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

Hand & Carlson, 2014
Plumes, if they exist, are transient.

Lorenz et al., 2014a,b; Sparks et al. 2016; Sparks et al., 2017
Europa Lander Mission Concept

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

July 9, 2017
“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

<table>
<thead>
<tr>
<th></th>
<th>Pioneer 10</th>
<th>Pioneer 11</th>
<th>Voyager 1</th>
<th>Voyager 2</th>
<th>Viking 1</th>
<th>Viking 2</th>
<th>Galileo</th>
<th>Cassini</th>
<th>GRAL</th>
<th>MSL</th>
<th>MESSENGER</th>
<th>Dawn</th>
<th>New Horizons</th>
<th>Juno</th>
<th>Insight</th>
<th>OSIRIS-REx</th>
<th>Lucy</th>
<th>Psyche</th>
<th>Mars 2020</th>
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# Programmatic Balance

## Discovery Missions

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<th>NEAR</th>
<th>Mars Pathfinder</th>
<th>Moon Mineralogy Mapper</th>
<th>Kepler</th>
<th>Stardust</th>
<th>GRAIL</th>
<th>Deep Impact</th>
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New Frontiers Missions

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</table>
# Programmatic Balance

## Flagship Missions

<table>
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<th>Voyager 1</th>
<th>Voyager 2</th>
<th>Viking 1</th>
<th>Viking 2</th>
<th>Galileo</th>
<th>Cassini</th>
<th>MSL</th>
<th>Mars 2020</th>
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Pre-Decisional Information – For Planning and Discussion Purposes Only
Europa Lander Mission Concept

**Launch**
- SLS Block 1B
- Oct. 2025

**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

**Jupiter Arrival** (Oct 2029)

**Earth Gravity Assist** (Oct 2026)

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

**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)

Deorbit Stage (DOS)

Powered Descent Vehicle (PDV)

Descent Stage (DS)

Lander

Carrier and Relay Stage (CRS)

Landed Mass: 480 kg

De-Orbit Vehicle: 2,670 kg

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Pre-Decisional Information – For Planning and Discussion Purposes Only
### Europa Clipper and Lander Reference Timelines

#### Support Site Selection Using Clipper Reconnaissance

<table>
<thead>
<tr>
<th>Mission</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
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<td>Backup Launch Opportunities</td>
<td>10/2025 Launch Opportunity</td>
<td>12/2025 to 1/2026</td>
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**Conjunction keepout periods**

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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

  – 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.

• Committee on Astrobiology & Planetary Sciences (NRC CAPS)
  – Progress report presentation, Fall 2016.

• Seven presentations, total of >16 hours of briefing and Q&A.

• Town Hall Executive Committee feedback to be addressed through response letter to NASA.

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

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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
  o Organic abundance
  o Organic composition
• Physical indicators
  o Size and shape
  o Abundance
  o Properties
Detection Limits & Measurement Requirements: Earth Environments as a Benchmark for Life Detection

<table>
<thead>
<tr>
<th></th>
<th>Lake Vostok (Subglacial)</th>
<th>Lake Vida (Salty)</th>
<th>Winter Circumpolar Deep Water (Deep Ocean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accretion Ice (Type I)¹</td>
<td>Accretion Ice (Type II)¹</td>
<td>Glacial Ice¹</td>
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<tr>
<td>Organic carbon (µM)</td>
<td>65</td>
<td>35</td>
<td>16</td>
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<tr>
<td>DFAA (nM); DFAA % Org. Carbon</td>
<td>1-45; ≤ 0.006-0.17%</td>
<td>50-174; 0.08-0.49%</td>
<td>20-62; 0.6 – 1.2%</td>
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<tr>
<td>Total Asp (nM)</td>
<td>15-49</td>
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<td>11-39</td>
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<td>DF L-Asp (nM)</td>
<td>6-10⁺</td>
<td>n.d.</td>
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<td>Cell density (cells mL⁻¹)</td>
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<td>80</td>
<td>120</td>
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<tr>
<td>Microbial size (µm)</td>
<td>~0.3 - 3.0</td>
<td>~0.3 - 3.0</td>
<td>~0.3 - 3.0</td>
</tr>
</tbody>
</table>

¹ Data from ref. [1].
² Brine concentration in Lake Vida, ref. [2].
³ Ice saturation concentration, ref. [3].
⁴ Winter Circumpolar Deep Water, ref. [4].

