Europa Lander
Science Definition Team Update

CAPS – September meeting

Alison Murray Desert Research Institute, University of Nevada, Reno,
Jim Garvin Goddard Space Flight Center,
Kevin Hand Jet Propulsion Laboratory, California Institute of Technology

OUTLINE

1. NASA Charter
2. SDT Description
3. Study Concept
4. Goals & Objectives
5. Other considerations

Europa Lander SDT Framework

NASA Chartered a science definition team study (prephase A) of a lander mission to Europa

- Concept is for a separate launch ~ 2 yrs following the Europa Multi Fly-By mission
- Timing emphasizes science return from Lander which would benefit from information gained by Multi Fly-By and set stage for future Europa missions
- Strategy targets a low complexity payload capable of addressing 3 *in situ* science goals

Critical Considerations

- Do we know ***how*** to land on Europa's largely unknown surface?
  - Engineering team task
- Do we know ***where*** to land?
  - Multi Fly-By mission and payload
- ***What*** science can be done from a landed mission?
  - Task of our SDT

Science Definition Team

Co-Chairs: Alison Murray, DRI/Univ. NV Reno, Jim 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 & Ocean Scientists, Microbiologists, Geochemists

Science Definition Team

- SDT Charter with mission concept goals defined:
  1. Search for evidence of biomarkers and/or signs of extant life.
  2. Assess the habitability (particularly through quantitative compositional measurements) of Europa via in situ techniques uniquely available by means of a landed mission.
  3. Characterize surface properties at the scale of the lander to support future exploration.

Europa Lander Concept

- Key pre-phase A mission parameters:
  - Lander would be launched on a separate mission.
  - Target launch: 2024 on a SLS.
  - Mission would carry its own communication relay (Multi Fly-By can only be used as a backup).
  - Battery powered mission: 20 day surface lifetime.
  - Spacecraft dry mass on surface is assumed approximately 350 kg with 35 kg allocation for science payload.
  - Threshold science includes chemical analyses of 3 samples from 10 cm depth or deeper.

Payload Resource Allocations

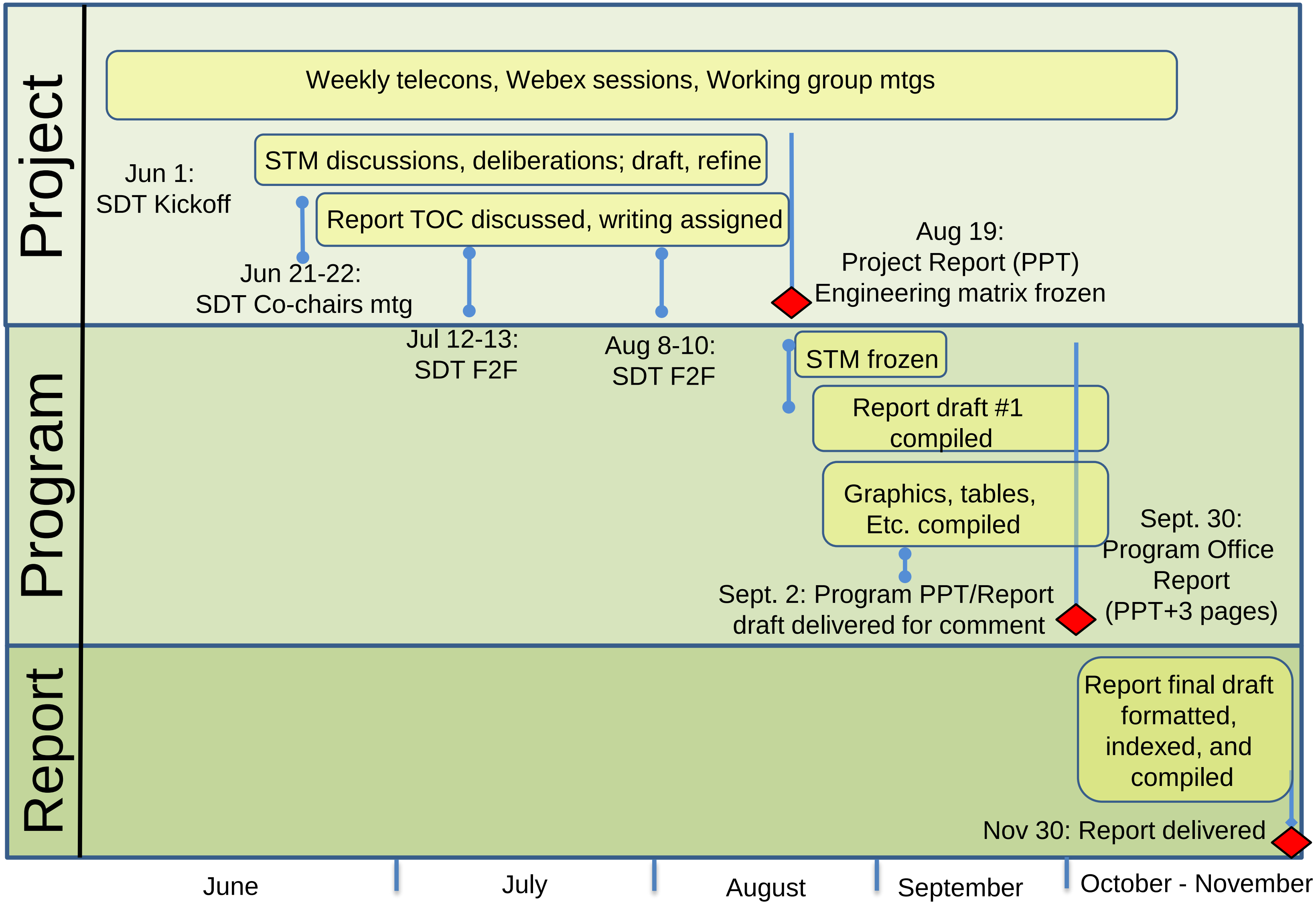
Europa Lander Resource	Allocation
Payload	35.0 kg (26.6 kg with 32% margin)
Current Volume cm^3 (MEV)	24,900
Total Energy per Mission* (W-hr) (CBE)	2500
Total Data Volume per Mission* (Mbits) (CBE)	2700

