Europa Lander SDT Report & Mission Concept

OPAG

February 22, 2017, Atlanta, GA

Kevin Hand, Alison Murray, Jim Garvin & Europa Lander Team

Science Definition Team

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- David Smith, MIT
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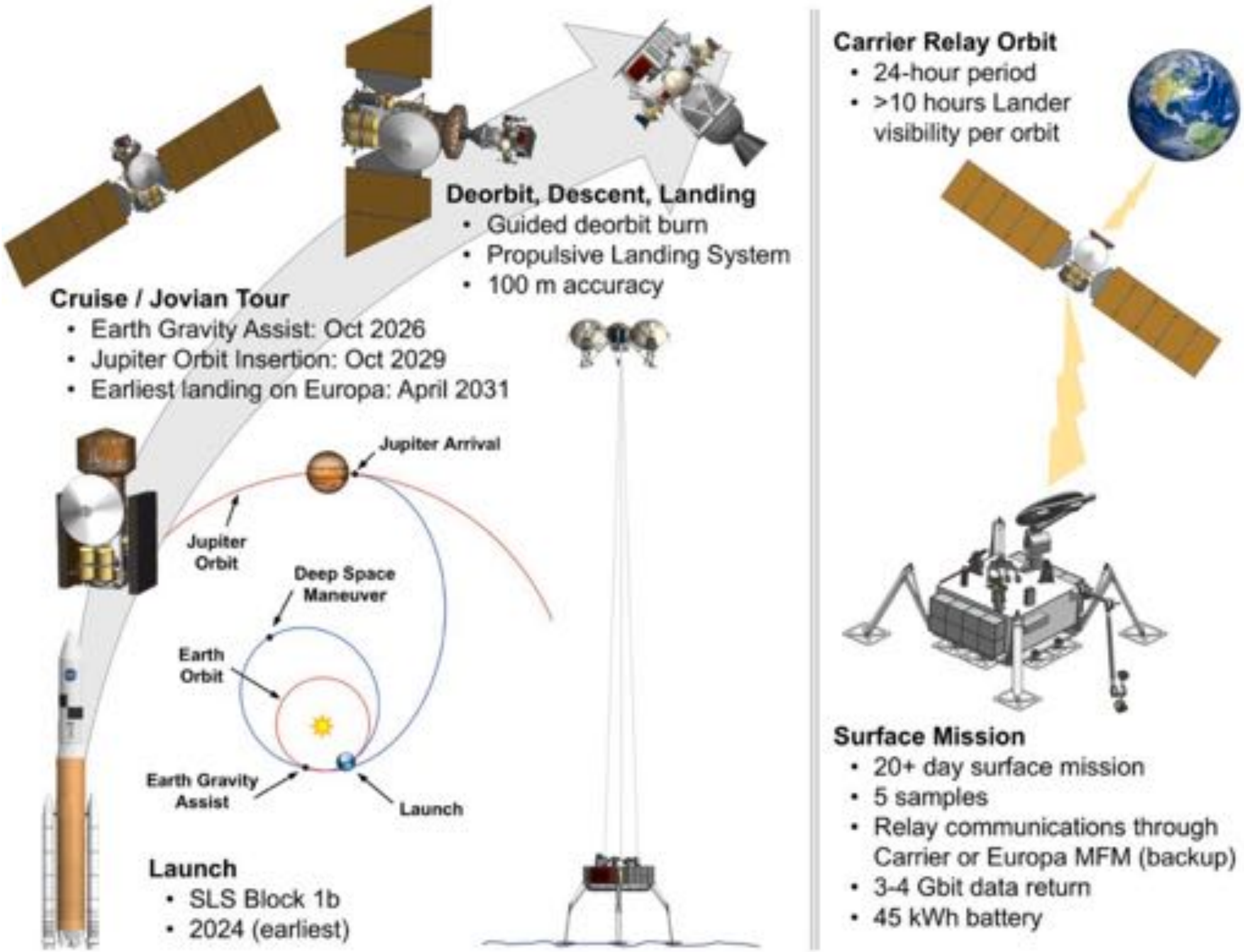
Planetary scientists, Microbiologists, Geochemists

Europa Lander Mission Concept

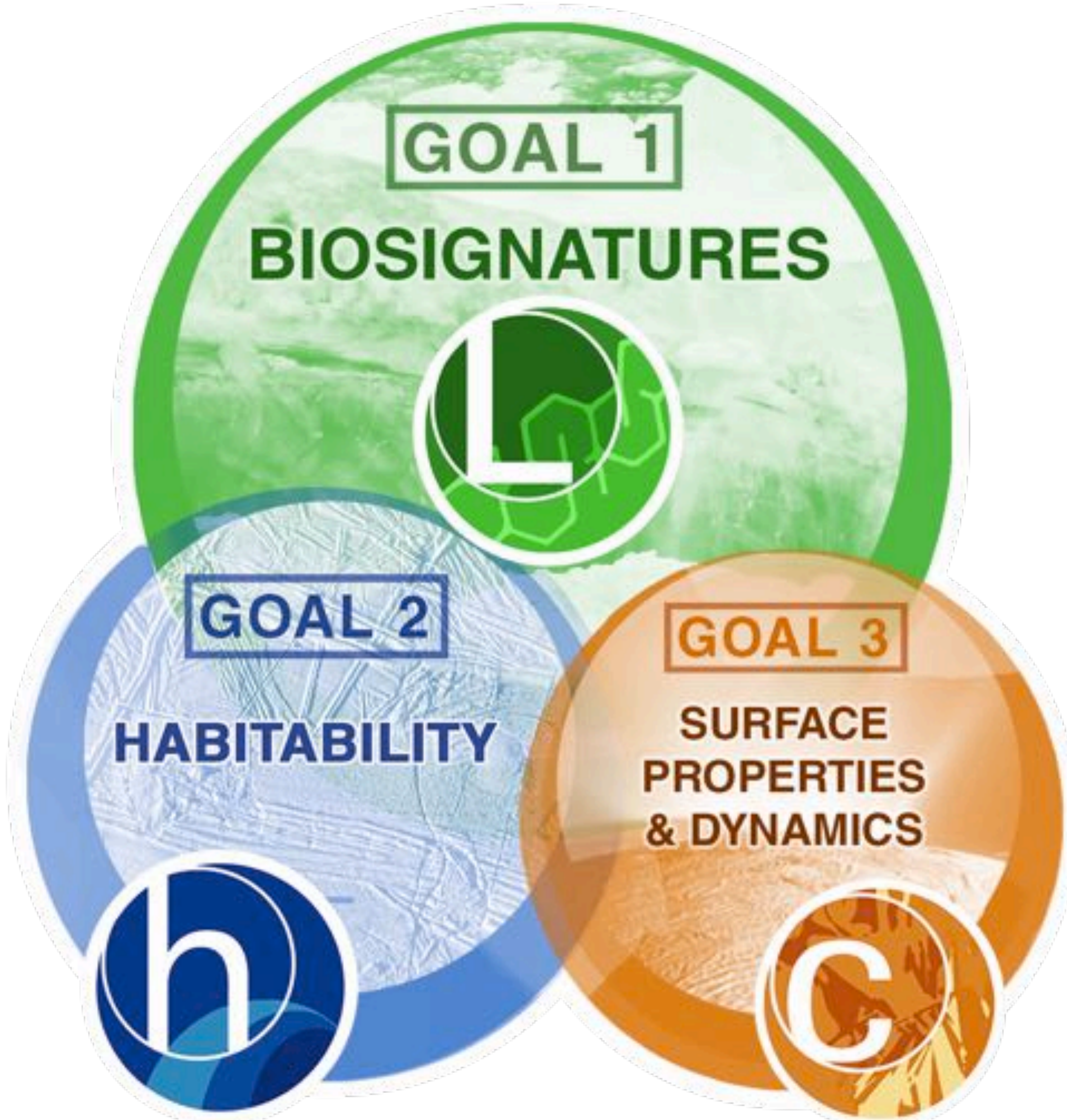
Key Parameters:

- Lander would be launched as a separate mission.
- Target launch: 2024-2025 on SLS rocket.
- 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.

Europa Lander Mission Concept

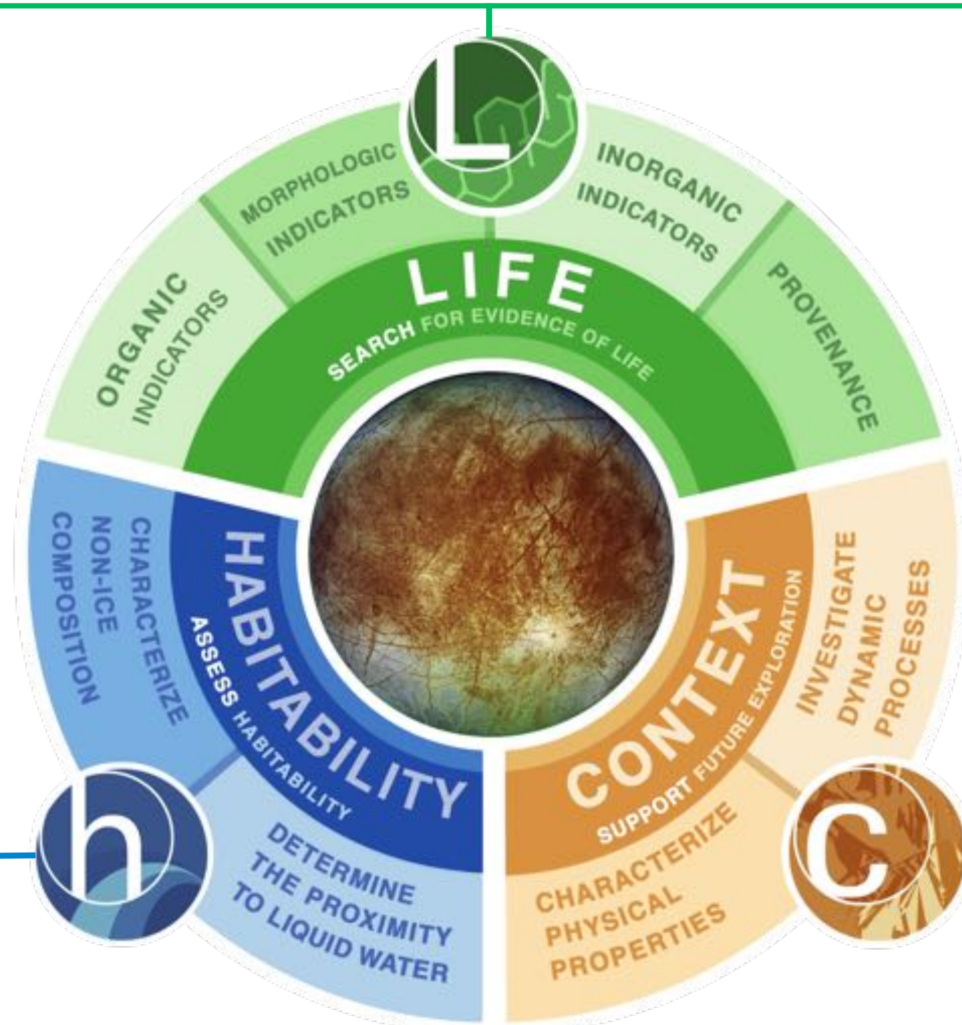


Europa Lander Goals:
A Robust Approach to Searching for Signs of Life



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

GC-MS | **Microscope** | **Raman spectrometer** | **Context cameras**



Habitability:

- Raman spectrometer
- GC-MS
- Context cameras
- Geophone

Context:

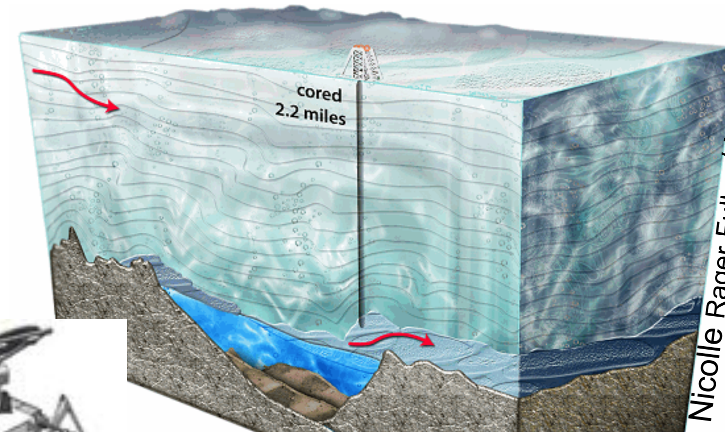
- Raman spectrometer
- Microscope
- GC-MS
- Context cameras
- Geophone

Goal 1: Search for Evidence of Life

Ocean World Analogues –
Value as benchmark environments

What biosignatures exist?

What thresholds are needed for detecting signs of life?



Nicolle Rager-Fuller / NSF

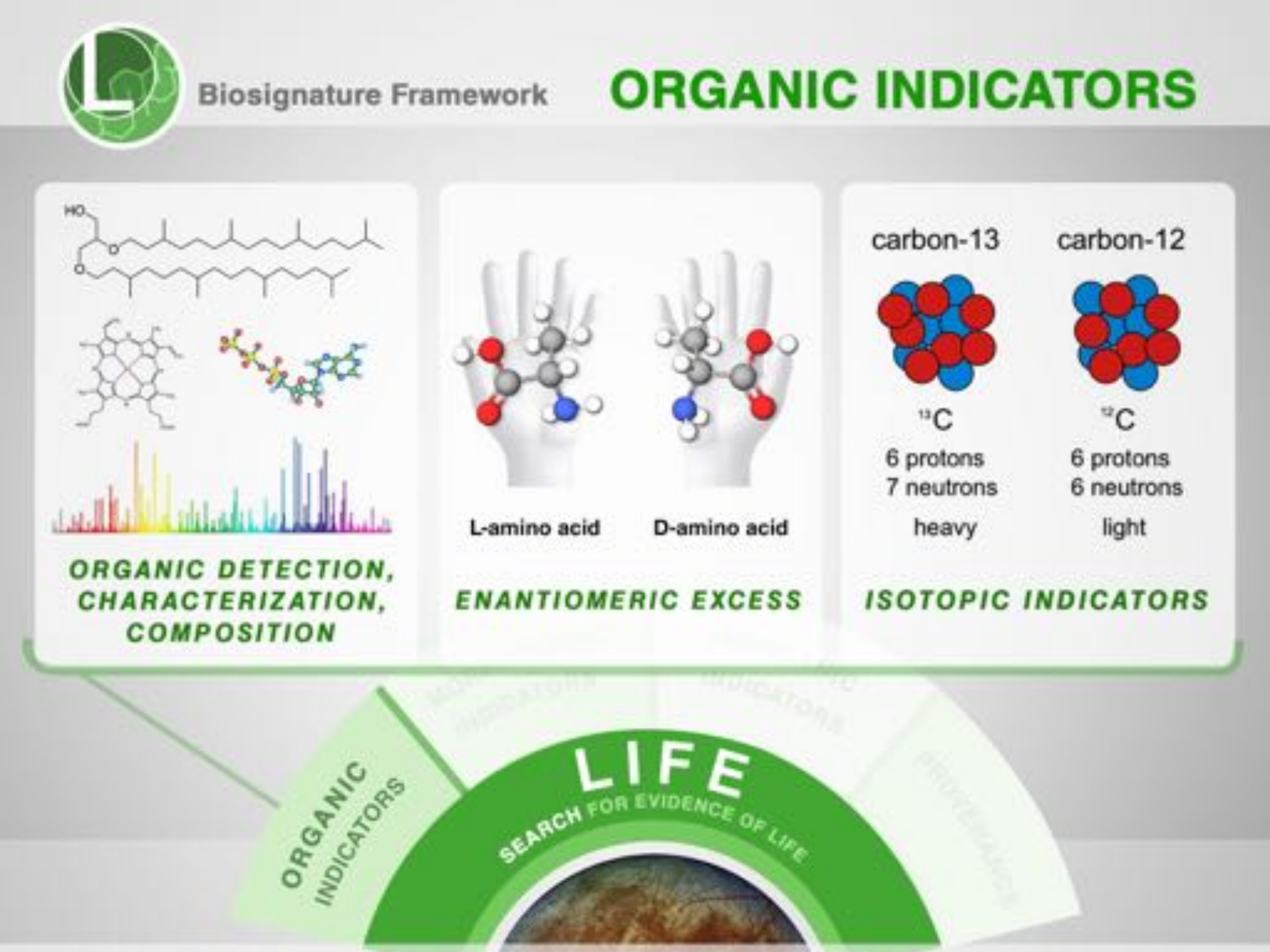
- Threshold signs of life
  - Chemistry associated with, and as a byproduct of life
    - Abundance levels
    - Composition
  - Physical lifeforms
    - Size
    - Abundance
    - Properties

