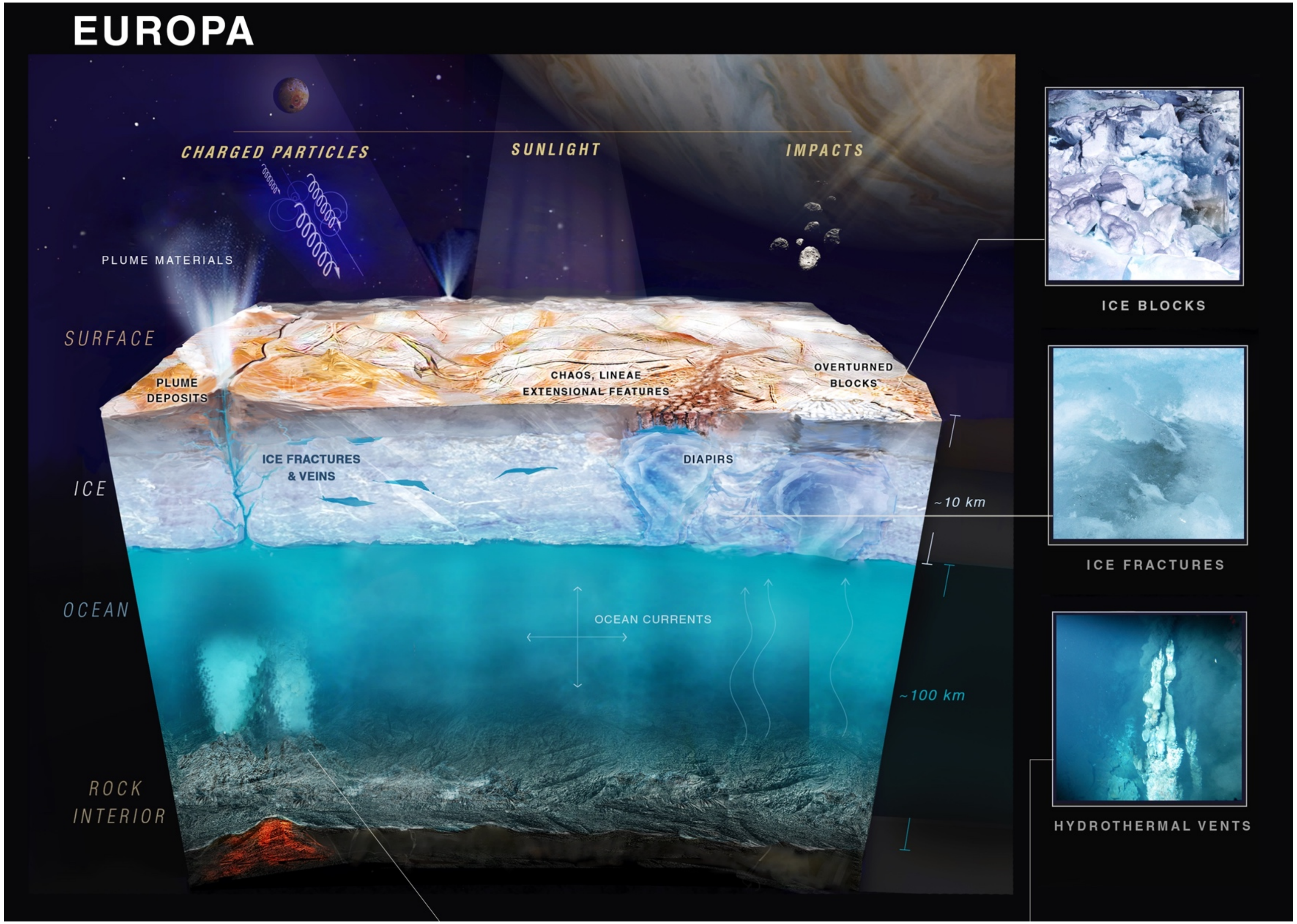




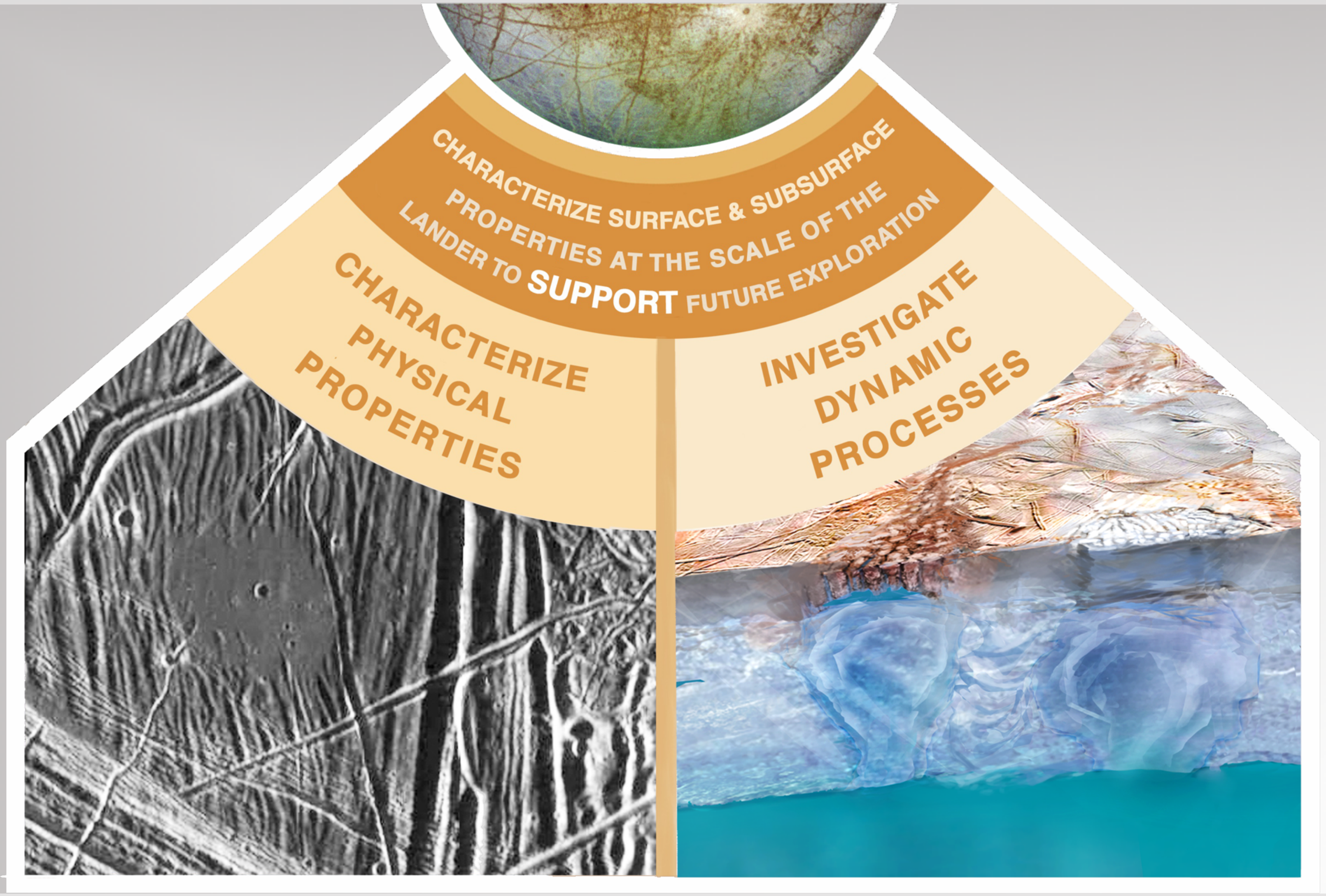
Hand et al., 2009

Goal 2: Habitability

- **Objective 2B: Determine the proximity to liquid water and recently erupted materials at the lander's location.**
  - **Investigation 2B1**: Search for any subsurface liquid water within 30 km of the lander, including the ocean.
  - **Investigation 2B2**: Search for evidence of interactions with liquid water on the surface at any scale.
  - **Investigation 2B3**: Search for evidence of active plumes and ejected materials on the surface.
  - **Investigation 2B4**: Determine the depth of Europa's ocean (Baseline only).