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GOAL 1  ORGANIC INDICATORS

ORGANIC DETECTION, CHARACTERIZATION, COMPOSITION

L-amino acid  D-amino acid

ENANTIOMERIC EXCESS

carbon-13  carbon-12

6 protons 6 neutrons 1.07% of all C
HEAVY

6 protons 6 neutrons 98.93% of all C
LIGHT

ISOTOPIC INDICATORS

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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 europian 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 europian surface material.

Abiotic organic synthesis
- Low specificity

Biological organic synthesis
- High specificity

Organic Detection & Characterization

• Model Payload employs complimentary techniques for organic detection and characterization:
  
  – Organic Compositional Analyzer:
    • Gas Chromatograph-Mass Spectrometer
  
  – Vibrational Spectrometer:
    • Raman spectrometer
GOAL 1  MORPHOLOGIC INDICATORS

MICROSCALE STRUCTURES

MACROSCALE STRUCTURES

CELLULAR PROPERTIES

ORGANIC INDICATORS

INORGANIC INDICATORS

PROVENANCE

SEARCH FOR EVIDENCE OF LIFE

LIFE

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Pre-Decisional Information – For Planning and Discussion Purposes Only
Microscale & Macroscale Structures

**Micro:**

Lake Vostok Accretion ice

- Pigments
- Filamentous aggregations
- Biomineral structures

Lake Vida Brine

Macro:

- Priscu et al. 1999, Science.

- Murray et al. 2012 PNAS.
Earth Benchmarks: Size ranges of microbial life

Most abundant Earth-Ocean Microbes

- Glacier Ice bacteria
- 6- Ostreococcus
- 5- Prochlorococcus
- 4- Marine Gl Thaumarchaea
- 3- SAR11
- 2- Vida Ultimicrobacteria
- 1- Phage

Average range of Ross Sea bacteria and archaea sizes

Measurement requirement for Europa Lander notional microscope

Cell length (longest dimension μm)
GOAL 1 INORGANIC INDICATORS

INORGANIC COMPOSITION

BIOMINERALS

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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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Pre-Decisional Information – For Planning and Discussion Purposes Only
GOAL 2  HABITABILITY

ASSESS HABITABILITY VIA IN SITU ANALYSIS METHODS

- CHARACTERIZE NON-ICE COMPOSITION
- DETERMINE THE PROXIMITY TO LIQUID WATER
Goal 3

CONTEXT

- Characterize surface & subsurface properties at the scale of the lander to support future exploration
- Characterize physical properties
- Investigate dynamic processes

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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

<table>
<thead>
<tr>
<th>Instrument Class</th>
<th>Model Payload</th>
</tr>
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<tbody>
<tr>
<td>Context Remote Sensing Instrument (CRSI) [4.3 kg, includes shielding]</td>
<td>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</td>
</tr>
<tr>
<td>Microscope for Life Detection (MLD) [5.4 kg]</td>
<td>Deep UV resonance Raman and optical microscope with fluorescence spectrometer</td>
</tr>
<tr>
<td>Vibrational Spectrometer (VS) [5.4 kg]</td>
<td>Atomic Force Microscope (AFM) with optical context imager</td>
</tr>
<tr>
<td>Organic Compositional Analyzer (OCA) [16.4 kg]</td>
<td>Gas Chromatograph Mass Spectrometer (GC-MS) with Chirality Analysis and Stable Isotope Analyzer (SIA)</td>
</tr>
<tr>
<td>Geophysical Sounding System (GSS) [1.2 kg]</td>
<td>Broad-band seismometer</td>
</tr>
</tbody>
</table>

## Baseline

| Context Remote Sensing Instrument (CRSI) | 2 identical RGB, fixed focus, stereo overlapping cameras |
| Microscope for Life Detection (MLD) | Atomic Force Microscope (AFM) with optical context imager |
| Vibrational Spectrometer (VS) | Raman Laser Spectrometer (RLS) |
| Organic Compositional Analyzer (OCA) | Gas Chromatograph Mass Spectrometer (GC-MS) with Chirality Analysis |
| Geophysical Sounding System (GSS) | 3-axis geophone |