Rationale

- Ground Truth
  - Directly determine the composition of Europa's non-ice material, thereby greatly enhancing the science return of the Multi-Flyby mission.
  - Significant science value even in the absence of any signs of life.

- Analyses of Potential Biosignatures
  - Detailed *in situ* chemical analyses of sample collected directly from Europa's surface.
  - Significant biosignature science requires surface sampling.

Schedule


Project
Program
Report
Weekly telecons, Webex sessions, Working group mtgs
STM discussions, deliberations; draft, refine
Jun 1:
SDT Kickoff
Report TOC discussed, writing assigned
Jun 21-22:
SDT Co-chairs mtg
Aug 19:
Project Report (PPT)
Engineering matrix frozen
Jul 12-13:
SDT F2F
Aug 8-10:
SDT F2F
STM frozen
Report draft #1
compiled
Graphics, tables,
Etc. compiled
Sept. 30:
Program Office
Report
(PPT+3 pages)
Sept. 2: Program PPT/Report
draft delivered for comment
Report final draft
formatted,
indexed, and
compiled
Nov 30: Report delivered
June
July
August
September
October - November

Decadal Survey Science Questions

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**?

Satellites Chapter:

How are potential Europa **surface biomarkers** from the ocean/surface exchange degraded by the radiation environment? (8-19)

What are the sources, sinks and evolution of **organic** material? (8-20)

What energy sources are available to sustain **life**? (8-20)

Is there evidence for life on the satellites? (8-21 & 8-24)

Are **organics** present on the surface of Europa, and if so, **what is their provenance?** (8-22)

What is the nature of any **biologically** relevant energy sources on Europa? (8-23)

Does (or did) life exist below the surface of Europa or Enceladus? (8-24)

Breakthrough Science: Lessons from Viking

- **Given limited payload, the biochemical definition of life deserves priority**.
- If the payload permits, conduct experiments that assume contrasting definitions for life.
- 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 commonly missions of exploration; and therefore, the above guidelines must be put in the context of exploration and discovery driven science.

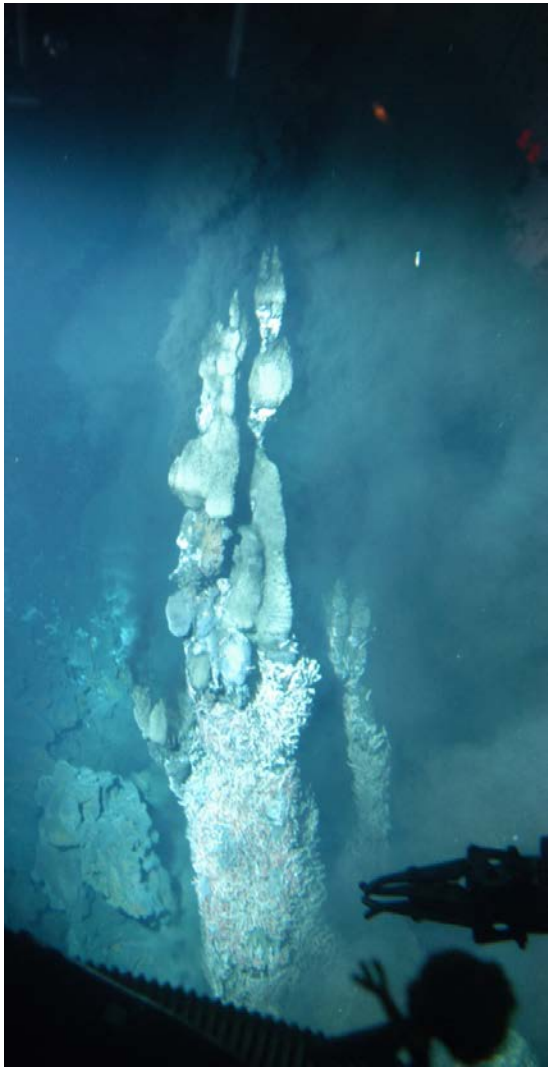
NRC 2000; Chyba and Phillips (2001)