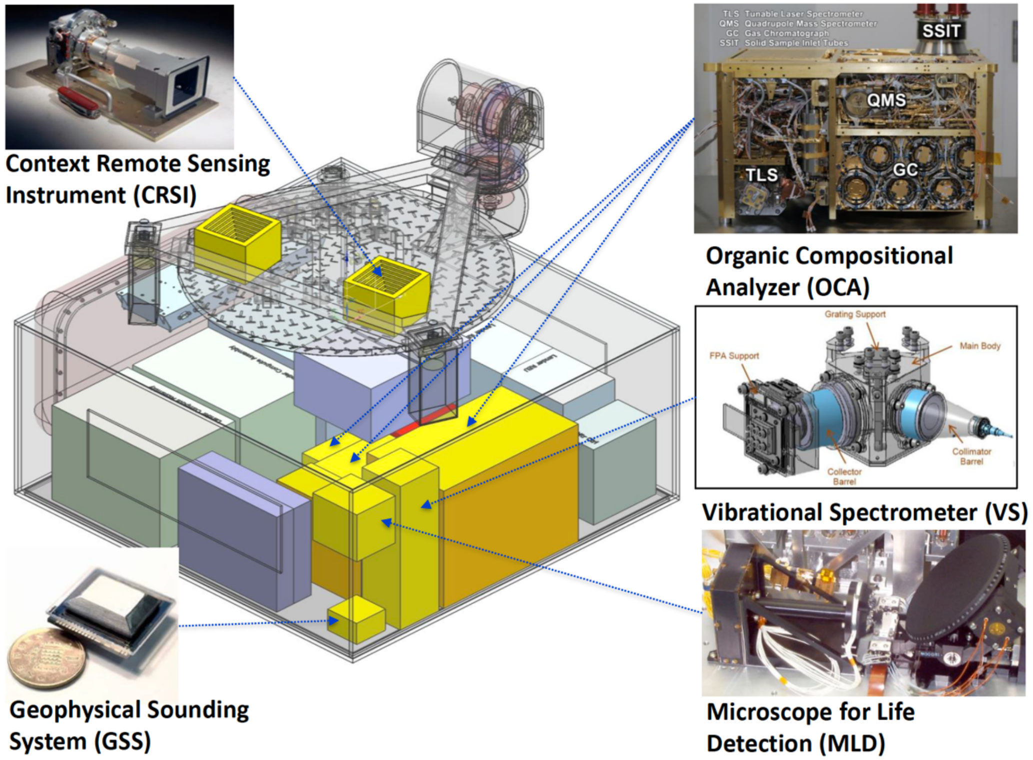


GOAL 3 CONTEXT



Europa Lander SDT 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



Sampling: 100 K ice with $MgSO_4$ & H_2SO_4

Video removed

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
OF THE NATIONAL ACADEMIES

- Large Initiatives:
  - Europa Geophysical Explorer
  - Titan Explorer
  - **Europa Lander**
  - 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 "*
BIOSIGNATURES	**1. Search for evidence of life on Europa.**	**1a.** Detect and characterize any organic indicators of past or present life.	**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"*
BIOSIGNATURES	**1. Search for evidence of life on Europa.**	**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."*
BIOSIGNATURES	**1. Search for evidence of life on Europa.**	**1c.** Detect and characterize any inorganic indicators of past or present 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."*
BIOSIGNATURES	**1. Search for evidence of life on Europa.**	**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