H Dugan/UIC

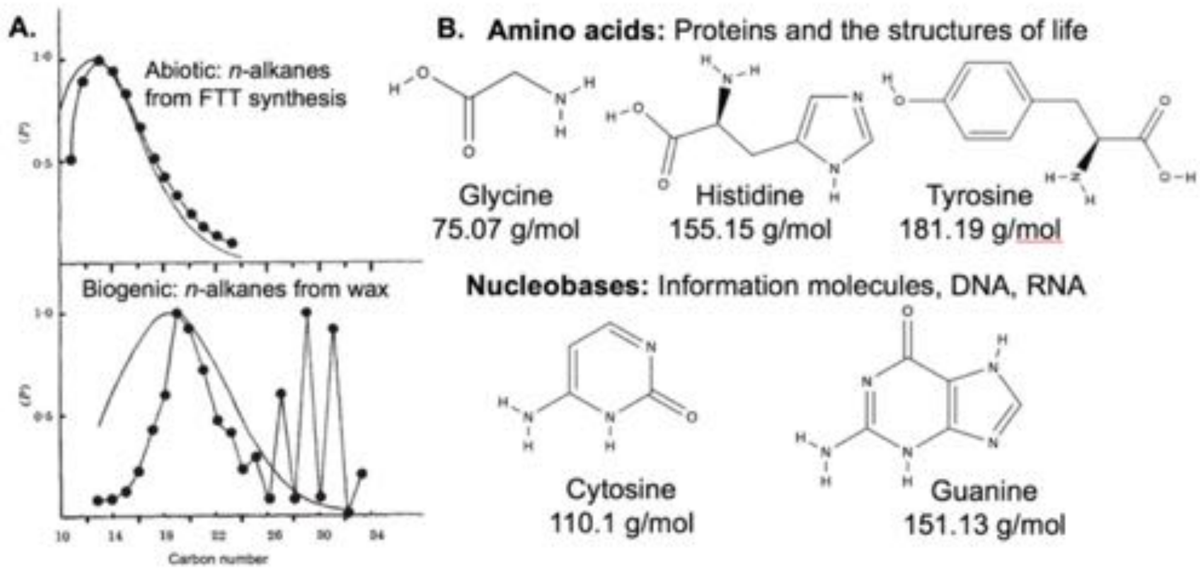
AE Murray /DRI

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**

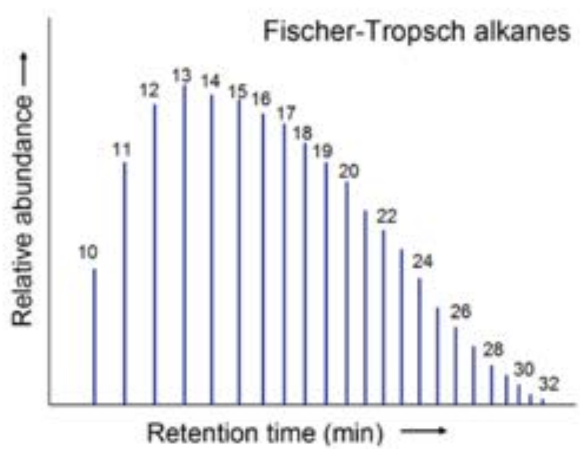

Biosignature Framework
ORGANIC INDICATORS
HO
carbon-13
carbon-12
^{13}C
^{12}C
6 protons
7 neutrons
heavy
6 protons
6 neutrons
light
L-amino acid
D-amino acid
ORGANIC DETECTION, CHARACTERIZATION, COMPOSITION
ENANTIOMERIC EXCESS
ISOTOPIC INDICATORS
ORGANIC INDICATORS
LIFE
SEARCH FOR EVIDENCE OF LIFE

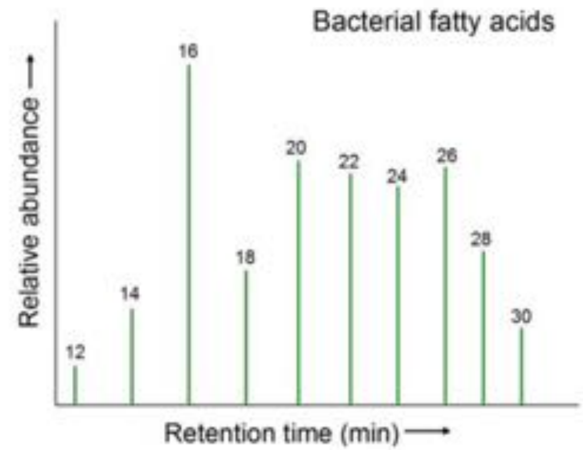
Organic Detection & Characterization



Abiotic organic synthesis
- Low specificity

Biological organic synthesis
- High specificity





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

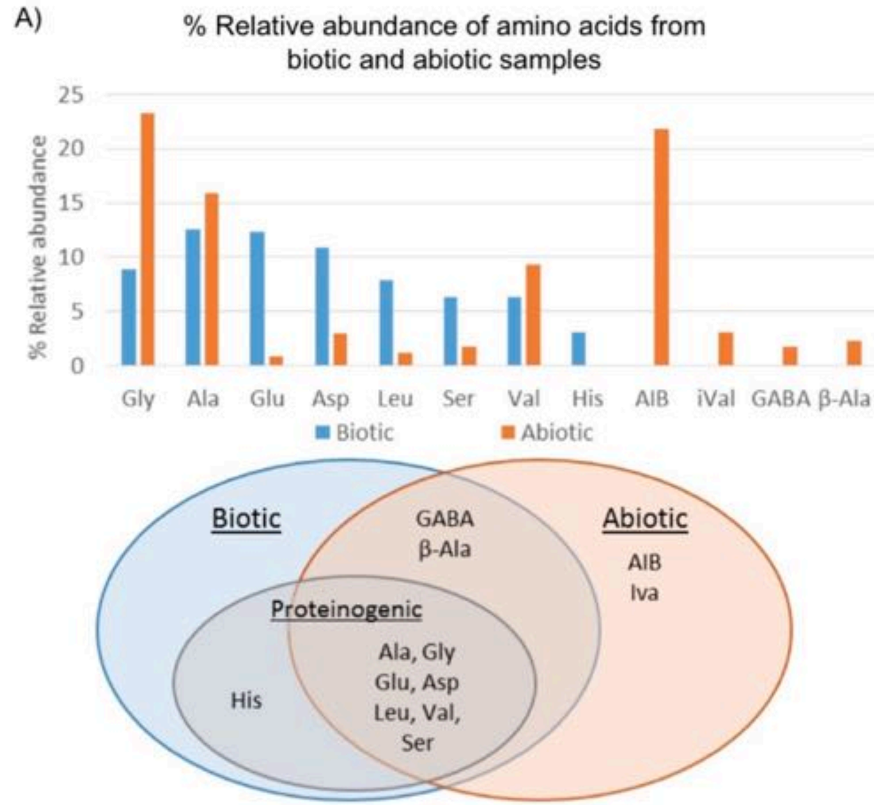
Organic Detection & Characterization: Amino acids

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



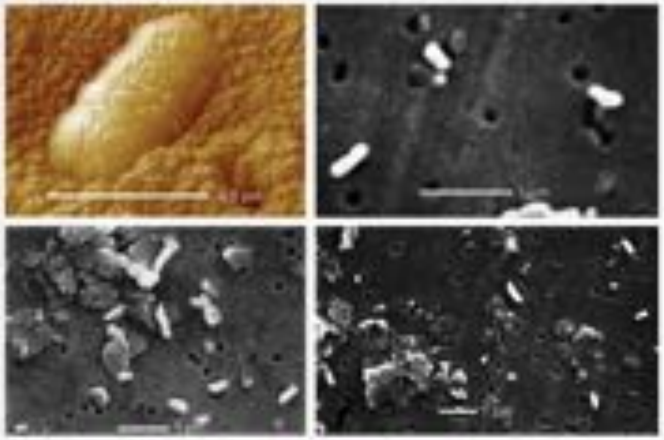
Creamer et al., (2017)

Measurement requirement:

- **Organic Carbon:** Determine presence, identities & relative abundance (**1 picomole in a 1 gram sample**). Molecular weight distribution to at least 500 amu and bulk structural characteristics of any organics to **1 picomole in a 1 gram sample**.

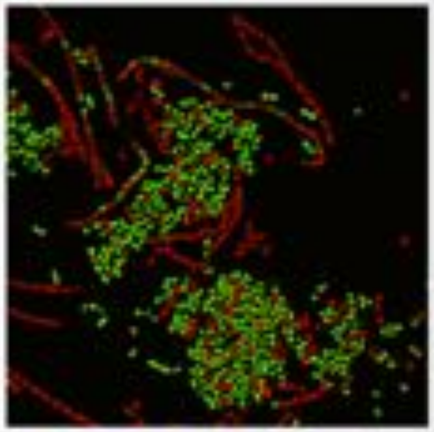
Biosignature Framework

MORPHOLOGIC INDICATORS



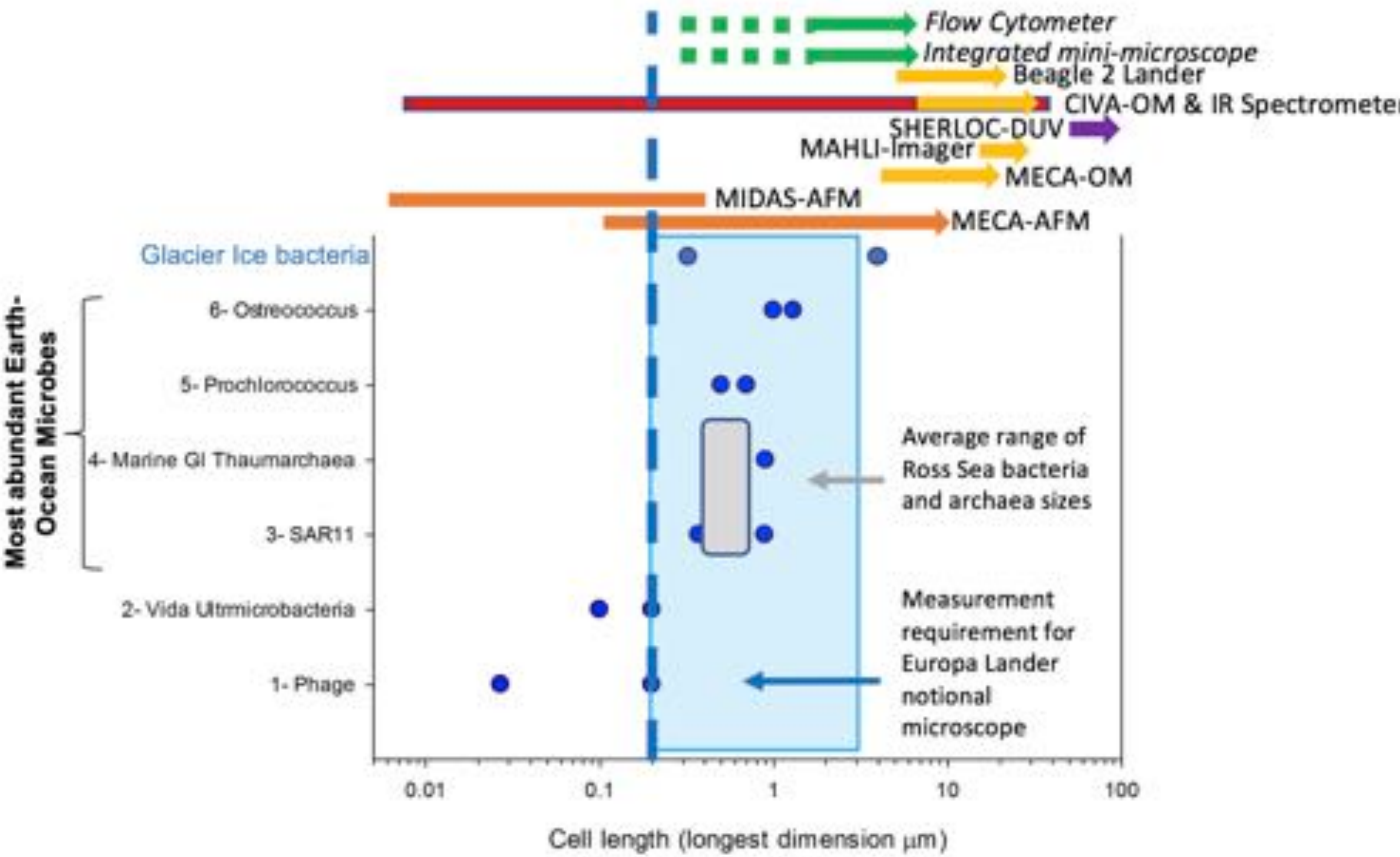
MICROSCALE STRUCTURES

MACROSCALE STRUCTURES



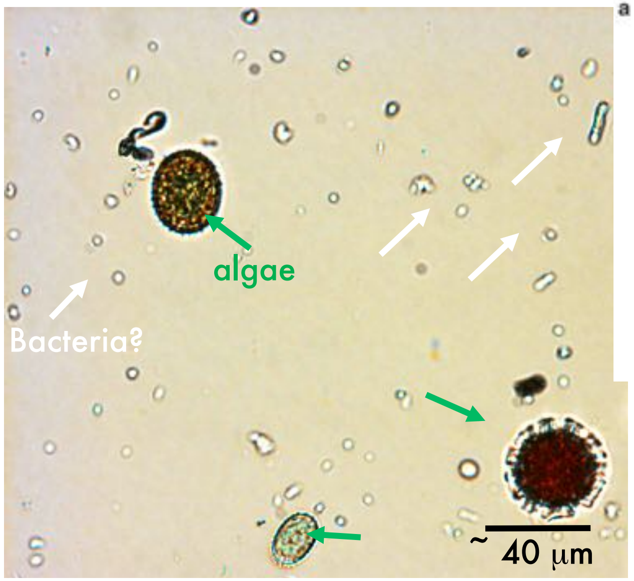
CELLULAR PROPERTIES

Earth Benchmark Environments

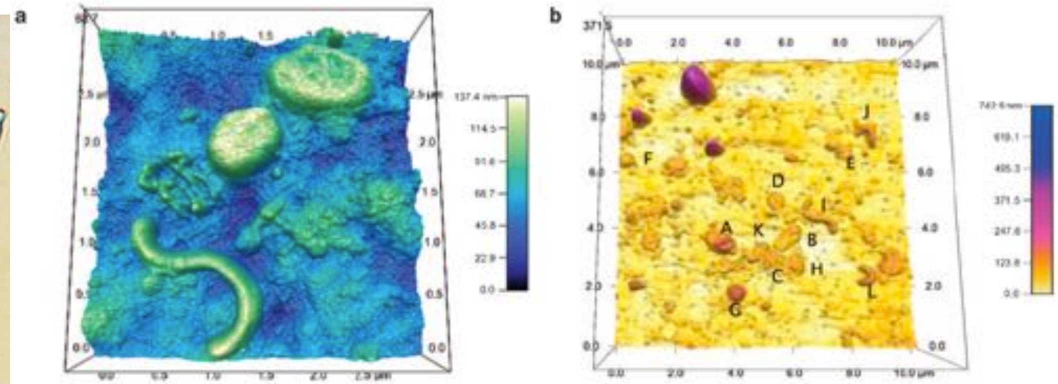


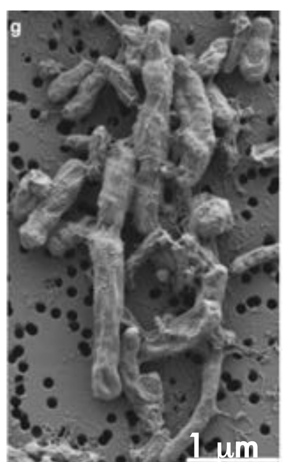
Microscopic Capabilities

Light Microscopy (400X mag):
Snow microbiota



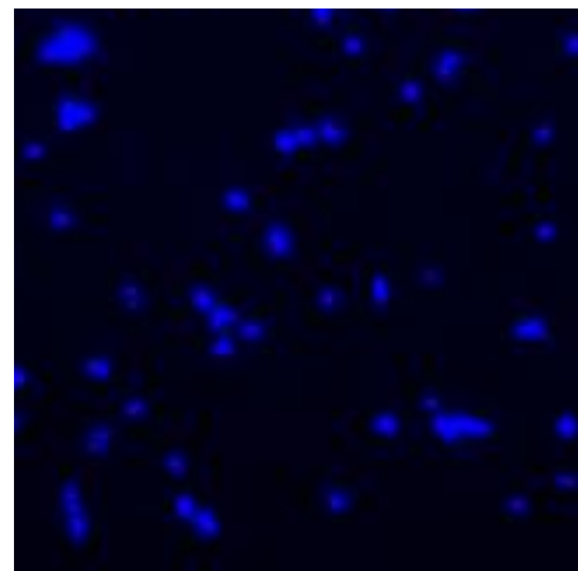
Atomic force microscopy:
Marine bacteria





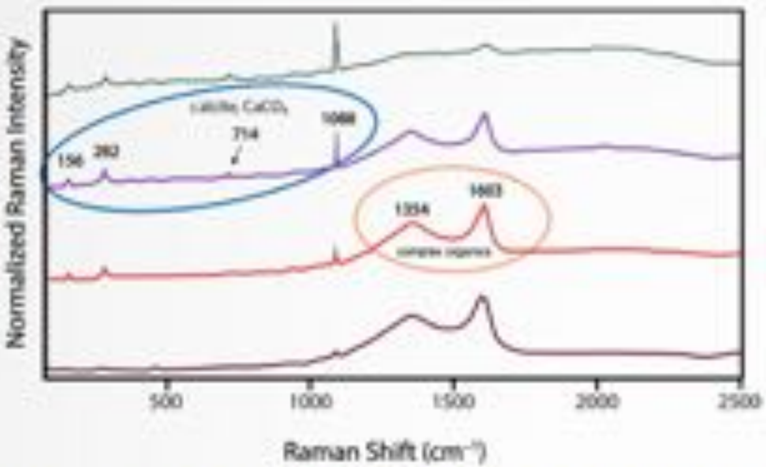
Scanning electron microscopy:
Glacial ice bacteria