Sampling and Detection Limits

Ecosystems and organics on Earth as a guide

Environment	Mass fraction (w/w)
Ocean surface (microbes)	1 ppb to 100 ppb
Deep ocean (microbes)	2 ppb
Hydrothermal vents (microbes)	20 ppb to 200 ppm
Lake Vostok (DOC)	~2 ppm (by number)
Lake Whillans (DOC)	~ 5 ppm (by number)
Arctic sea ice, bottom (EPS)	185 ppb to 10 ppm
Ocean (Total Organic Carbon)	0.5 ppm to 2 ppm

Christner et al., 2014;
Stewart & Fritsen 2004;
Riedel et al., 2006;
Priscu et al., 1999



Earth References

	Vostok Accretion Ice (Type I)	Vostok Accretion Ice (Type II)	Vostok Glacial Ice	Winter Circumpolar Deep Water	Lake Vida Brine	Lake Vida Ice
Organic carbon levels µM	65	35	16	38-42	64700	n.a.
Microbial abundance cells mL^{-1}	260	80	120	30-100,000	49,000,000	444000
Na^+	22 µM	0.92 µM	2.4 µM	~469 mM	1954 mM	2.32 mM
Cl^-	17µM	0.94 µM	2.8 µM	~546 mM	3187 mM	3.49 mM
SO_4^{-2}	9.1 µM	0.15 µM	1.8 µM	~28 mM	66.34 mM	60.15 µM
Citation	Christner et al. 2006 L&O 51:2485-2501	Christner et al. 2006	Christner et al. 2006	Yuan et al. in review	Murray et al. 2012 PNAS	At 20 m (Dugan et al. 2015; Kuhn, 2015)

Science Trace Matrix (Draft)

- **Goal 1**: Search for Evidence of Biosignatures and Signs of Life on Europa
  - Obj. 1: Detect and characterize any organic indicators of past or present life.
  - Obj. 2: Identify and characterize morphological and textural indicators of life.
  - Obj. 3: Detect and characterize any inorganic indicators of past or present life.
  - Obj. 4: Determine the provenance (origin/source/history) of sampled material.
  - Obj. 5: Determine if living organisms persist in sampled material [*Not part of Threshold*].

Science Trace Matrix (Draft)

- **Goal 2**: Assess the habitability of Europa via in situ techniques uniquely available to a lander mission.
  - Obj. 1: Characterize the non-ice composition of Europa's near-surface material and determine whether there are indicators of chemical disequillibirum and other components essential for life.
  - Obj. 2: Determine the proximity to liquid water at the lander's location.
  - Obj. 3: Detect whether Europa is active today and characterize any observable surface exchange processes to support sample context.

Science Trace Matrix (Draft)

- **Goal 3**: Characterize surface properties at the scale of the lander to support future exploration.
  - Obj. 1: Characterize the biosignature preservation potential (BPP) of accessible surface materials at the landing site.
  - Obj. 2: Characterize the surface dynamics of Europa at the landing site in all three dimensions.
  - Obj. 3: Characterize the material properties of Europa at the landing site.