Europa Lander			Decadal Survey	
Goals		Objectives	Themes/Goals	Questions/Objectives
SURFACE PROPERTIES AND DYNAMICS	3. Characterize surface and subsurface properties at the scale of the lander to support future exploration.	**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.	**Crosscutting Theme 3:** Workings of Solar Systems	**Priority Question 10:** How have the myriad chemical and physical processes that shape the solar system operated, interacted, and evolved over time?
			Satellite Science Goal 2: What processes control the present-day behavior of these bodies?	**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?
		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.	**Satellite Science Goal 1:** How did the satellites of the outer solar system form and evolve?	**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?
			Satellite Science Goal 2: What processes control the present-day behavior of these bodies?	**Objective 1:** How do active endogenic processes shape the satellites' surfaces and influence their interiors? **Objective 3:** How do exogenic processes modify these bodies?

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
OF THE NATIONAL ACADEMIES

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	Europa 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														/	

Searching for Signs of Life: Lessons from Viking

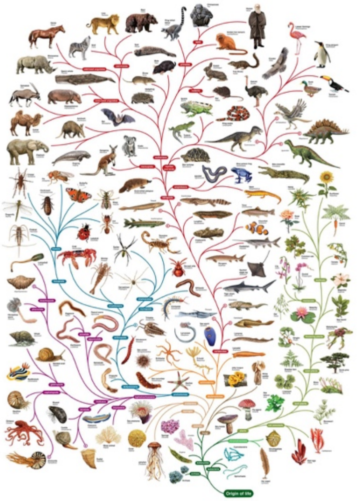
- If the payload permits, conduct experiments that assume contrasting definitions for life.
- **Given limited payload, the biochemical definition of life deserves priority**.
- Establishing the geological and chemical context of the environment is critical.
- **Life-detection experiments should provide 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 search for signs of life beyond Earth

1953

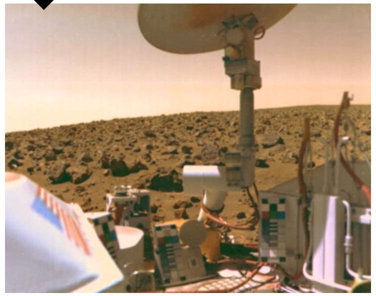
DNA discovered



Tree of Life Then…

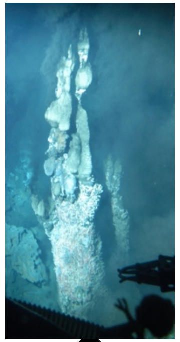
1976

Viking Landers



1977

Hydrothermal vents discovered



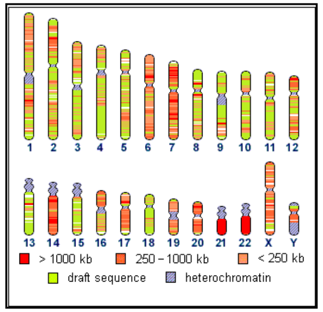
Archaea discovered (3rd domain of life)

Cryptoendoliths in Antarctica discovered

1983

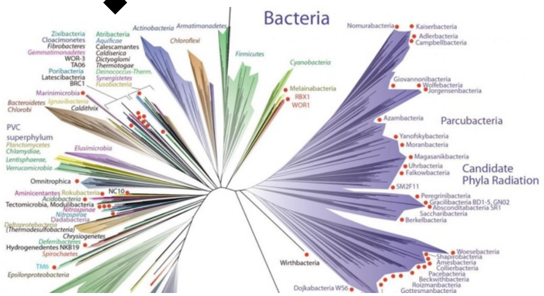
PCR Invented

2003



Human genome sequenced

2016



…Tree of Life Now.

2017

Europa Lander SDT Report

Backup
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