Fluorescence microscopy:
Antarctic marine bacteria with DNA-binding stain



Biosignature Framework

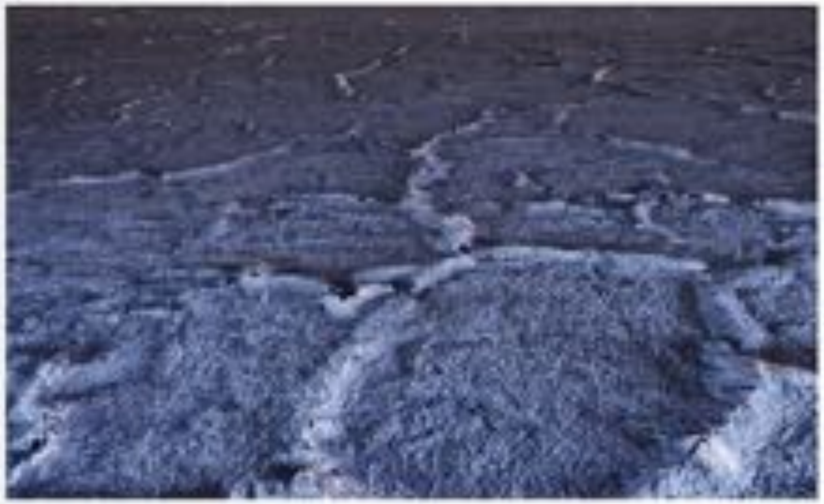
INORGANIC INDICATORS



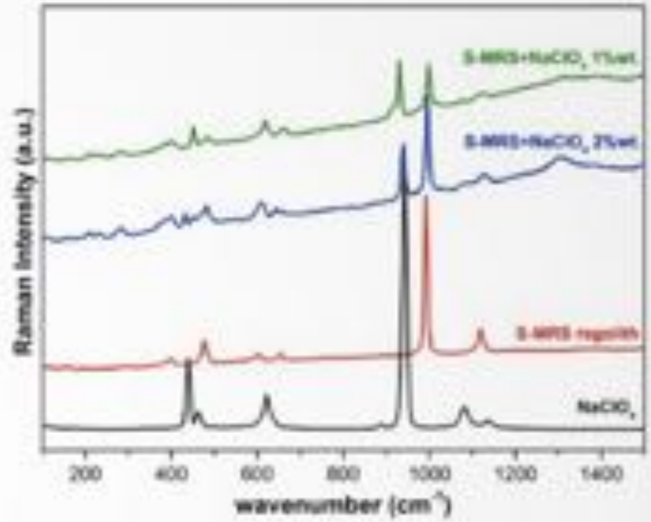
INORGANIC COMPOSITION

BIOMINERALS

PROVENANCE

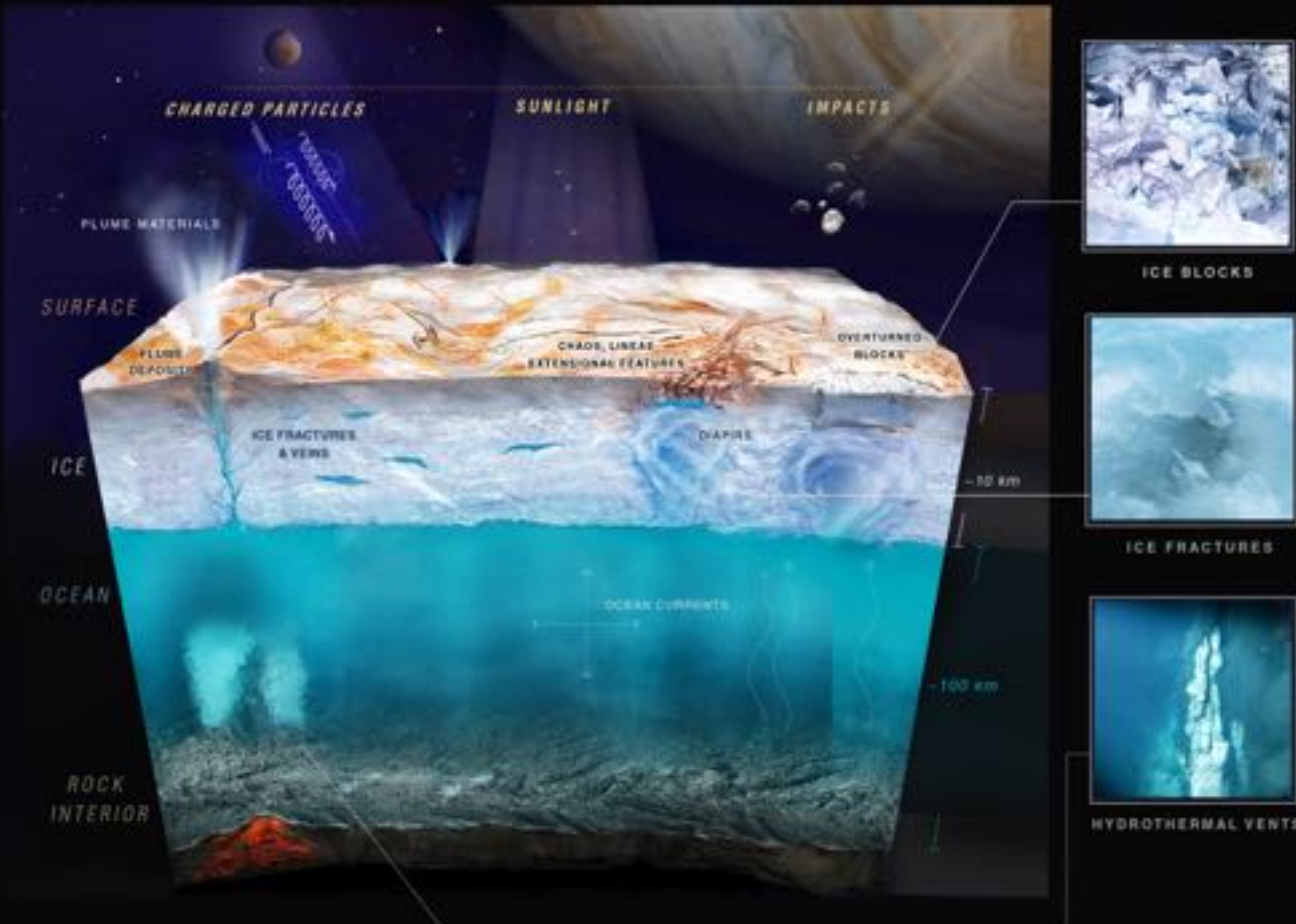


GEOLOGICAL CONTEXT



ENDOGENOUS vs. EXOGENOUS ORIGINS AND PROCESSING

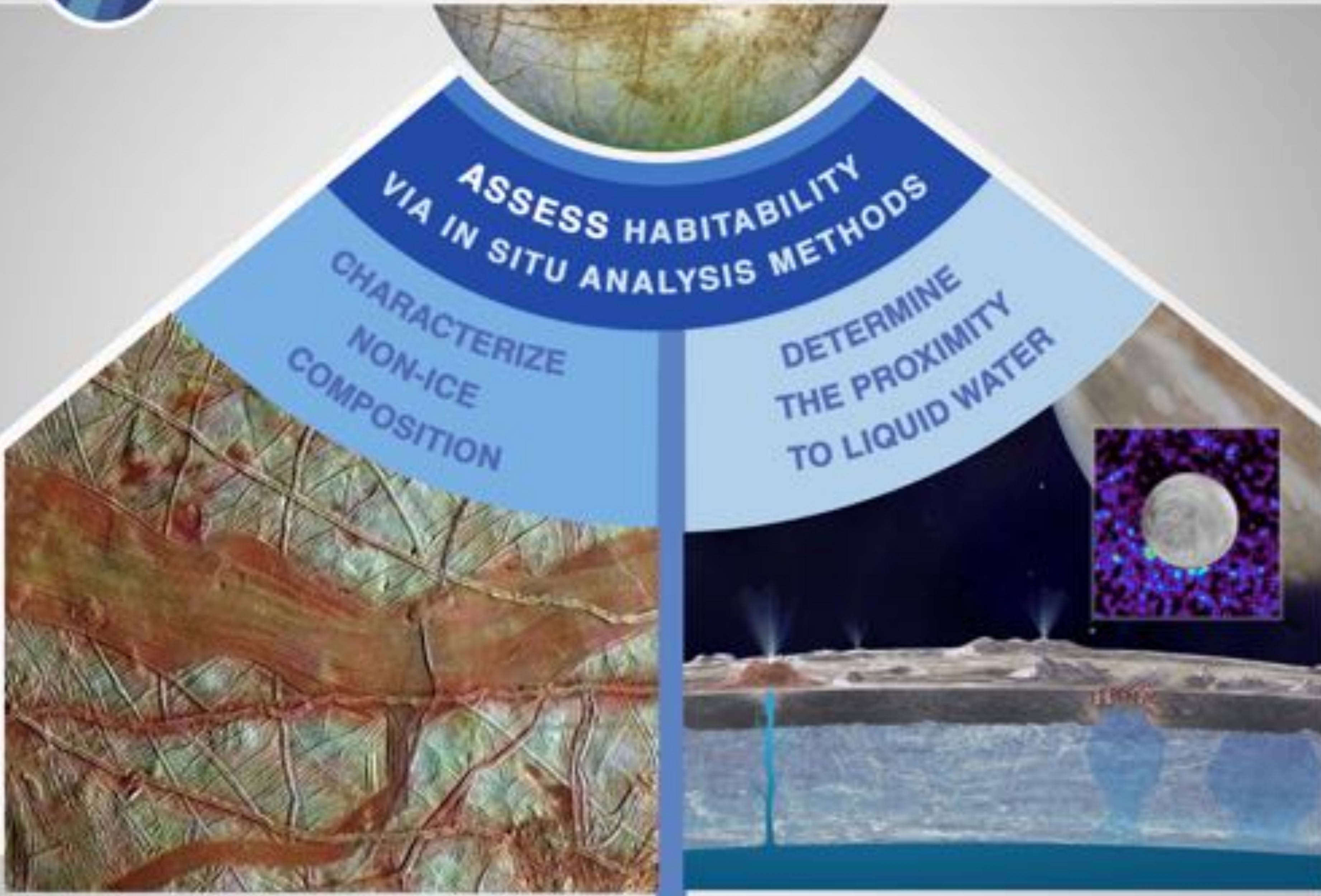
EUROPA



CHARGED PARTICLES
SUNLIGHT
IMPACTS
PLUME MATERIALS
SURFACE
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

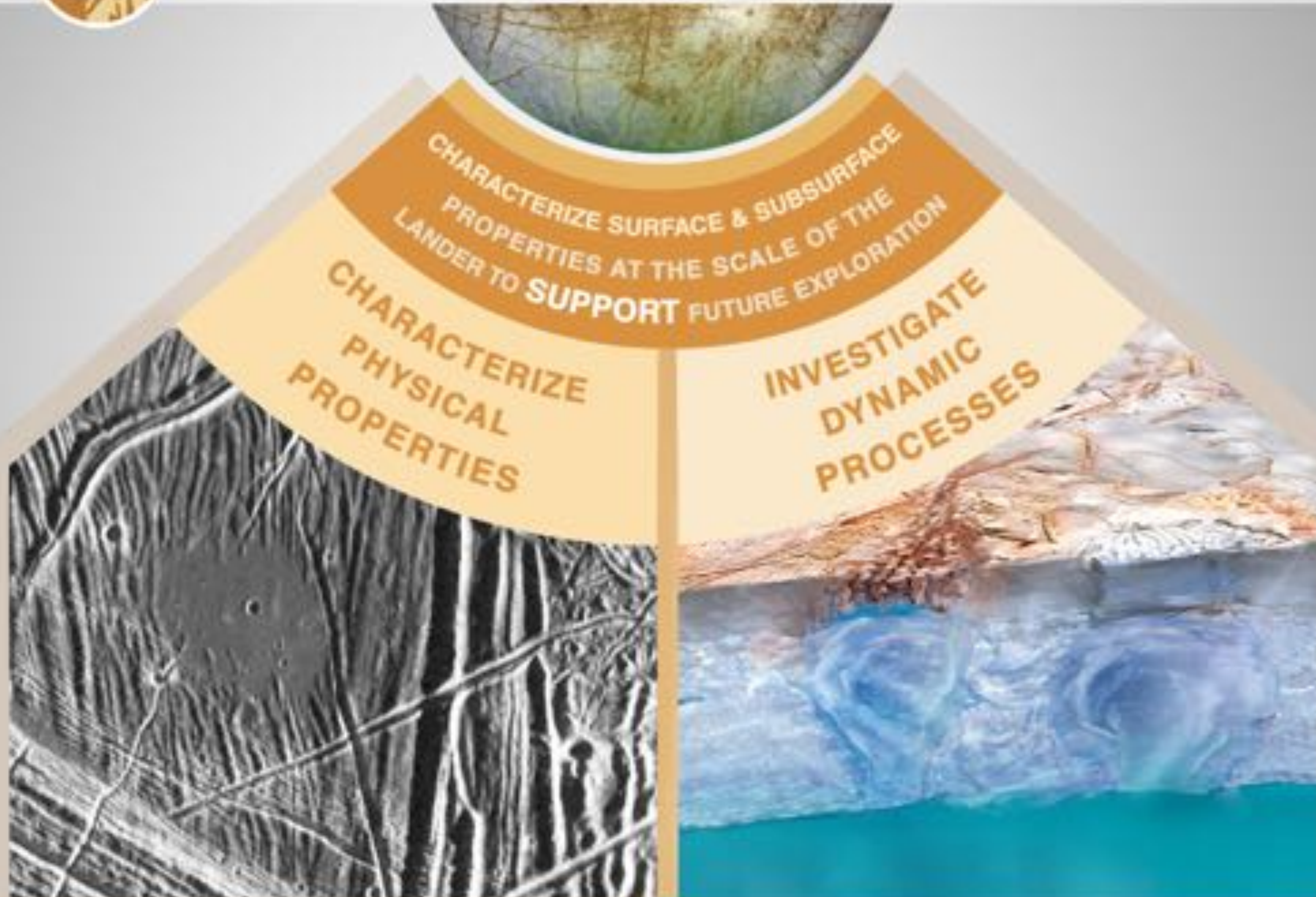
Biosignature Framework

HABITABILITY

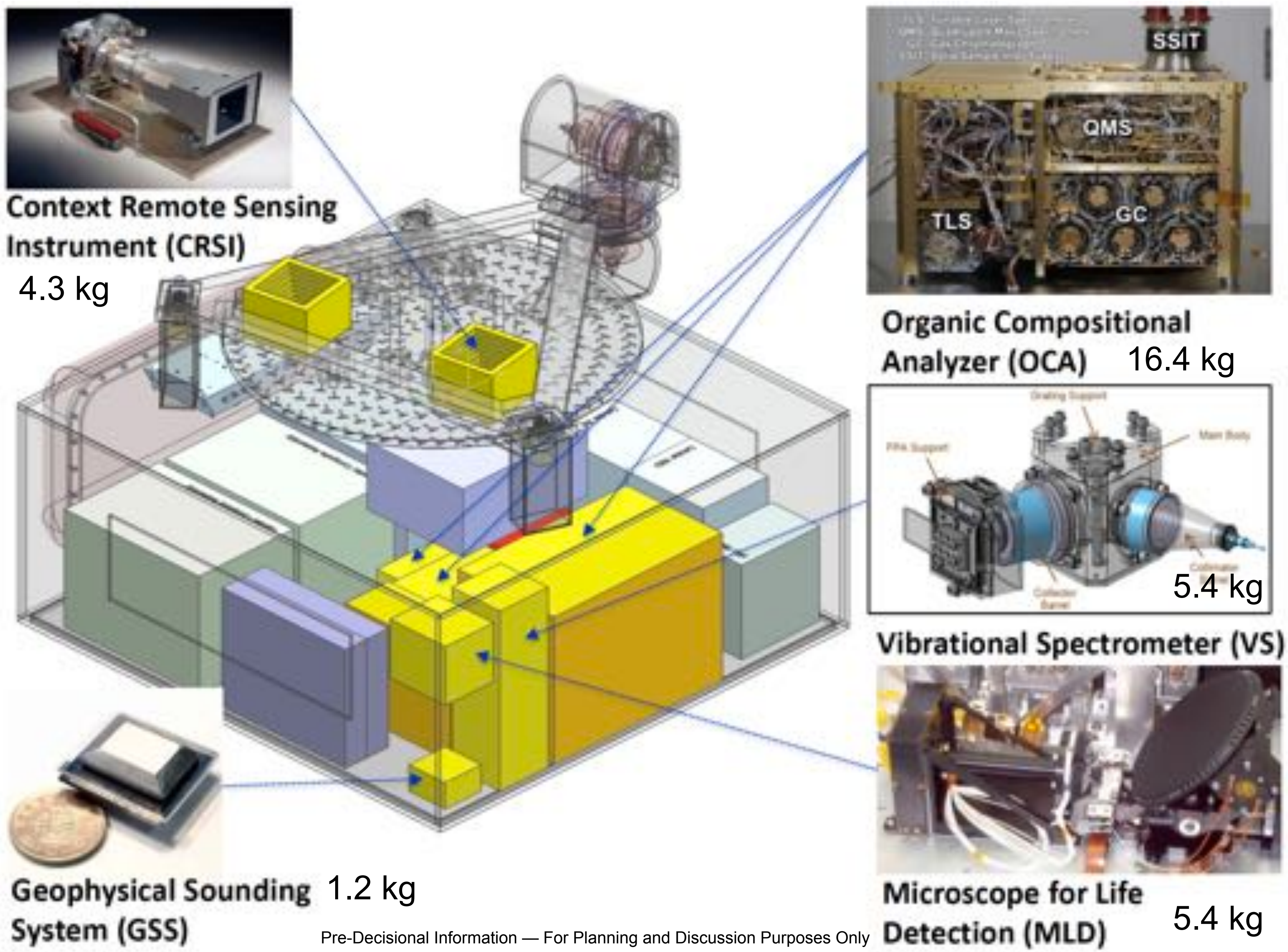


Biosignature Framework

CONTEXT

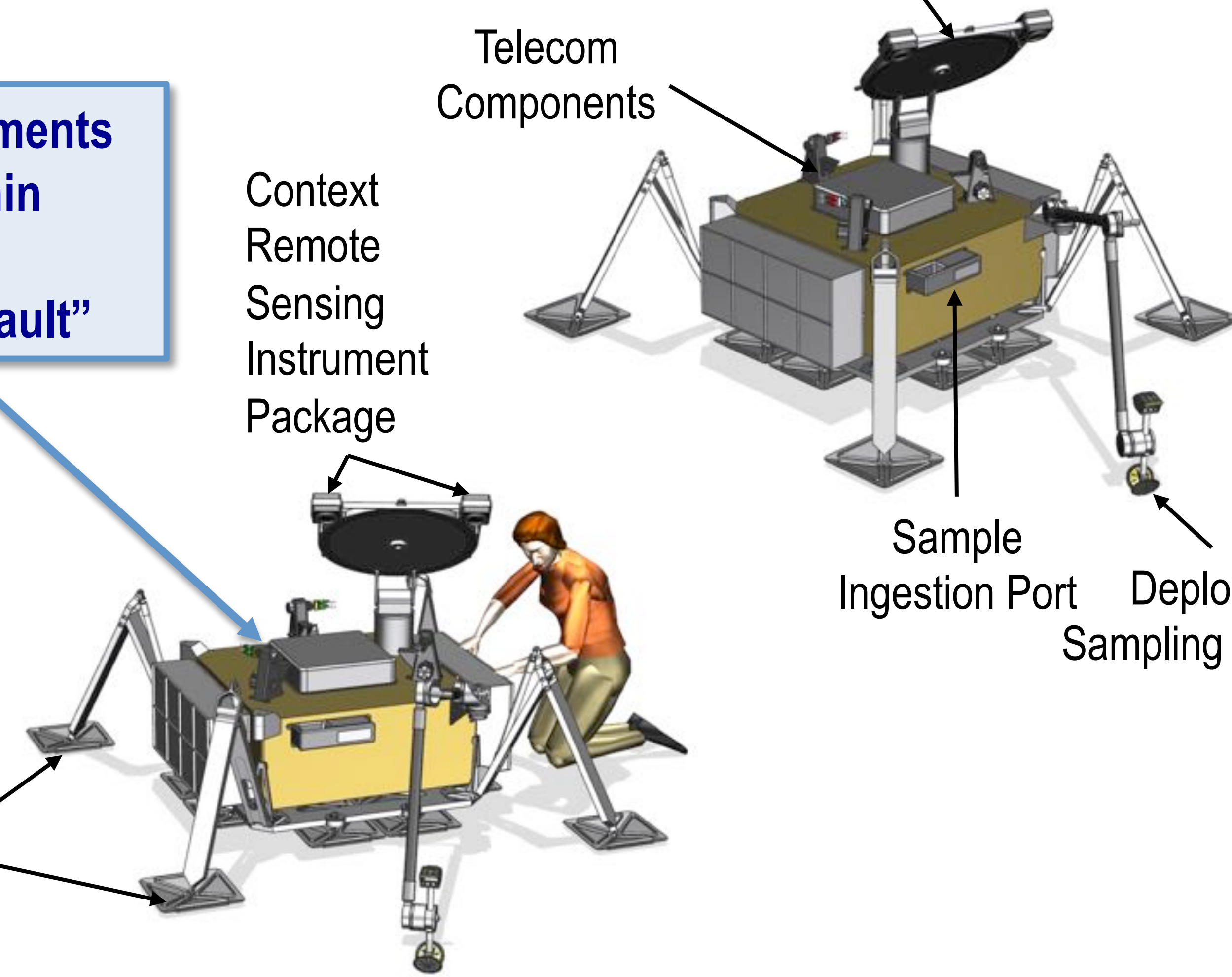


Mission Concept Payload Allocation: 42.5 kg (with margin, sampling system held separately)



Lander Accommodates Model Instrument Payload and Supporting Equipment

Most instruments located within protective radiation “vault”



Searching for Signs of Life: Lessons from Viking

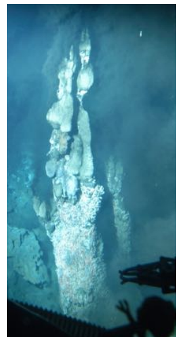
- If the payload permits, conduct experiments that assume contrasting definitions for life.
- **Given limited payload, the biochemical definition of life deserves priority**.
- Establishing the geological and chemical context of the environment is critical.
- **Life-detection experiments should provide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

Viking Results: Then & Now

DNA discovered

Hydrothermal vents discovered



Archaea discovered (3rd domain of life)