Europa Mission Compatibility

Europa Multi Fly-By

Habitability

- Ice shell and ocean
- Composition
- Geology

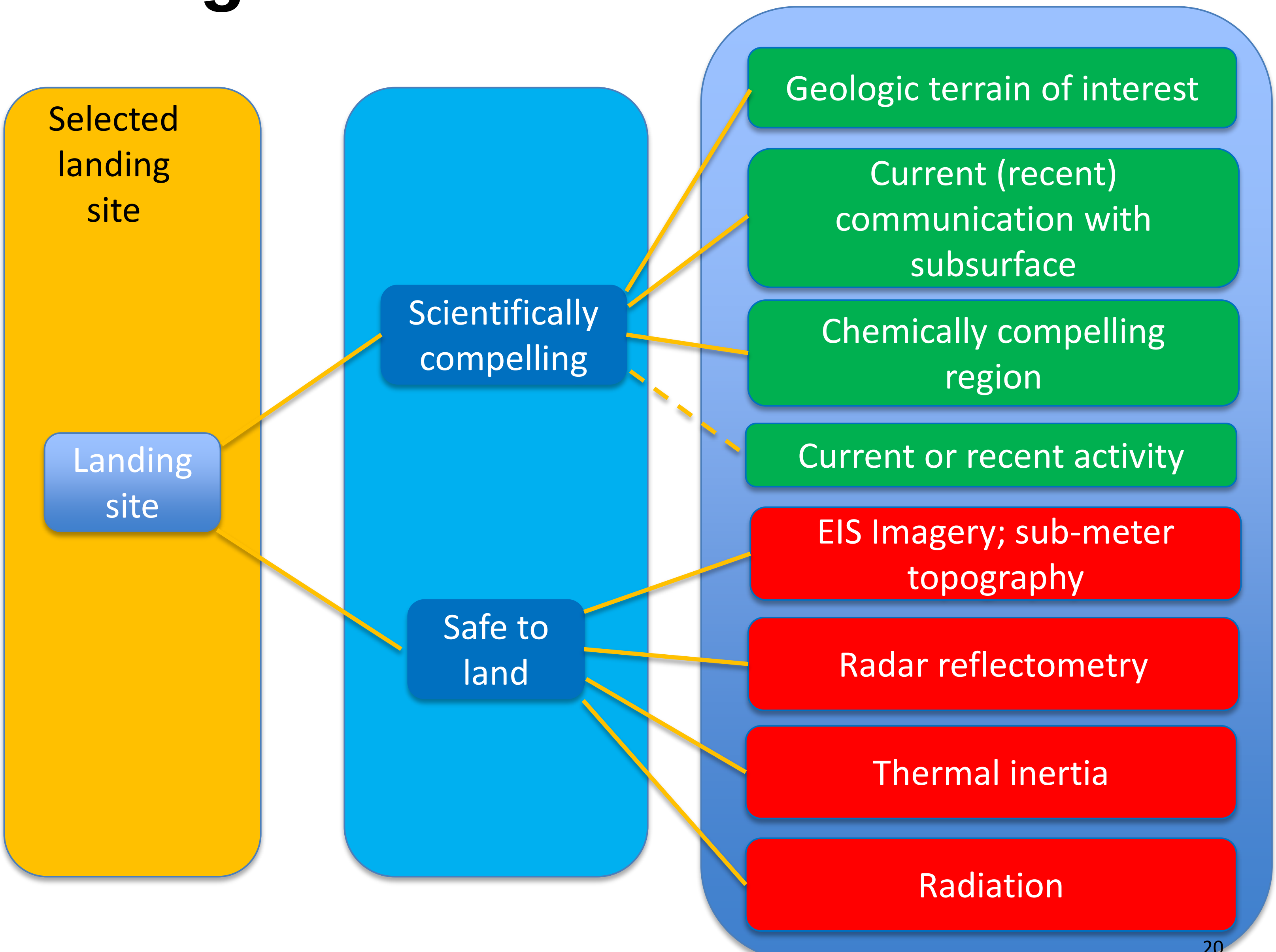
Lander

- Biosignature search
- Habitability using in situ techniques
- Surface properties