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Pre-Decisional Information – For Planning and Discussion Purposes Only
### Framework for Sampling & Life Detection

<table>
<thead>
<tr>
<th>GCMS</th>
<th>Microscope</th>
<th>Raman</th>
<th>Context Remote Sensing</th>
<th>Biosignature Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance</td>
<td>Pattern</td>
<td>Chirality</td>
<td>Isotopes</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
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<td></td>
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<tr>
<td></td>
<td>1</td>
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<td></td>
</tr>
</tbody>
</table>

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Pre-Decisional Information – For Planning and Discussion Purposes Only
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
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.
• 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

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Pre-Decisional Information – For Planning and Discussion Purposes Only
Europa Lander Mission Concept
Sampling: 100 K ice with MgSO$_4$ & H$_2$SO$_4$
Relevance to NASA & the Decadal Survey
2003 Decadal Survey: Europa Lander for Astrobiology

- **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
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?”
<table>
<thead>
<tr>
<th>Europa Lander</th>
<th>Decadal Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goals</strong></td>
<td><strong>Themes/Goals</strong></td>
</tr>
</tbody>
</table>
| **Objectives** | **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” |

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”

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.

**Satellite Science Goal 3**: What are the processes that result in habitable environments?

**Question 3**: Are organics present on the surface of Europa, and if so, what is their provenance?

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

<table>
<thead>
<tr>
<th>Goals</th>
<th>Objectives</th>
<th>Themes/Goals</th>
<th>Decadal Survey</th>
<th>Questions/Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SURFACE HABITABILITY</strong></td>
<td>2. Assess the habitability of Europa via in situ techniques uniquely available to a lander mission.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>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.</strong></td>
<td>Crosscutting Theme 2: Planetary Habitats</td>
<td><strong>Priority Question 4:</strong> What were the primordial sources of organic matter, and where does organic synthesis continue today?</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>2b. Determine the proximity to liquid water and recently erupted materials at the lander’s location.</strong></td>
<td>Satellite Science Goal 3: What are the processes that result in habitable environments?</td>
<td><strong>Objective 3:</strong> What energy sources are available to sustain life? <strong>Question 1:</strong> What is the nature of any biologically relevant energy sources on Europa? “Important directions for future investigations ...include (1) measurement of the oxidant content.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Satellite Science Goal 1:</strong> How did the satellites of the outer solar system form and evolve?</td>
<td>Objective 3: How are satellite thermal and orbital evolution and internal structure related? <strong>Question 8:</strong> What is the thickness of Europa’s outer ice shell and the depth of its ocean?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Satellite Science Goal 3:</strong> What are the processes that result in habitable environments?</td>
<td>Objective 4: What is the diversity of geologic activity and how has it changed over time? <strong>Question 5:</strong> 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”</td>
<td></td>
</tr>
</tbody>
</table>

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Pre-Decisional Information – For Planning and Discussion Purposes Only
## Europa Lander

### Goals

**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.

**Themes/Goals:**

- **Crosscutting Theme 3:** Workings of Solar Systems

**Questions/Objectives:***

- **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?

- **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.

**Themes/Goals:**

- **Satellite Science Goal 1:** How did the satellites of the outer solar system form and evolve?

**Questions/Objectives:**

- **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
• 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

Hydrothermal vents discovered

Archaea discovered (3rd domain of life)

Cryptoendoliths in Antarctica discovered

PCRs Invented

Europa Lander SDT Report

1953

1976

1977

1983

2003

2016

2017

Tree of Life Then...

Viking Landers

Human genome sequenced

…Tree of Life Now.
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.
Provenance
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.
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 bond 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

Radiolytic timescales at Europa

- Trailing hemisphere apex (electrons 10 keV – 20 MeV + protons)
- High latitude trailing (electrons up to 250 keV + protons)
- Leading hemisphere apex (electrons 20 MeV – 100 MeV + protons)
- High latitude leading (electrons 40 MeV – 100 MeV + protons)

10 cm 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)
Gold mirrors ~ 1 cm spot size with e⁻ beam
Residue Pics

Propane

Isobutane

1-Butene

2-Butene

850 µm
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
Phosphodiester (RNA, DNA, ATP): 1240 cm⁻¹, 1260 cm⁻¹, 1078 cm⁻¹