Cryptoendoliths in Antarctica discovered

PCR Invented

Europa Lander SDT Report delivered

1953

1976

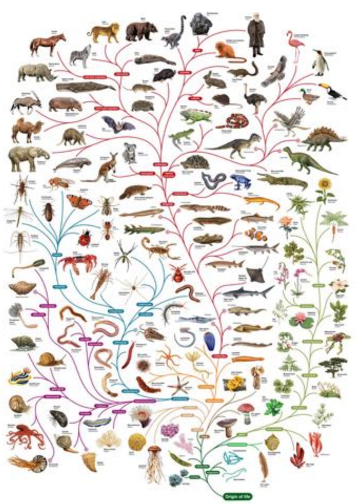
1977

1983

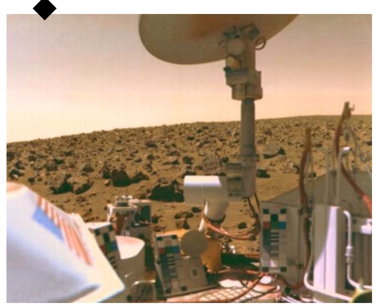
2003

2016

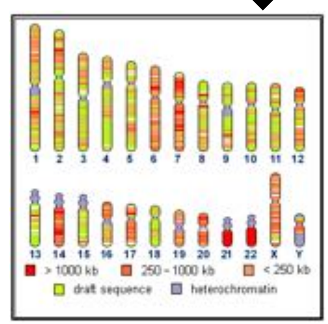
2017



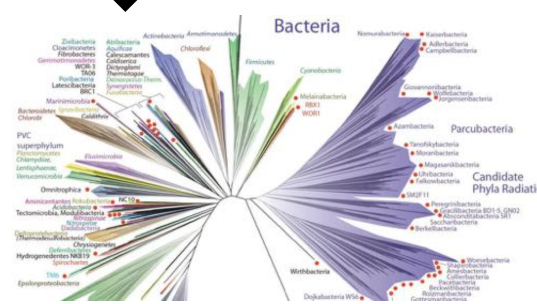
Tree of Life Then…



Viking Landers



Human genome sequenced



…Tree of Life Now.

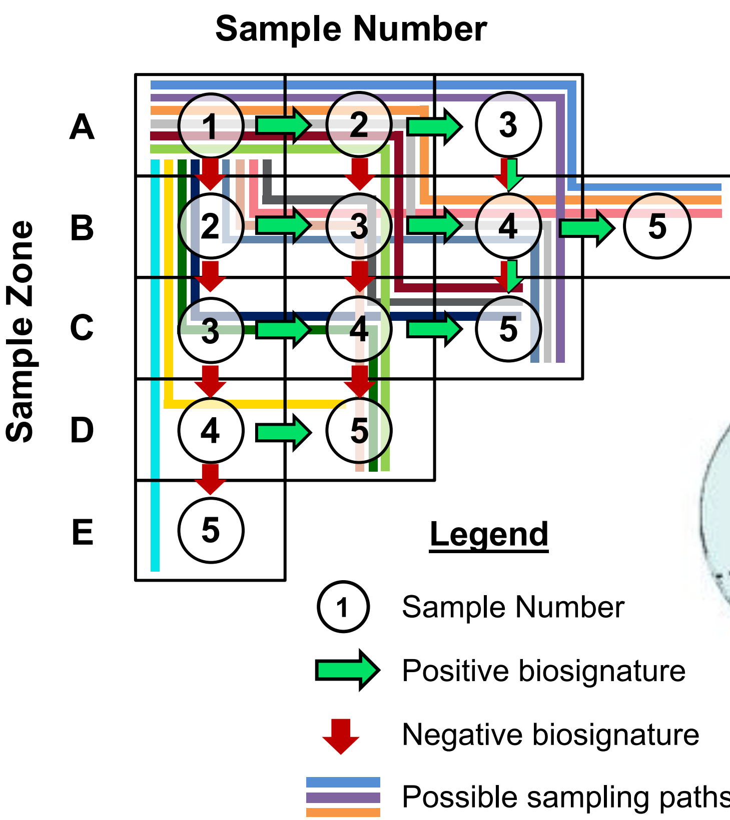
Framework for Sampling & Life Detection

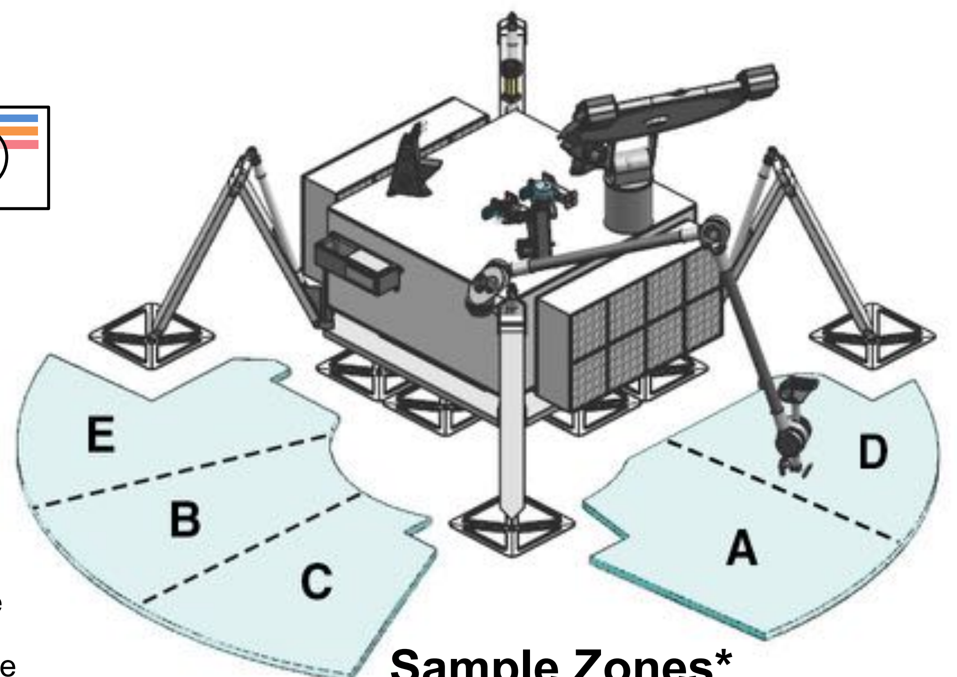
Sample Analysis Scenarios	GCMS				Microscope		Raman	Context Remote Sensing		Biosignature Result
	Abundance	Pattern	Chirality	Isotopes	Cell-like structures	Cellular properties	Biominerals	Context	Endo vs Exo	
	1	1	1	1	1	0	1	1	1	1

Sampling and Measurement Sequence can be Designed Ahead of Time for Rapid Execution

Five Samples Provide Sufficient Measurement Set to Sample Multiple Work Areas and Identify Biosignatures

- 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-EMFM’ Science Scenarios

EMFM could lead to one of four scenarios:

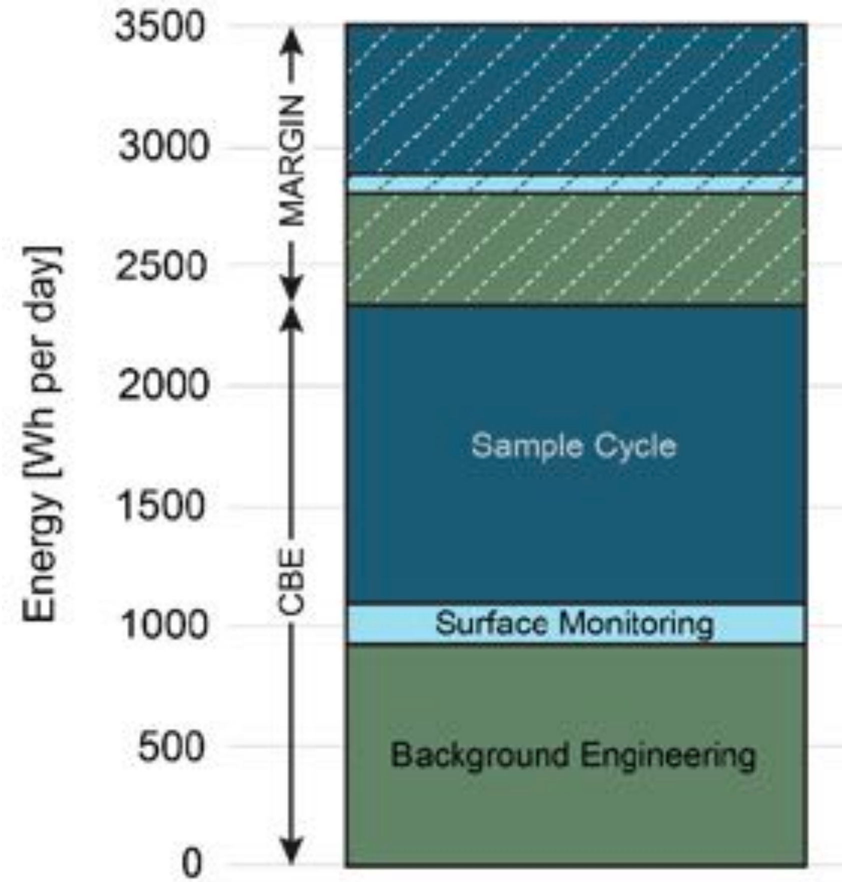
- Not Habitable
  - Europa Lander would be critical for determining why (e.g. detection limits on carbon; geological activity).
- Maybe Habitable
  - Lander critical to resolving ambiguity of remote sensing.
- Habitable
  - Lander needed to detect and characterize any potential biosignatures.
- Inhabited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

Mission Concept Enables 5+ Samples

Batteries provide

45 kWh

of energy for surface operations.