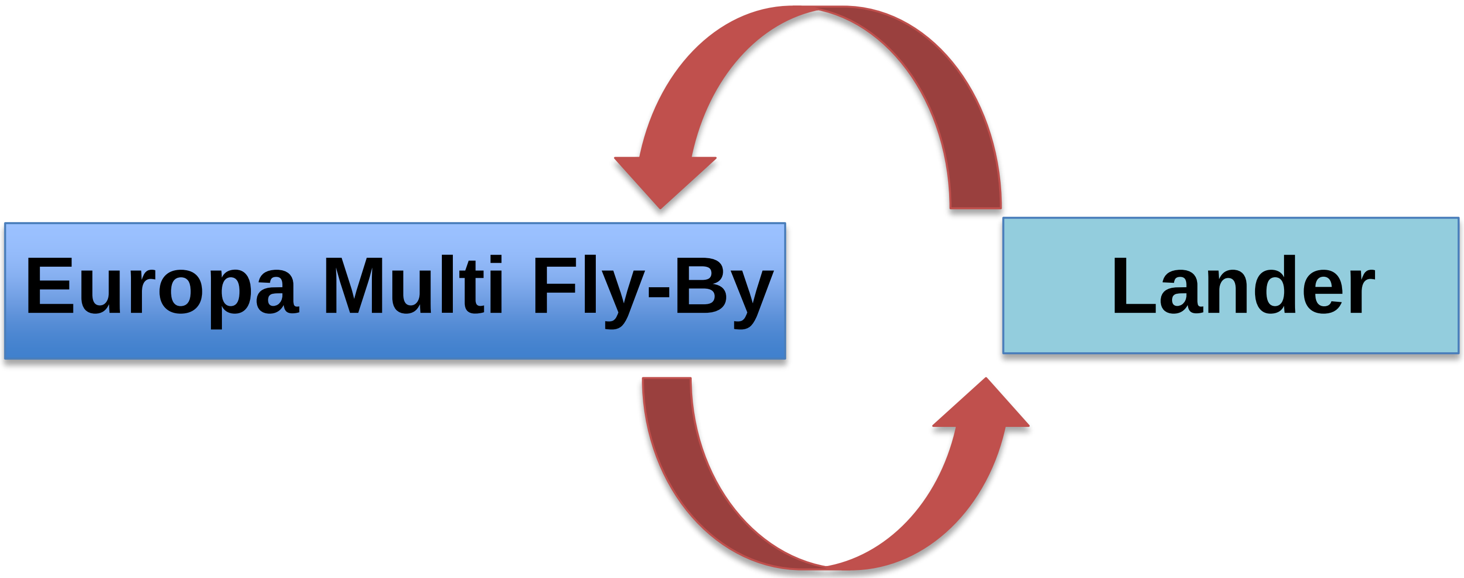
Europa Multi Fly-By → **Lander**

Landing site selection

Landing Site Selection



- Local to regional & global scaling
- Ground-truth acoustics, radar
- Nearfield observation – context remote sensing, composition, chemistry and microscopy



Landing site selection

Goal 1: Search for Evidence of Biosignatures and Signs of Life on Europa: Objectives

- Obj. 1: Organic indicators
- Obj. 2: Morphological and textural indicators
- Obj. 3: Inorganic indicators
- Obj. 4: Provenance
- Obj. 5: Persistence of life

Goal 1: Search for Evidence of Biosignatures and Signs of Life on Europa: Objectives & Investigations

- Obj. 1: Organic indicators
  - Abundances and patterns of potentially biogenic molecules
  - Enantiomeric ratios of chiral organics
  - Carbon isotopic distribution among organic and inorganic carbon *
- Obj. 2: Morphological and textural indicators
- Obj. 3: Inorganic indicators
- Obj. 4: Provenance
- Obj. 5: Persistence of life

Goal 1: Search for Evidence of Biosignatures and Signs of Life on Europa: Objectives & Investigations

- Obj. 1: Organic indicators
  - abundances and patterns of potentially biogenic molecules
  - enantiomeric ratios of chiral organics
  - carbon isotopic distribution among organic and inorganic carbon *
- Obj. 2: Morphological and textural indicators
  - resolve and characterize microscale evidence for life in samples
  - resolve and characterize the landing site for any macroscale morphological evidence for life *
- Obj. 3: Inorganic indicators
- Obj. 4: Provenance
- Obj. 5: Persistence of life

Goal 1: Search for Evidence of Biosignatures and Signs of Life on Europa: Objectives & Investigations

- Obj. 1: Organic indicators
  - abundances and patterns of potentially biogenic molecules
  - enantiomeric ratios of chiral organics
  - carbon isotopic distribution among organic and inorganic carbon *
- Obj. 2: Morphological and textural indicators
  - resolve and characterize microscale evidence for life in samples
  - resolve and characterize the landing site for any macroscale morphological evidence for life *
- Obj. 3: Inorganic indicators
  - Detect and characterize potential biominerals
- Obj. 4: Provenance
- Obj. 5: Persistence of life

Goal 1: Search for Evidence of Biosignatures and Signs of Life on Europa: Objectives & Investigations

– Obj. 1: Organic indicators
  - Abundances and patterns of potentially biogenic molecules
  - Enantiomeric ratios of chiral organics
  - Carbon isotopic distribution among organic and inorganic carbon *

– Obj. 2: Morphological and textural indicators
  - Resolve and characterize microscale evidence for life in samples
  - Resolve and characterize the landing site for any macroscale morphological evidence for life *

– Obj. 3: Inorganic indicators
  - Detect and characterize potential biominerals

– Obj. 4: Provenance
  - Determine the geological context from which samples are collected
  - Determine endogenous versus exogenous origin (chemistry), surface processing of potential biosignatures

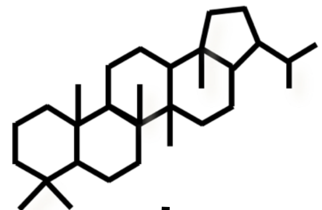
– Obj. 5: Persistence of life

Goal 1: Search for Evidence of Biosignatures and Signs of Life on Europa: Objectives & Investigations

- Obj. 1: Organic indicators
  - abundances and patterns of potentially biogenic molecules
  - enantiomeric ratios of chiral organics
  - carbon isotopic distribution among organic and inorganic carbon *
- Obj. 2: Morphological and textural indicators
  - resolve and characterize microscale evidence for life in samples
  - resolve and characterize the landing site for any macroscale morphological evidence for life *
- Obj. 3: Inorganic indicators
  - Detect and characterize potential biominerals
- Obj. 4: Provenance
  - Determine the geological context from which samples are collected
  - Determine endogenous versus exogenous origin (chemistry), surface processing of potential biosignatures
- Obj. 5: Persistence of life
  - Detect activity indicative of biological processes such as motion, change, metabolism*