Absorbance (relative units)

Wavenumber (cm⁻¹)
• 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

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

- 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

<table>
<thead>
<tr>
<th>Instrument Class</th>
<th>Baseline Model Payload</th>
<th>Threshold Model Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Context Remote Sensing Instrument (CSRI)</strong></td>
<td>- 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</td>
<td>- Two Identical RGB, fixed focus, stereo overlapping cameras</td>
</tr>
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<td><strong>Microscope for Life Detection (MLD)</strong></td>
<td>- Deep UV resonance Raman and optical microscope with fluorescence spectrometer</td>
<td>- Atomic Force Microscope (AFM) with optical context imager</td>
</tr>
<tr>
<td><strong>Vibrational Spectrometer (VS)</strong></td>
<td>- Optical microscope (OM): o Resolution appropriate to provide context imaging of samples o FOV: 100 microns x 100 microns o Co-boregistered to spectrometer</td>
<td>- Optical context imager: o Fixed focus with 6x magnification o FOV: 2 mm x 1 mm</td>
</tr>
<tr>
<td><strong>Organic Compositional Analyzer (OCA)</strong></td>
<td>- Gas Chromatograph Mass Spectrometer (GC-MS) with both chirality analysis and Stable Isotope Analyzer (SIA)</td>
<td>- Gas Chromatograph Mass Spectrometer (GC-MS) with chirality analysis</td>
</tr>
<tr>
<td><strong>Geophysical Sounding System (GSS)</strong></td>
<td>- Broad-band seismometer</td>
<td>- 3-axis geophone</td>
</tr>
</tbody>
</table>

### Characteristics
- **Baseline Model Payload**
  - Multispectral filter wheel spanning the 350–1050 nm range
  - 34-mm fixed focal length, 16 lenses with 21° x 15° FOV
  - Camera heads:
    - Mounted on the HGA, ±1 m above the local European 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

- **Threshold Model Payload**
  - 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 European 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

### Similar Instruments
- **Baseline Model Payload**
  - Mastcam-34 or -100 on MSL
  - Mastcam-2 on Mars 2020
  - ChemCam on MSL
  - SuperCam on Mars 2020

- **Threshold Model Payload**
  - Navcam on MSL
  - EECAM for Mars 2020

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Pre-Decisional Information – For Planning and Discussion Purposes Only
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
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**

<table>
<thead>
<tr>
<th>Compound</th>
<th>On Earth</th>
<th>Murchison</th>
<th>Murray</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Amino-2,3-dimethyl-pentanoic acid</td>
<td>Unknown</td>
<td>7.6</td>
<td>1.0</td>
</tr>
<tr>
<td>2S,3S/2R,3R</td>
<td>Unknown</td>
<td>9.2</td>
<td>2.2</td>
</tr>
<tr>
<td>α-Methylnorleucine</td>
<td>Unknown</td>
<td>4.4</td>
<td>1.8</td>
</tr>
<tr>
<td>α-Methylnorvaline</td>
<td>Unknown</td>
<td>2.8</td>
<td>1.4</td>
</tr>
<tr>
<td>α-Methylvaline</td>
<td>Unknown</td>
<td>2.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>Rare</td>
<td>8.4</td>
<td>6.0</td>
</tr>
<tr>
<td>Norvaline</td>
<td>Rare</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>α-amino-n-butyric acid</td>
<td>Common</td>
<td>0.4</td>
<td>-0.4</td>
</tr>
<tr>
<td>Valine</td>
<td>Ubiquitous</td>
<td>2.2</td>
<td>-0.4</td>
</tr>
<tr>
<td>Alanine</td>
<td>Ubiquitous</td>
<td>1.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>

*Natural abundance of the amino acid in Earth’s biosphere.

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.

---

**Diagram:**

- **carbon-12**
  - 6 protons
  - 6 neutrons
  - 98.93% of all C
  - **LIGHT**

- **carbon-13**
  - 6 protons
  - 7 neutrons
  - 1.07% of all C
  - **HEAVY**

- Sedimentary organic material, petroleum, coal
- Marine + nonmarine organisms
- Freshwater carbonates
- Marine carbonates
- Air CO$_2$
- Carbonatites, diamonds

$\delta^{13}$C depletion
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