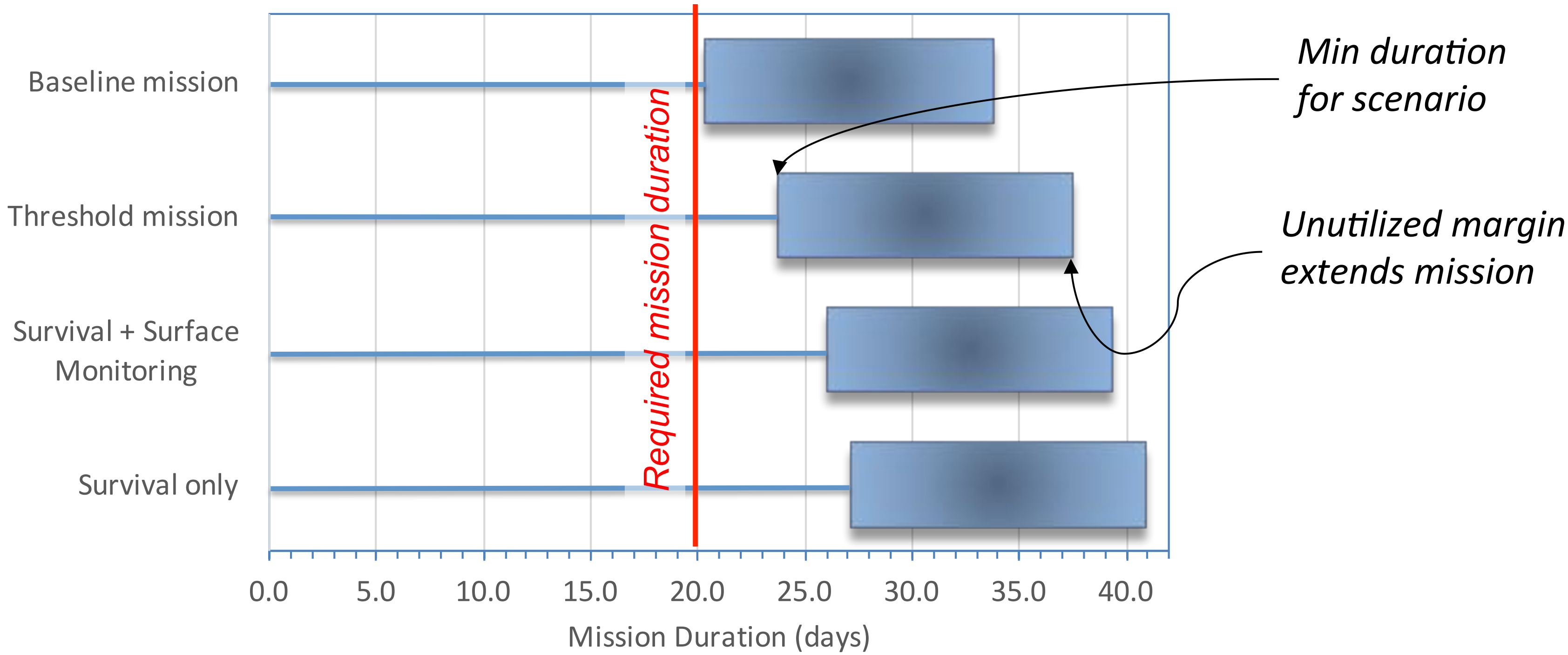


Baseline mission scenario:

20 day lifetime

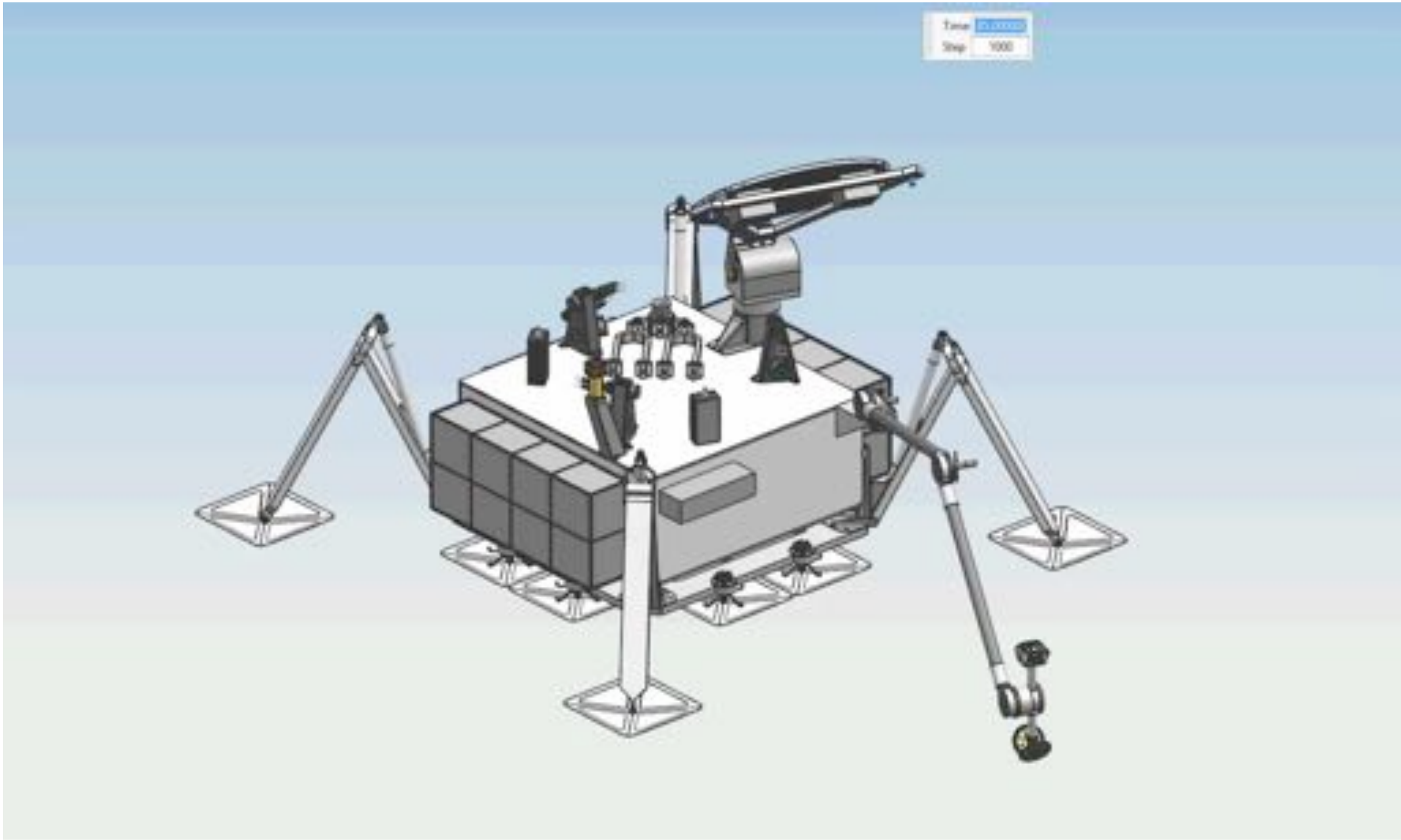
[5 days for sampling + 15 days for monitoring/ contingency]

Mission Duration: 45 kWh



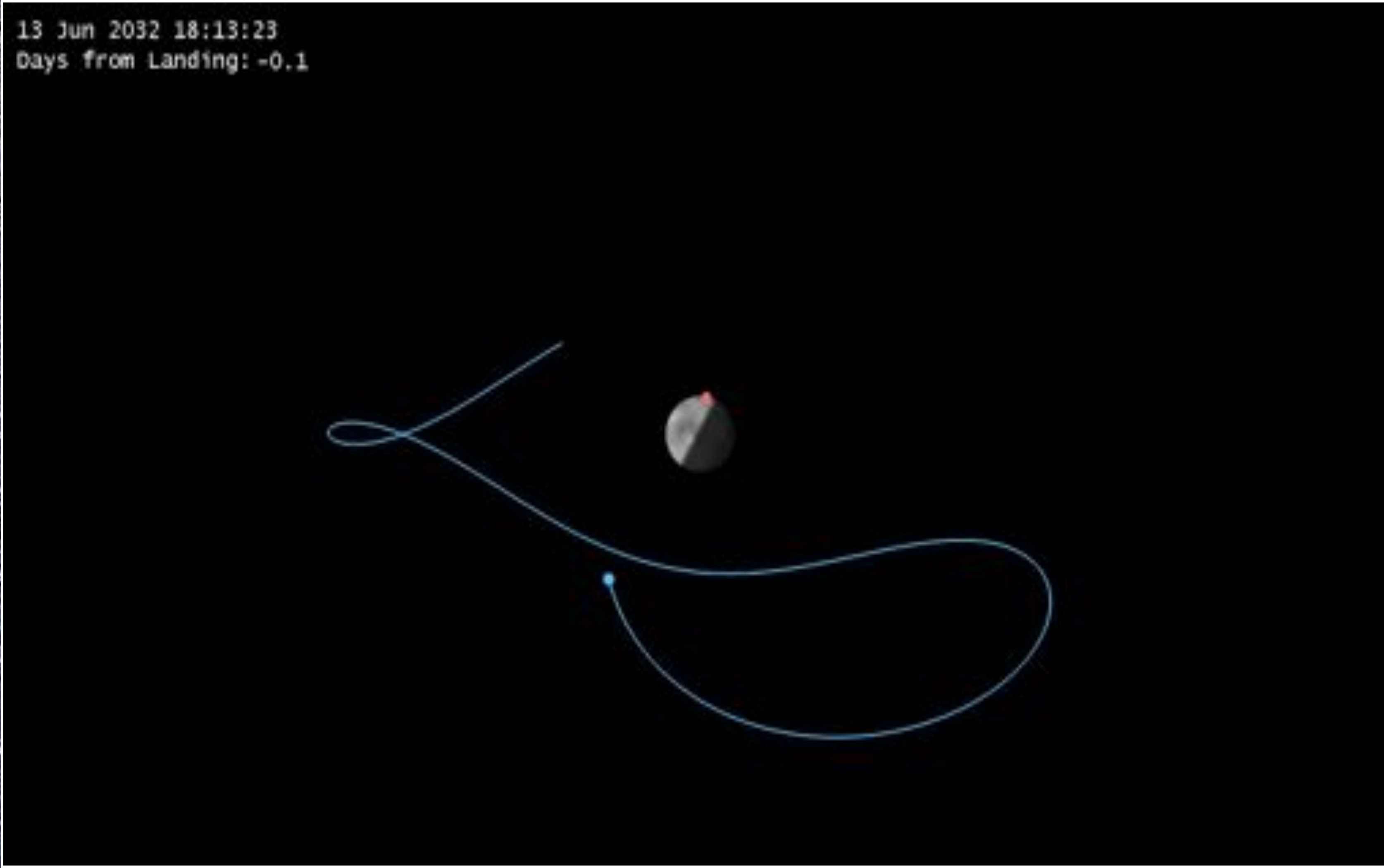
Mission scenario	# Samples	Monitoring tals	Survival tals
Baseline mission	5	continuous	0
Threshold mission	3	7	remainder
Survival + monitoring	0	continuous	0
Survival only	0	0	continuous