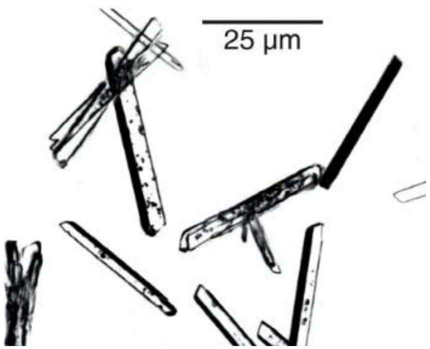
Biosignature Framework

Organic detection, characterization, composition relationships



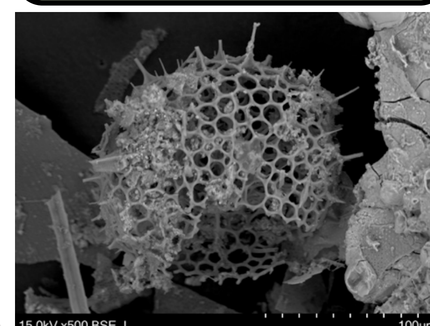
Macro-structures, Textures

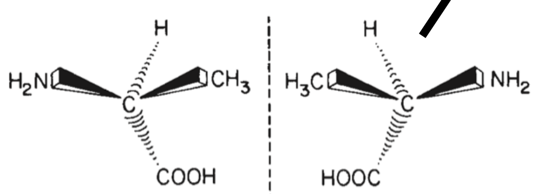
Inorganic indicator detection & characterization



Potential Biosignature Linkages

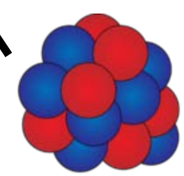
Micro-structures, Textures





Chemical indicators

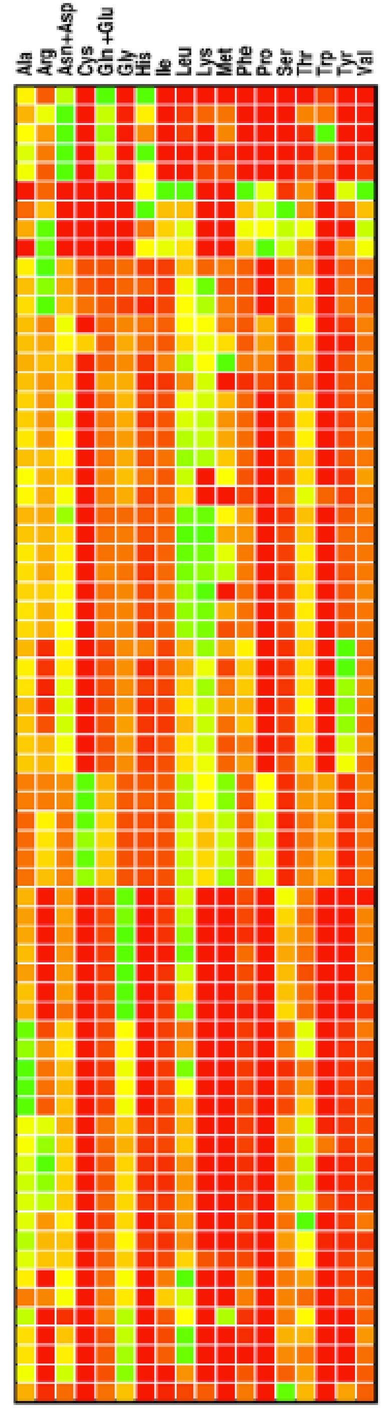
$\delta^{13}C$



Isotopic indicators

Amino acid composition across diverse Earth habitats

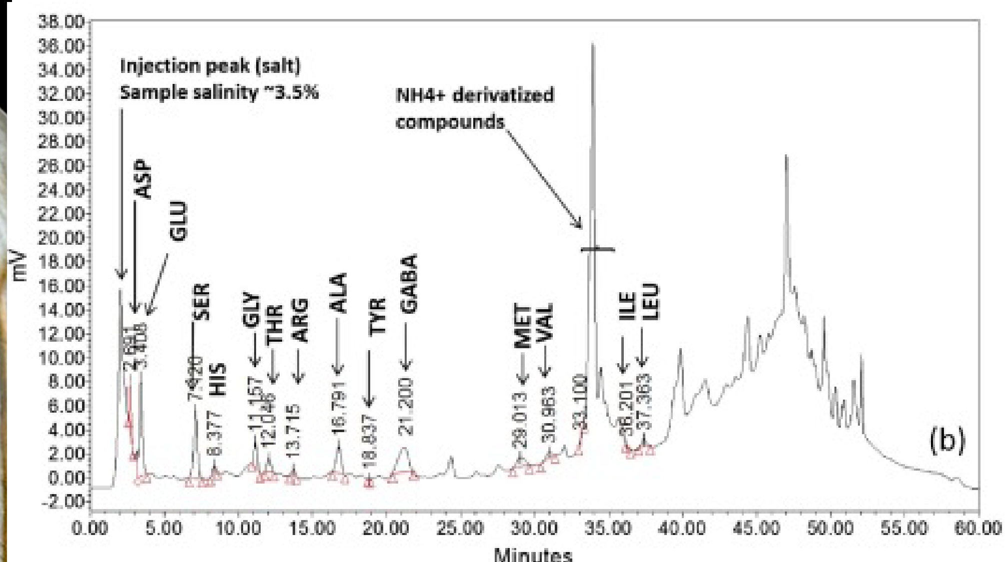
Non-uniform distributions:
Red – overrepresented
Green – underrepresented