Lander Workspace Panorama & Sampling System Deployment



Pre-Separation

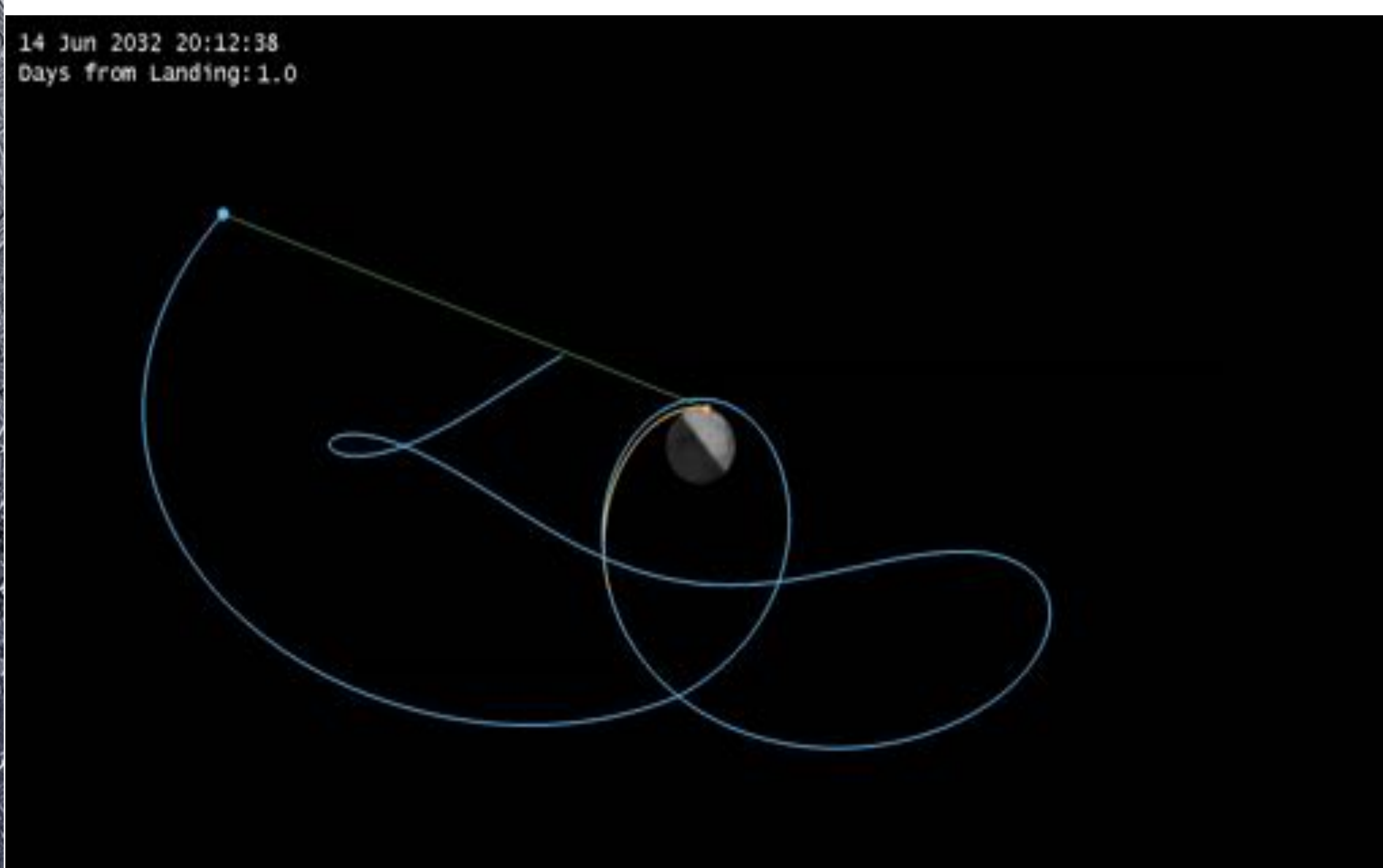
Separation to Landing



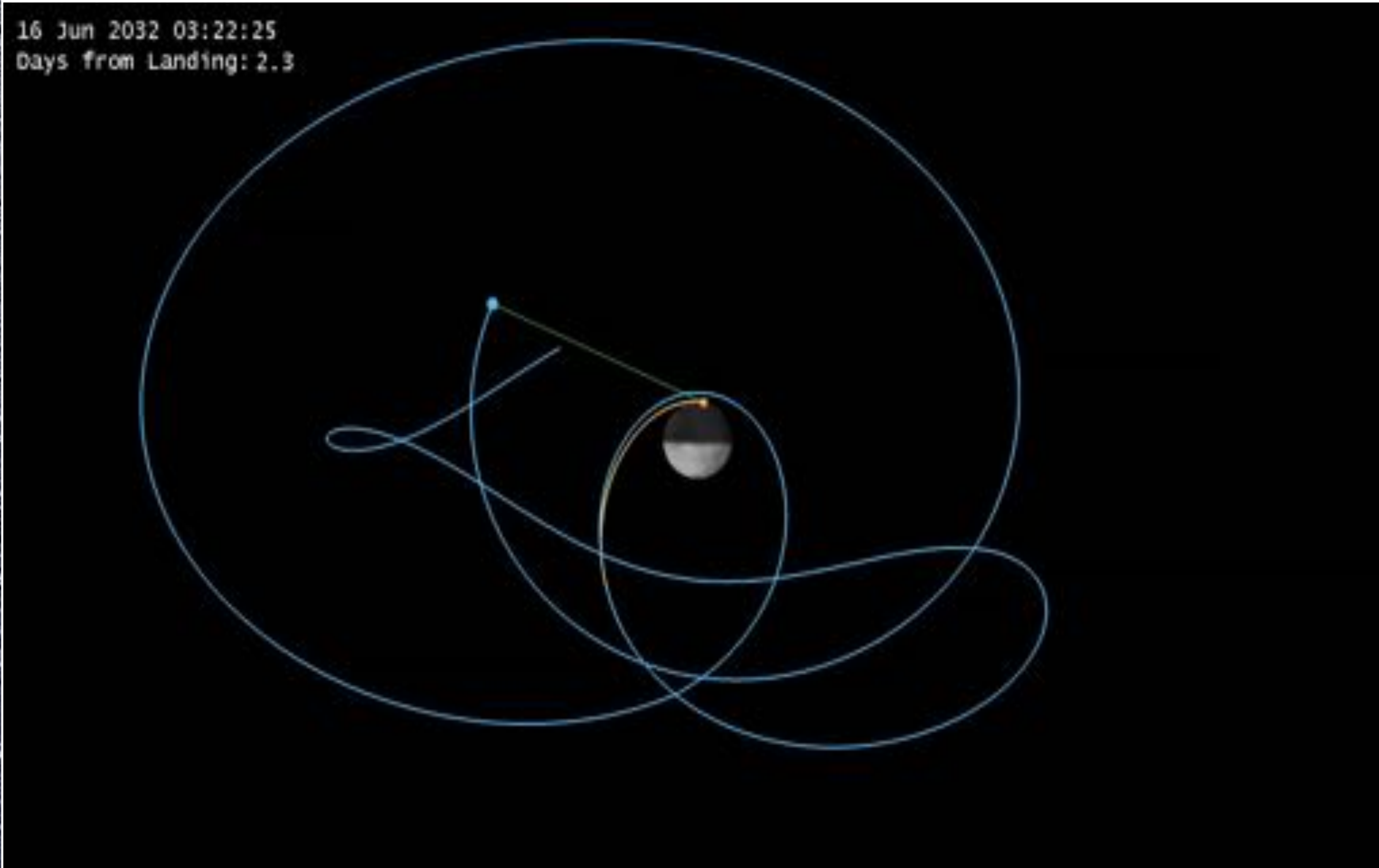
Landing to End of Landing Pass

End of Landing Pass to First Relay Pass

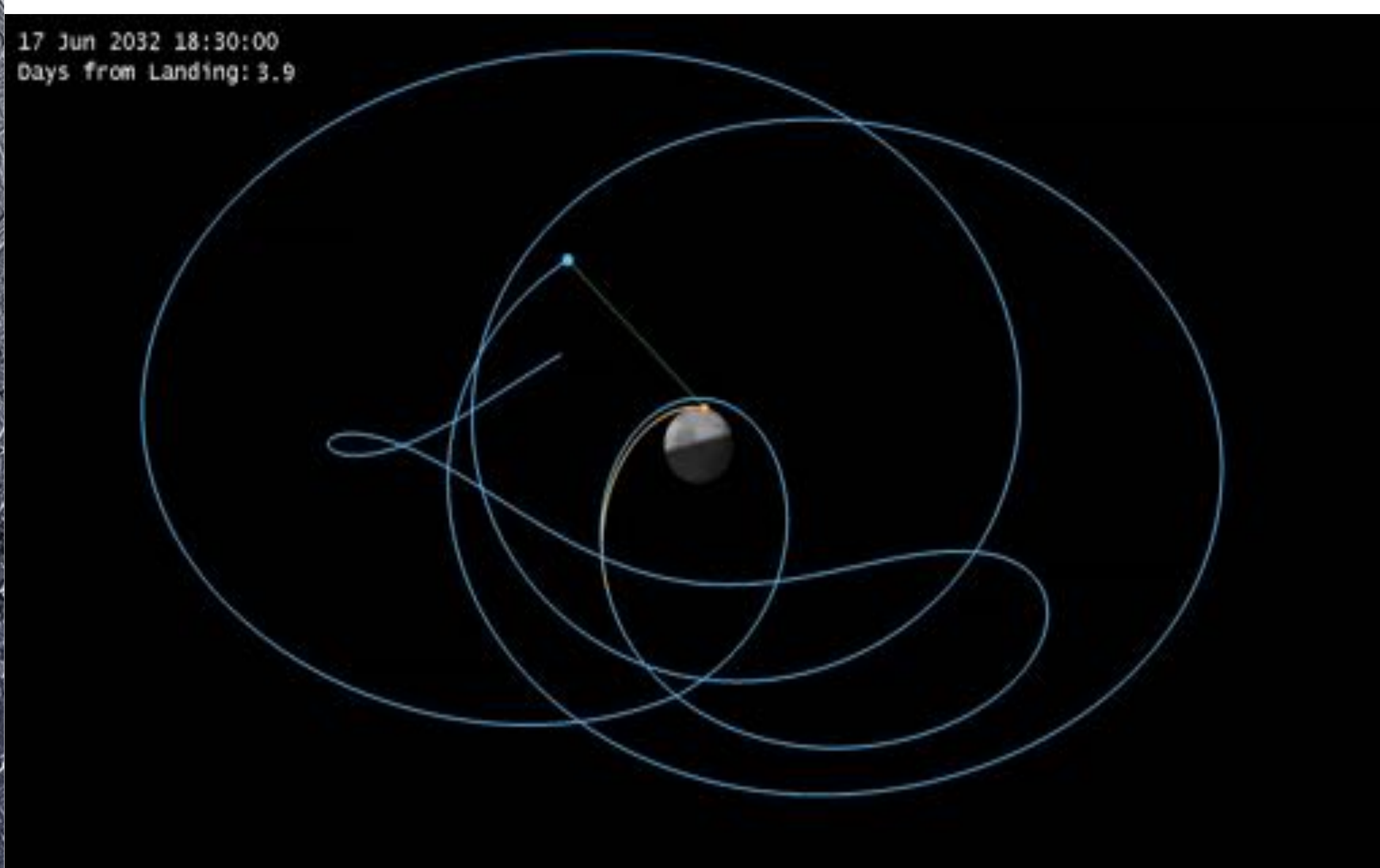
First Relay Pass to Second Relay Pass



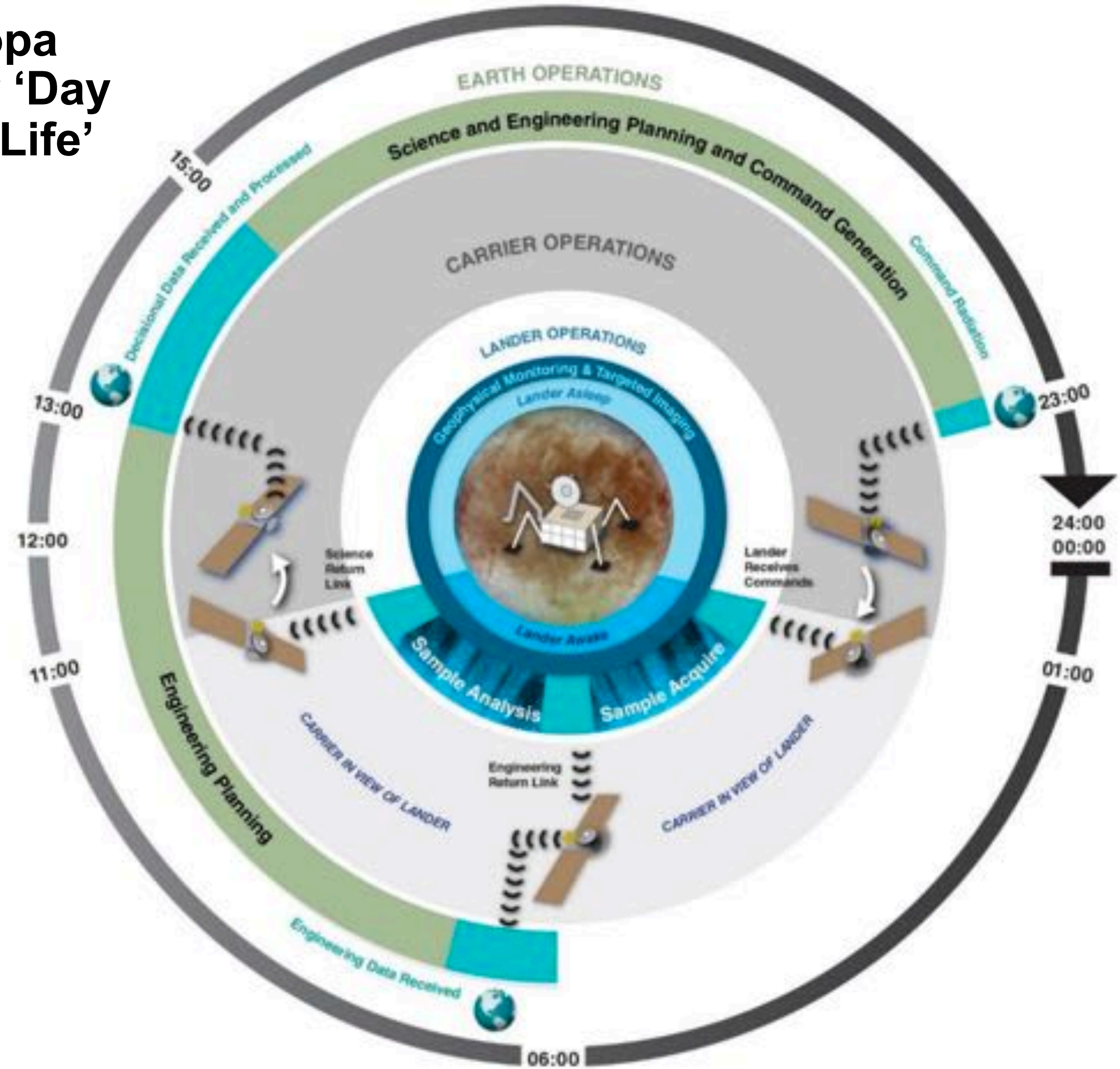
Second Relay Pass to Relay Orbit Insertion



Initial Relay Orbits

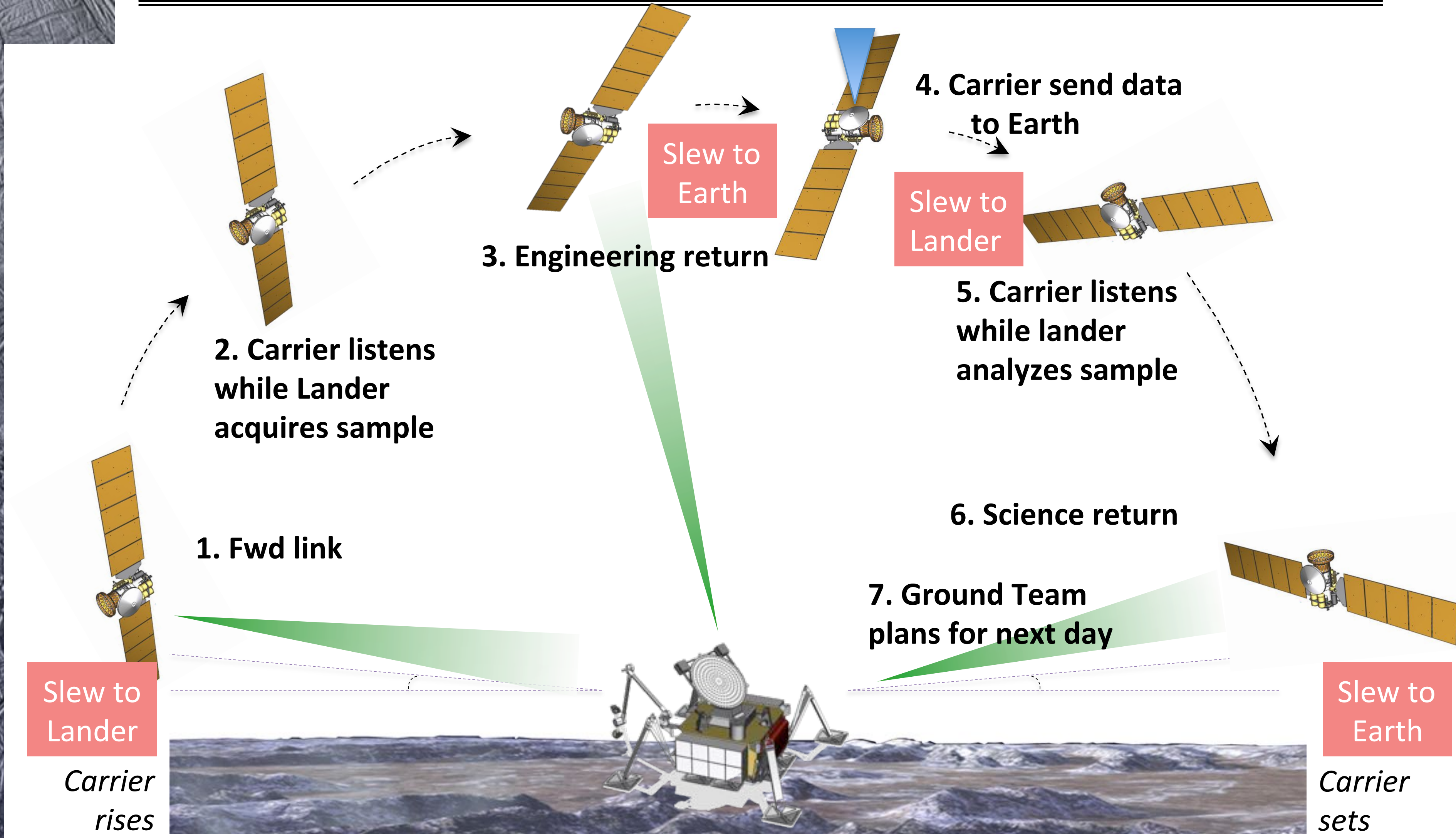


Europa Lander 'Day in the Life'

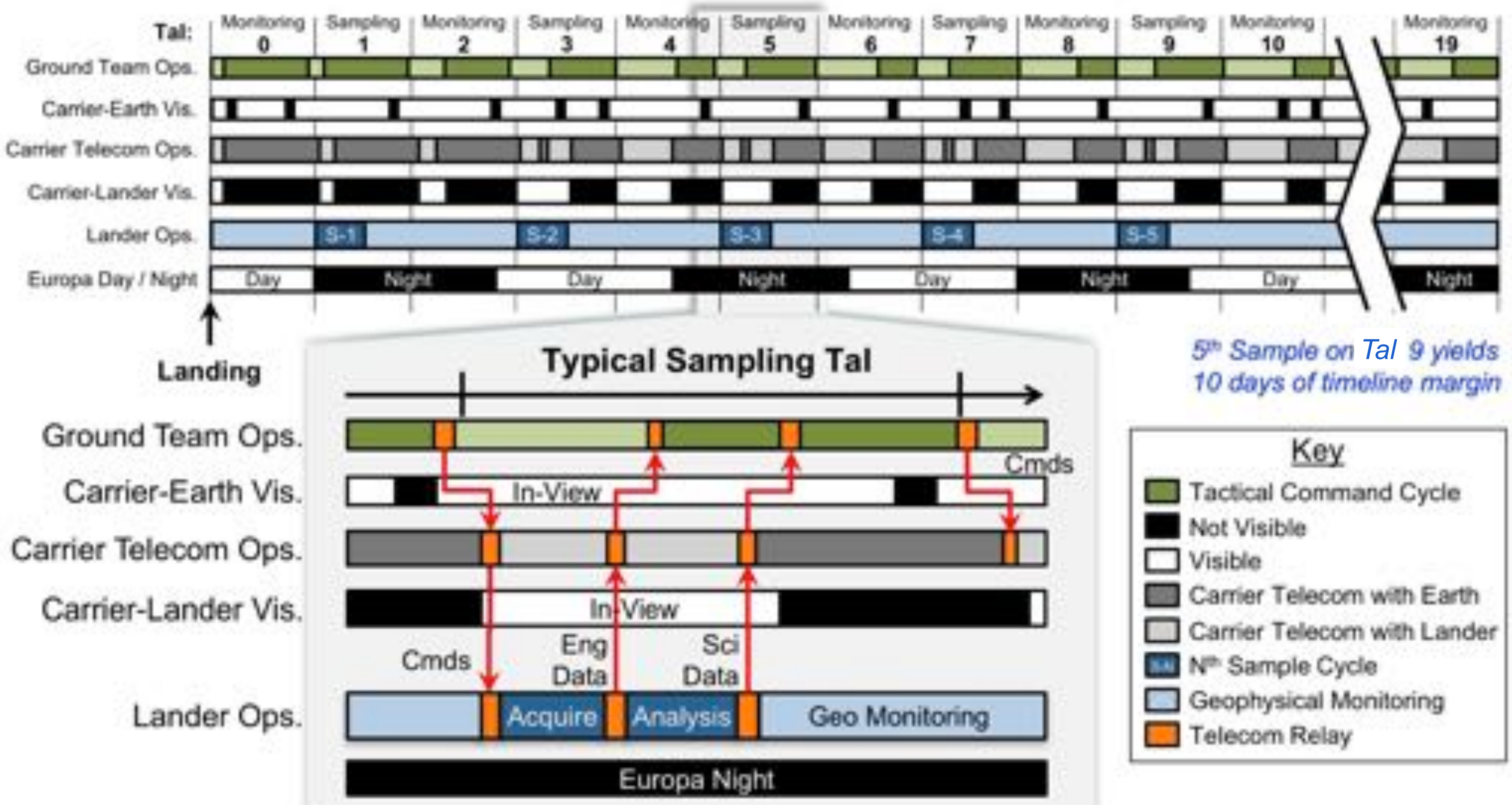


A Day in the Life of Lander

Relay Operations



Europa Lander Surface Phase



- Baseline mission achieved in 10 days
  - One full sample cycle completed in one Earth day
  - Five sample cycles could be done back-to-back
- 20 day prime mission provides 100% contingency
- Extended mission possible based on battery margin

Europa Lander Surface Lifetime

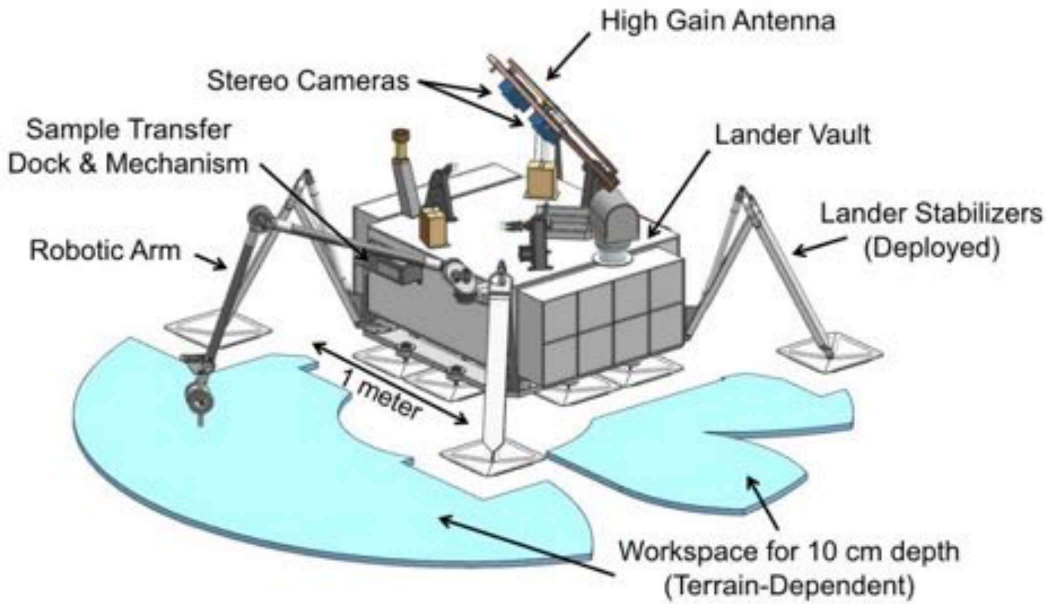
Trades & Considerations:

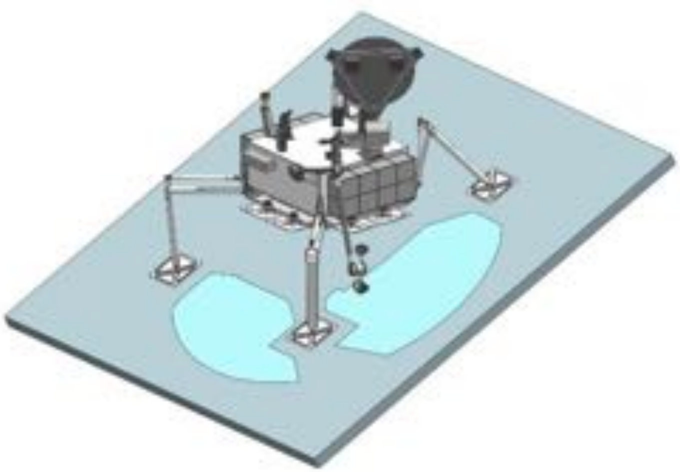
- Lander was required to bring a carrier-relay for data uplink/ downlink to Earth
  - Carrier Relay Orbiter (CRO) lifetime limited by radiation environment (~30 days).
  - EMFM could only be used for backup.
  - Direct-to-Earth (DTE) options are too massive.
- Radioactive Power Source (RPS) option
  - 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.

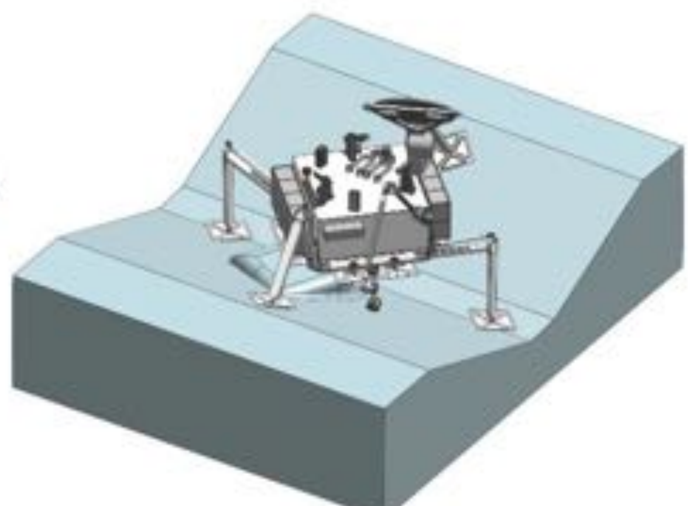
EMFM-Lander Cadence

- Landing site recon must be acquired close in time prior to landing so as to ensure accurate knowledge of site.
- Without timely EMFM recon, any future lander would need to carry its own recon suite.
- Mechanical configuration unlikely to change much between EMFM vs. post-EMFM design
  - Decimeter-scale surface accommodation still required.
  - Mass is still going to be a limiting factor.

Lander Surface Accommodation Trade







Sampling System Trade Study

Mission	Tool	Excavation	Excavation to >> 1cm		Topography Robustness*	Sample Volume	Sample Temperature	Mass / Power
			Hard	Soft / Loose				
Viking Scoop								
Phoenix Scoop + Rasp	 							
MSL Drill								
Europa Lander Saw + Scoop + Rasp								

Europa Lander Example Trajectory

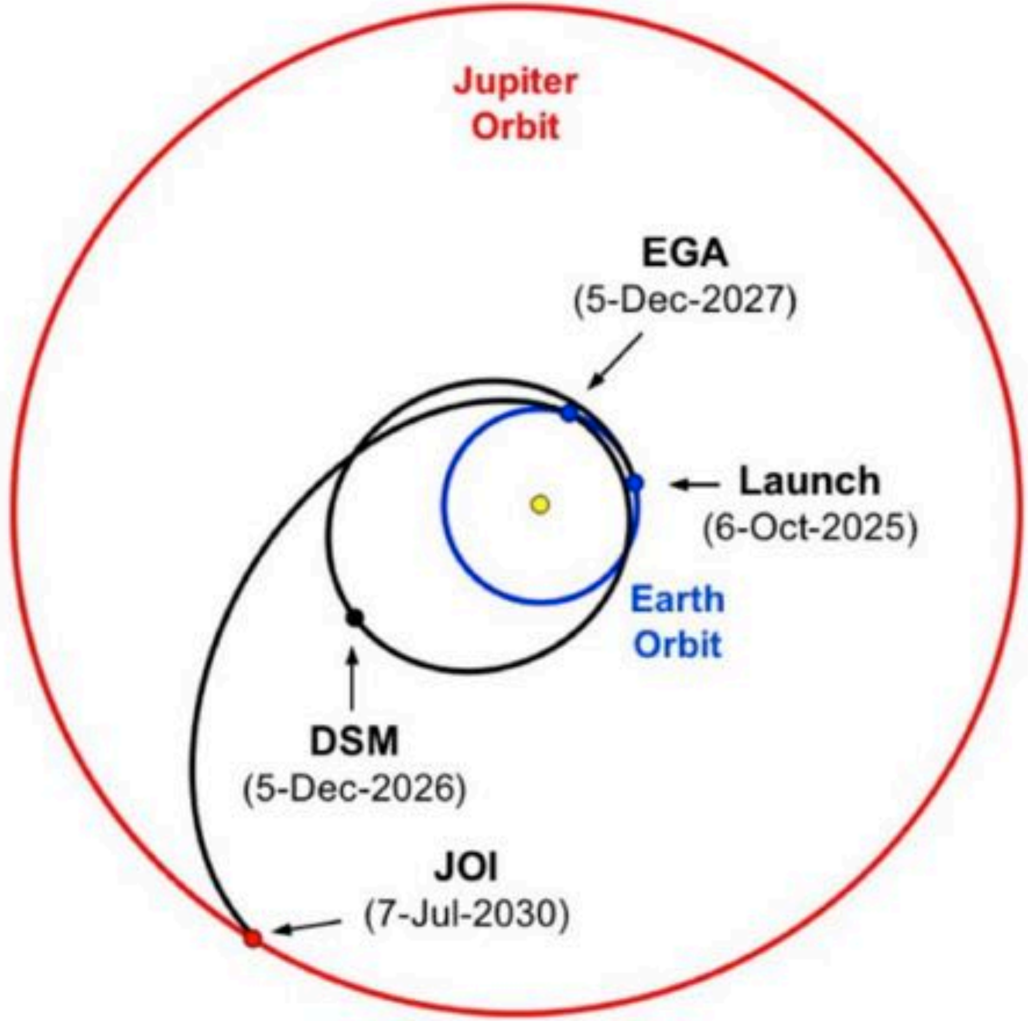
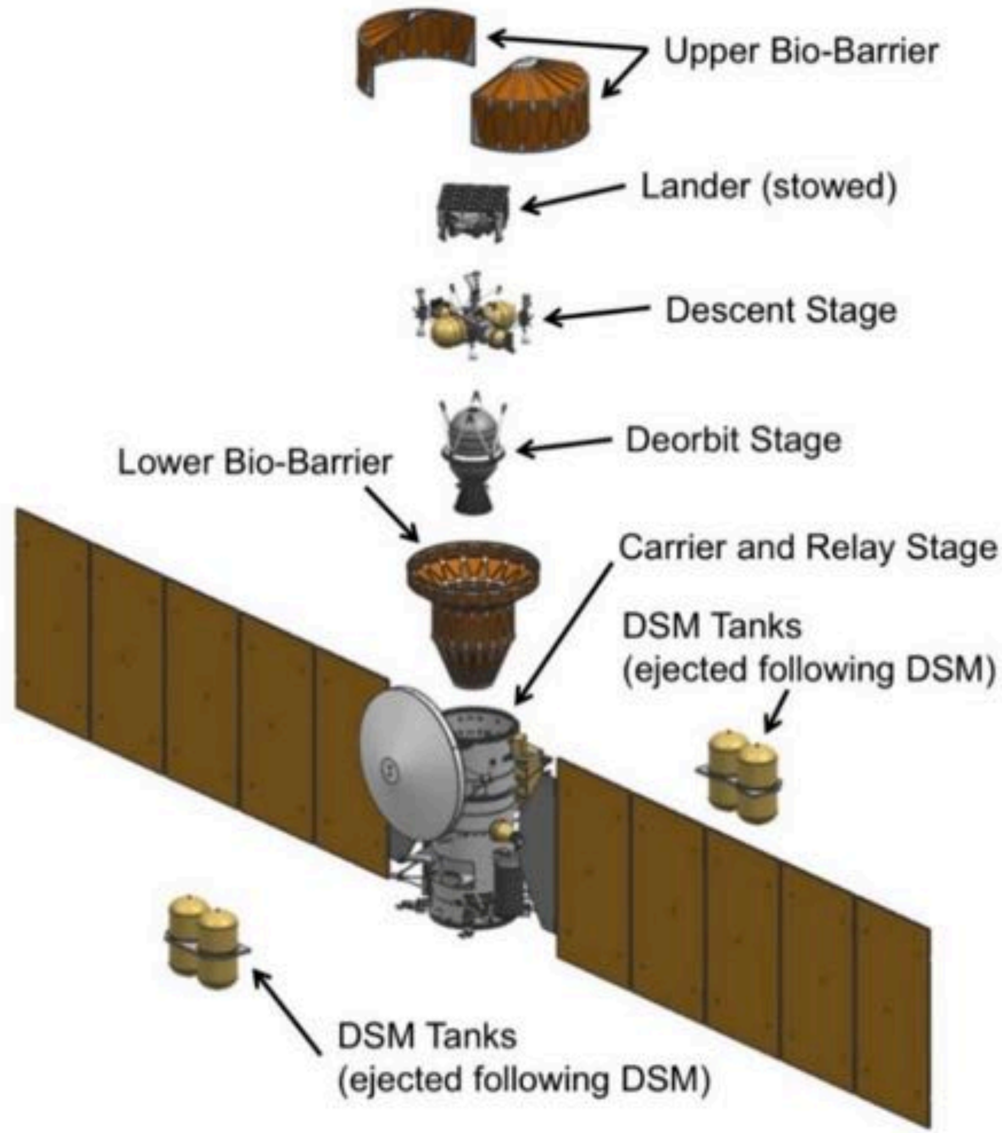


Figure 10.4. An example 2025 launch with a ΔV-EGA trajectory and a 4.8-year transfer time.

Europa Lander Integrated Spacecraft



Europa Lander 2003 Decadal Survey

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

Medium Initiatives

1. New technology developments to support future missions
2. Io Explorer
3. Ganymede Orbiter

Large Initiatives

1. Europa Geophysical Explorer
2. Titan Explorer
3. Europa Lander (Pathfinder or Astrobiology)
4. Neptune Orbiter

8. Does (or did) life exist beyond Earth?	Europa Lander Mars Sample Return

NRC, 2003

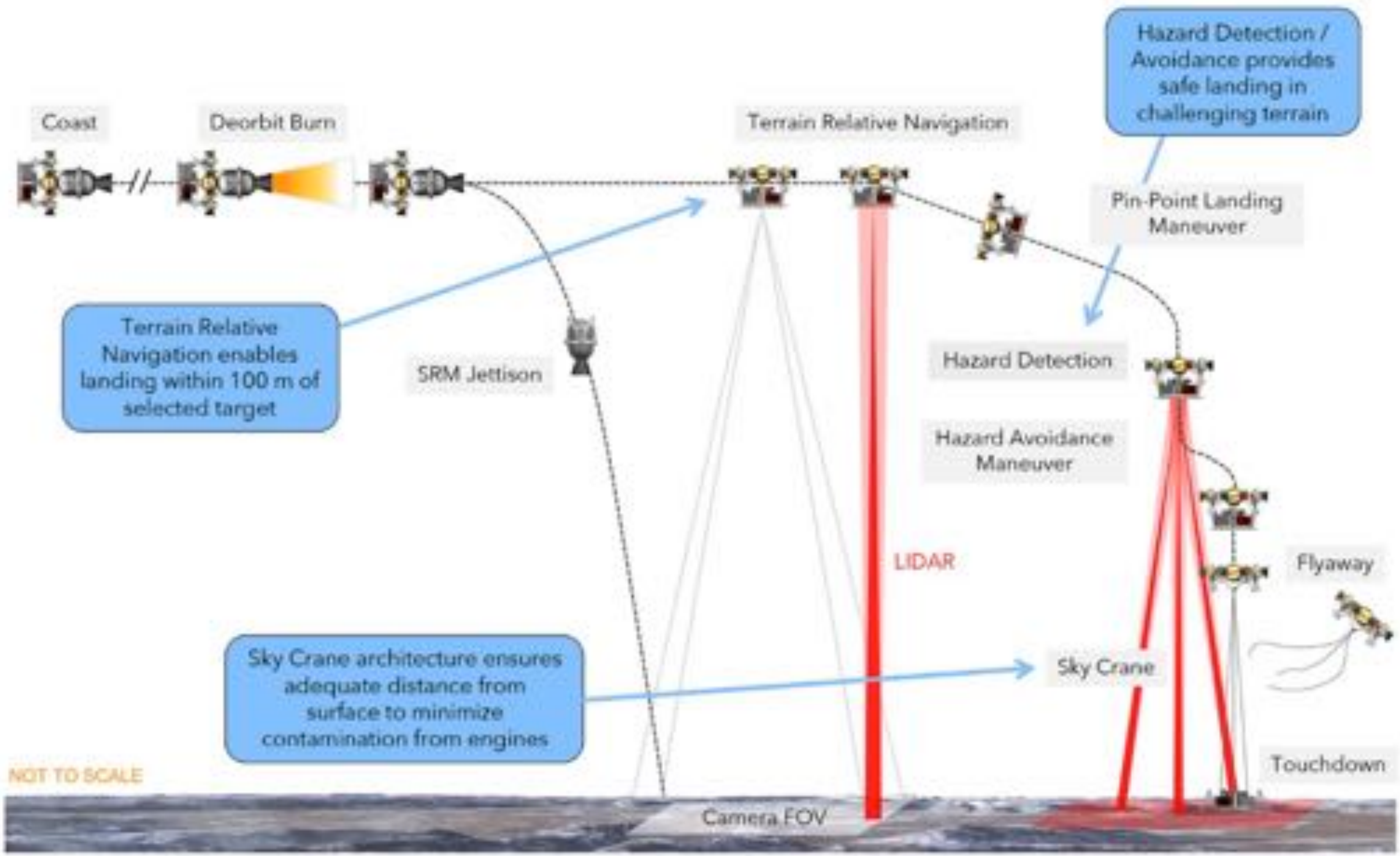
Europa Lander			Decadal Survey	
	Goal	**Objectives**	**Themes & Goals**	**Questions & Objectives**
1. BIOSIGNATURES	**1. Search for evidence of life on Europa.**	**1A.** Detect and characterize any organic indicators of past or present life.	**Crosscutting Theme 2:** Planetary Habitats	**Priority Question 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 "*
				Priority Question 4: What were the primordial sources of organic matter, and where does organic synthesis continue today?
		1B. Identify and characterize morphological, textural and/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?

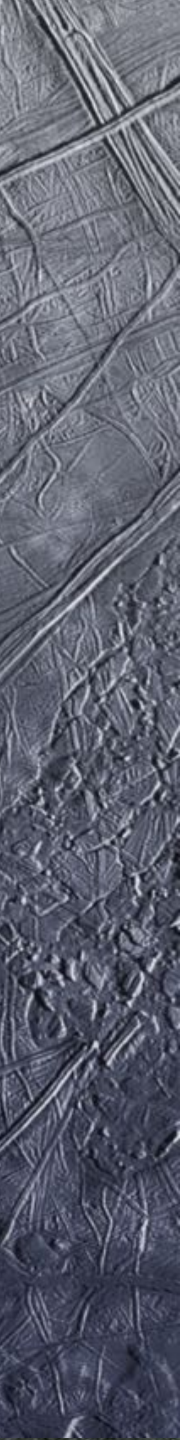
Europa Lander		Decadal Survey	
Goal	**Objectives**	**Themes & Goals**	**Questions & Objectives**
2. SURFACE HABITABILITY **2. Assess the habitabilit y of Europa via in situ technique s uniquely available to a lander mission.**	**2A.** Characterize the non-ice composition of Europa's near-surface material and determine whether there are indicators of chemical disequilibria and other environmental factors essential for life.	**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?

Europa Lander			Decadal Survey	
Goal		Objectives	Themes & Goals	Questions & Objectives
3. SURFACE PROPERTIES AND PROCESSES	**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?