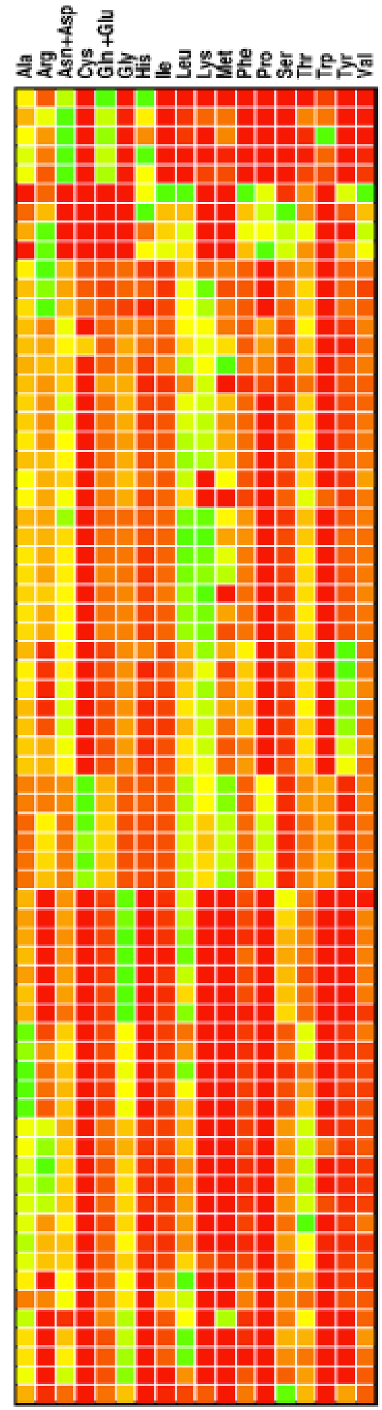
Moura et al. Plos One, 2013 8, e77319

Amino acid composition across diverse Earth habitats

nM detection: Juan de Fuca basement fluid samples



Composition can reflect life's preferences, diagenetic status and biological activities

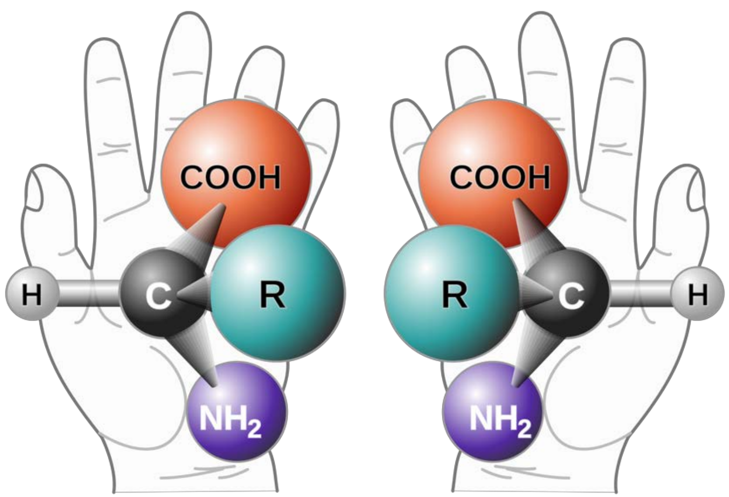


Lin et al. 2015 GCA 164:175-190

Moura et al. Plos One, 2013 8, e77319

Biosignatures: Chirality and Life's little twist

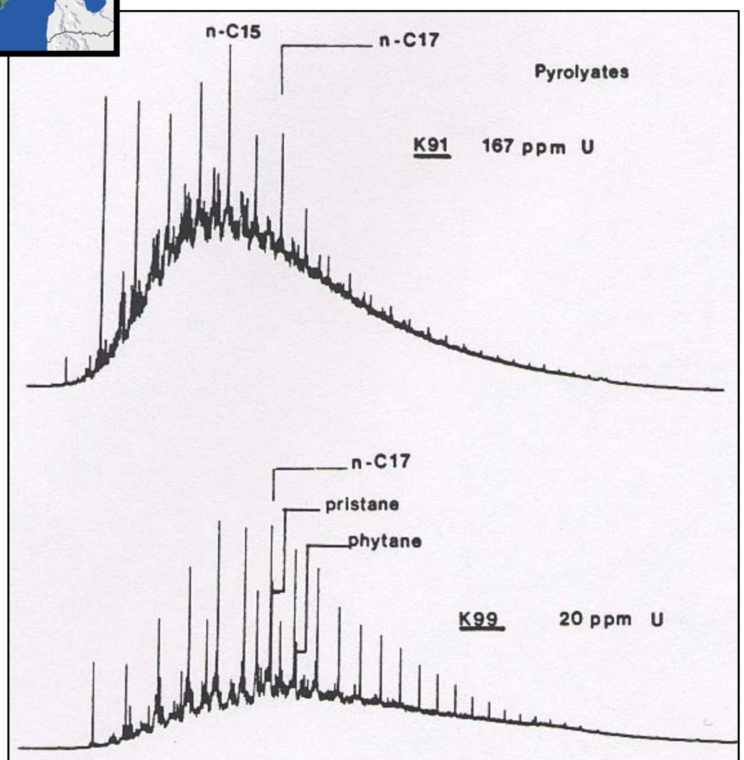
- Life's Legos consist of almost exclusively one enantiomer (i.e. one hand)
  - Earth: L-amino acids and D-sugars
- Abiotic processes produce racemic mixtures*
- Enantiomeric excess may be a 'universal principle' for building carbon-based life.



Biosignatures: Organic Patterns & Complexity

Irradiation Effects on Biosignatures

- Uranium-rich rocks on Earth provide a useful guide.
- With $>10^9$ rad the relative pattern changes but the biological ‘Legos’ can still be measured.



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

Ladder of Life

Ladder Rung	Feature	Measurement	Instrument	Lander Payload
Life (metabolism, growth, reproduction)				
Darwinian Evolution	changes in heritable traits in response to selective pressures	Not possible		
Growth and Reproduction	concurrent life stages or identifiable reproductive form	Cell(like?) structures in multiple stages. Morphology that is 'suspicious' for biology	microscope	✓
Metabolism	isotopes	Isotopes indicative of active metabolism	irMS	✓
	co-located reluctant and oxidant (e.g. oxygen and methane)	Chemical concentrations of substrates and products involved in redox reactions	spectroscopy	✓
Suspicious biomaterials [not necessarily biogenic]				
Functional Molecules	DNA	Material produced by extraterrestrial life	spectrographic, immunoassay, PCR, hi-prec MS	✓
	RNA	Material produced by extraterrestrial life	spectrographic, immunoassay, PCR, hi-prec MS	✓
	pigments	Material produced by extraterrestrial life	Spectrometer	✓
	structural preferences in organic molecules [non random and enhancing function)	Evidence of non random chemistries (such as specific biochemical pathways)	LCMS	✓
Potential Building Blocks	complex organics (peptides, PAH, nucleic acids, hopanes)	Increasing complexity of potential biomolecules	LCMS	✓
	amino acids (e.g. glycine)	Material produced by extraterrestrial life	GCMS	✓
	lipids (fatty acids, esters, carboxylic acids)	Material produced by extraterrestrial life	GCMS	✓
General indicators	distribution of metals [e.g. vanadium in oil reserves]	Deviation from background bulk concentrations (Preferences)	XRF	
	patterns of complexity (organics)	Deviation from random organic complexity distribution	LCMS	✓
	chirality	Material produced by extraterrestrial life	LC-MS/MS	✓
Habitability				
	water, presence of building blocks for use, energy source	Environments conducive to habitability	T/pH/energy	Flyby Mission

Planetary Protection Considerations

TABLE 1.1 COSPAR Planetary Protection Categories

	Category I	Category II	Category III	Category IV
Type of mission	Any but Earth return	Any but Earth return	No direct contact (flyby, some orbiters[a])	Direct contact (lander, probe, some orbiters[a])
Target body[b]	Not of direct interest for understanding of chemical evolution or the origin of life; Group 1	Of significant interest relative to chemical evolution and the origin of life, but where there is only a remote[c] chance of contamination; Group 2	Of interest relative to chemical evolution and the origin of life, but where there is a significant[d] chance of contamination; Group 3	Of interest relative to chemical evolution and the origin of life, but where there is a significant[d] chance of contamination; Group 4
Degree of concern	None	Record of planned impact probability and contamination control measures	Limit on impact probability; passive bioburden control	Limit on non-nominal impact probability; active bioburden control
Planetary protection policy requirements	None	Documentation: planetary protection plan, pre-launch report, post-launch report, post-encounter report, end-of-mission report	Documentation: Category II plus: contamination control, organics inventory (as necessary)	Documentation: Category III plus: probability of contamination analysis plan, microbial reduction plan, microbial assay plan, organics inventory
			Implementing procedures such as: trajectory biasing, cleanroom, bioburden reduction (as necessary)	Implementing procedures such as: partial sterilization of contacting hardware (as necessary), bioshield, monitoring of bioburden via bioassay

Planetary Protection Considerations

- SDT experience with clean access developed and executed for access to isolated Antarctic lakes

- SDT discussions regarding risk
  - Cold, salt, and radiation resistance, desiccation tolerance

- Engineering design in step with Category 4
- Aseptic assembly
- Biobarrier during launch-flight

Questions?