Flying 'the right lander'

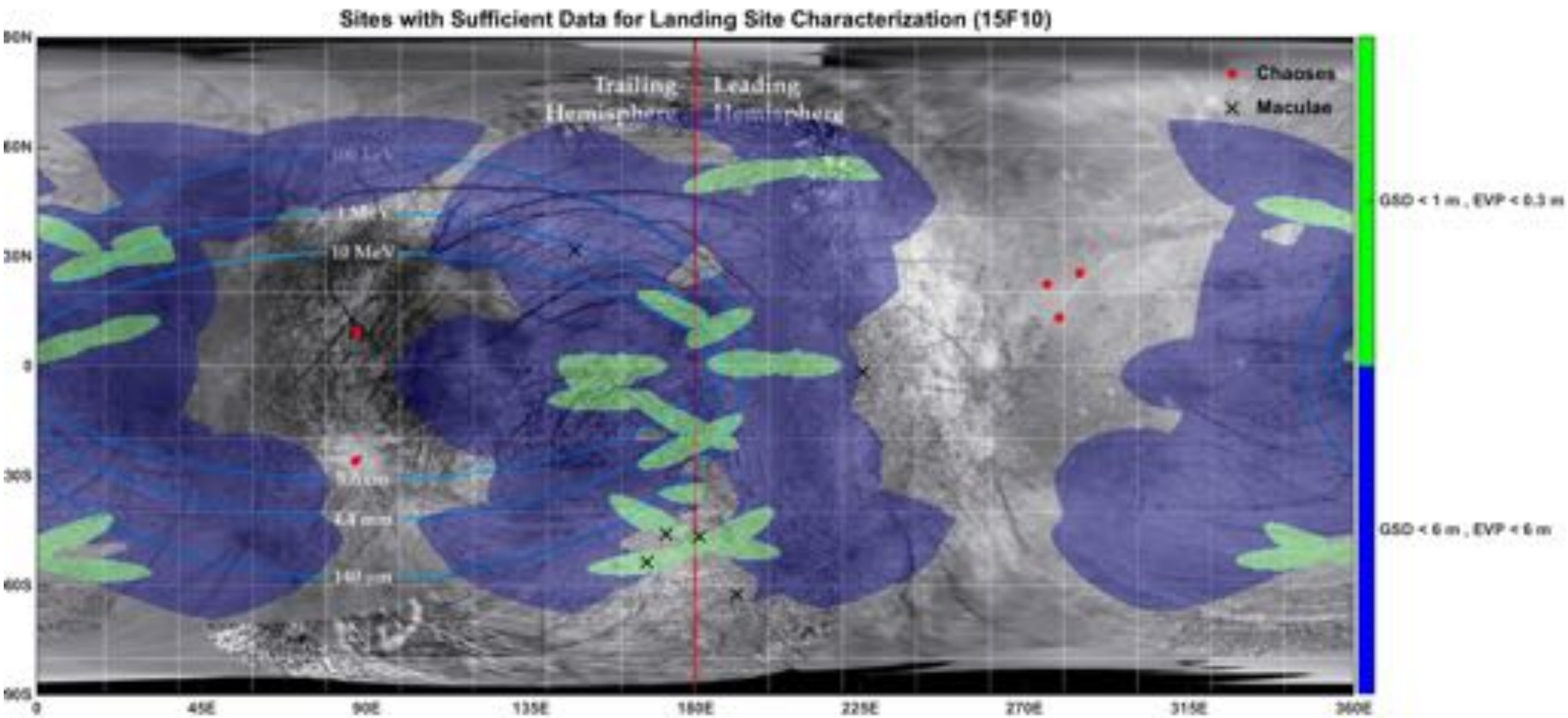
- Why not wait until we have the science and recon data back from Clipper before building and launching a lander?
- Pro's
  - Possibly more science and surface knowledge.
- Con's
  - Earliest Phase-A would be ~2029; earliest launch would be ~2036; earliest landing would be ~2044.
  - Would require new recon spacecraft.


Hazard Detection / Avoidance provides safe landing in challenging terrain
Coast
Deorbit Burn
Terrain Relative Navigation
Pin-Point Landing Maneuver
Terrain Relative Navigation enables landing within 100 m of selected target
SRM Jettison
Hazard Detection
Hazard Avoidance Maneuver
LIDAR
Flyaway
Sky Crane architecture ensures adequate distance from surface to minimize contamination from engines
Sky Crane
Touchdown
NOT TO SCALE
Camera FOV



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


Sites with Sufficient Data for Landing Site Characterization (15F10)
Trailing Hemisphere
Leading Hemisphere
Chaoses
Maculae
1 MeV
10 MeV
GSD < 1 m , EVP < 0.3 m
GSD < 6 m , EVP < 6 m
90N
60N
30N
0
30S
60S
90S
0
45E
90E
135E
180E
225E
270E
315E
360E

NRC 2000 Signs of Life Report

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

Biosignatures: Specificity for Life Detection, and Applicability to Detecting Extant and Extinct Life and Terrestrial Contamination on Spacecraft

Signatures of Life	Application for Life Detection	Specificity	Fossil and Nonterrestrial Life Detection
Morphology (Micro- and Macroscopic) [illegible]	[illegible]	[illegible]	[illegible]
Organic Chemistry and Biochemistry [illegible]	[illegible]	[illegible]	[illegible]
Inorganic Chemistry [illegible]	[illegible]	[illegible]	[illegible]
Isotopic Analyses [illegible]	[illegible]	[illegible]	[illegible]
Environmental Measurements [illegible]	[illegible]	[illegible]	[illegible]

Mission	Payload mass (kg)	# of Samples, Threshold (Baseline)	Sample volume (cubic centimeters)	Mission surface lifetime (Threshold)
Mars Pathfinder	7.98 (includes weather station on landing platform; rover had <1.5 kg)	NA	NA	30 sols (7 sols for the rover)
Mars Exploration Rovers	5.5 (7 instruments)	3 (6) [RAT grindings]	NA	90 sols (92 earth days)
Phoenix	59 (with robotic arm and sampling systems)	2 (9)	1 cc	90 sols
Mars Science Laboratory (Curiosity)	75 (10 instruments)	5	<1 cc from 20-50 mm depth	668 sols (683 earth days)
Europa Lander (this study)	42.5 (instruments only)	3 (5)	5 cc from at least 100 mm depth	20 earth days (5.63 eurosols)

Organic Detection & Characterization

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

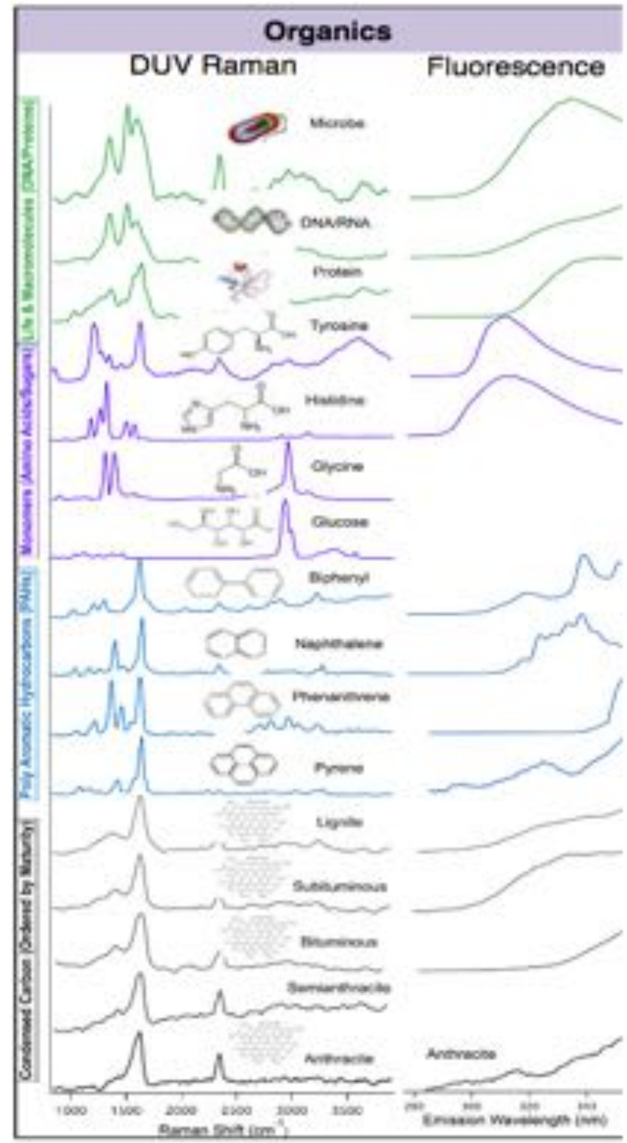
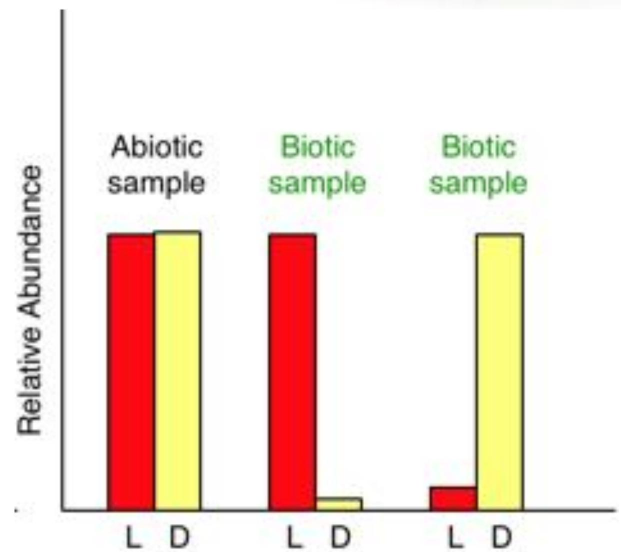


Image courtesy Beegle et al.

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?

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

Compound	On Earth[a]	Enantiomeric Enrichment (%) Murchison	Enantiomeric Enrichment (%) 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.

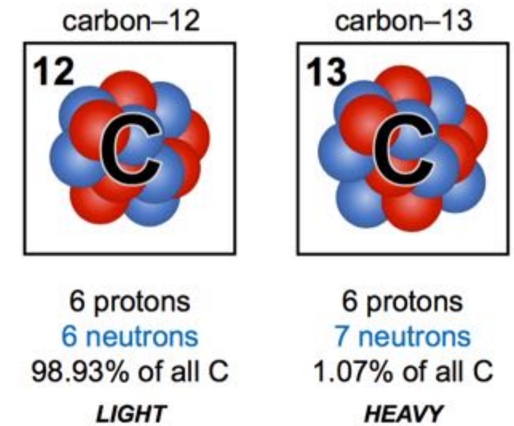
7-9% EE detected in some amino acids in Murchison meteorite – an 'abiotic benchmark'.

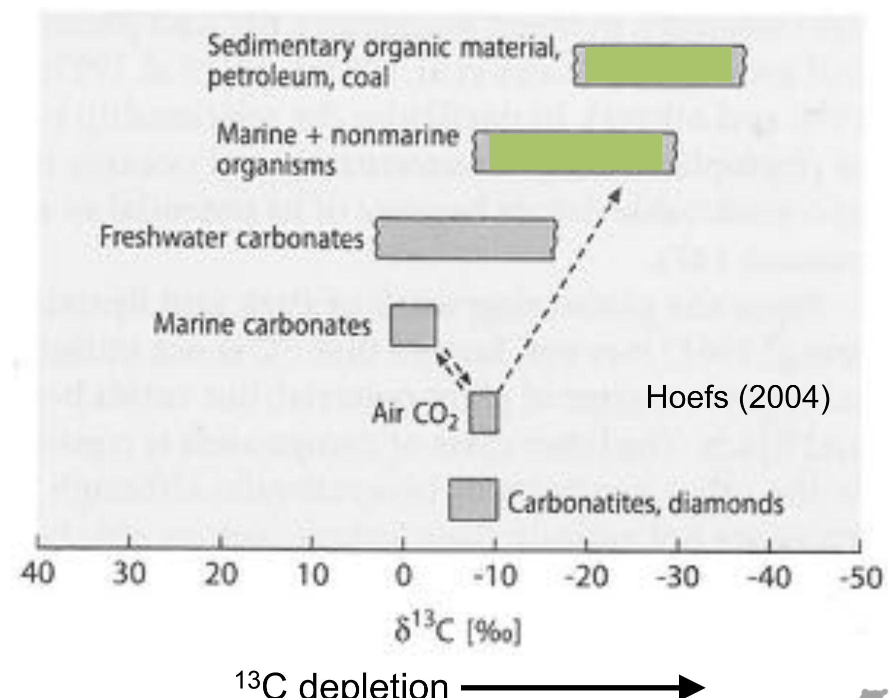
SDT set an EE 'biogenic' threshold of 2X Murchison value: ~ 20%.

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

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.

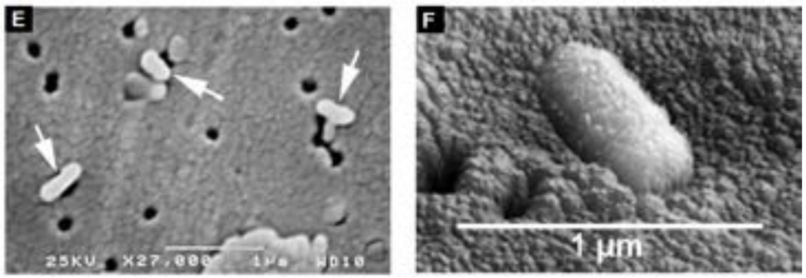




Microscale & Macroscale Structures

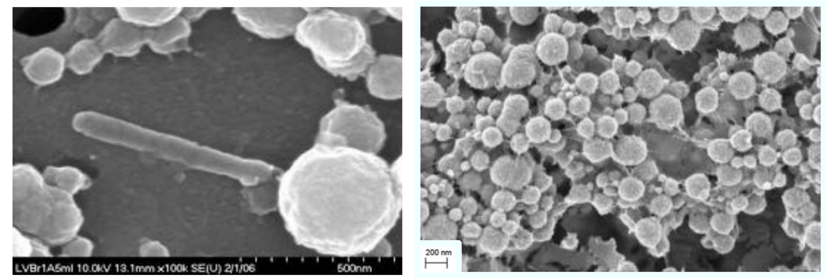
Micro:

Lake Vostok Accretion ice



Priscu et al. 1999, Science.

Lake Vida Brine



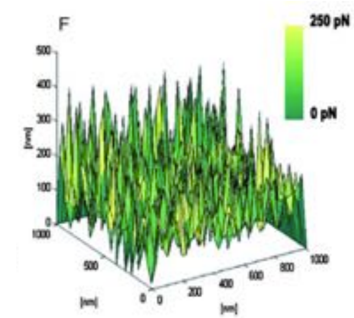
Murray et al. 2012 PNAS.

Macro:

- Pigments
- Filamentous aggregations
- Biomineral structures

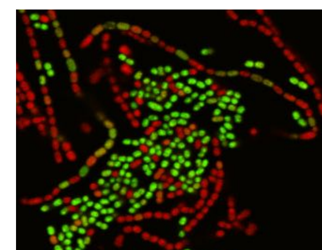
Detect structural, compositional or functional indicators of life

- Properties that provide supporting data concerning nature of microscale structures
  - Biophysical properties (AFM)
  - Spectral characterization (Spectroscopy)
  - Molecular or particle motion (AFM, holographic microscope)
  - Fluorescence detection (EFM, FCM, Deep UV)
    - Native fluorescence
    - Molecular stains



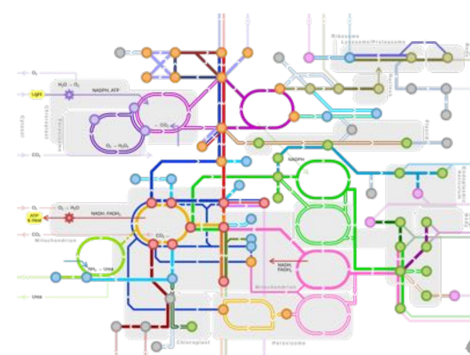
Liu and Wang, 2010

3D map: cell surface adhesion forces



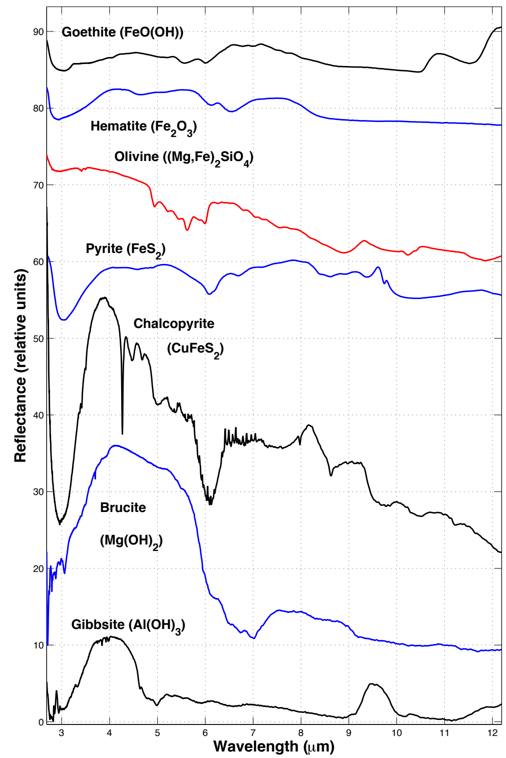
Membrane integrity

- Search for metabolic by-products
  - Low molecular weight “waste” organics
  - High molecular weight excesses
  - Molecular biocomplexity– only produced by biological synthesis

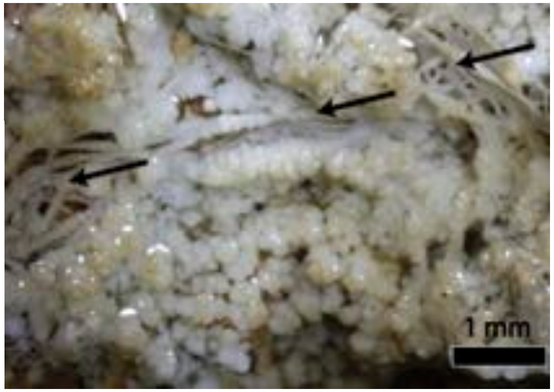


Inorganic Indicators of Life

- 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.

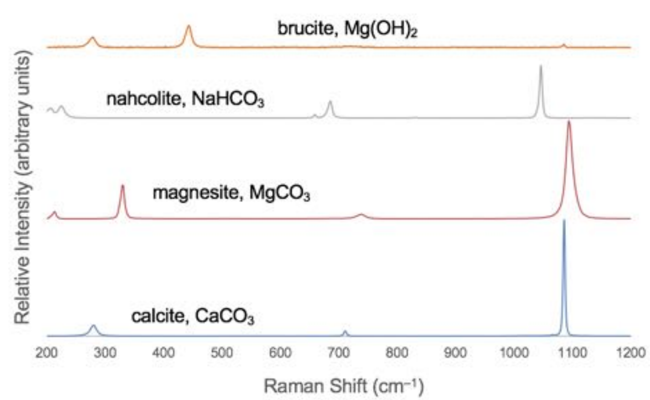


Priscu et al. (1999)

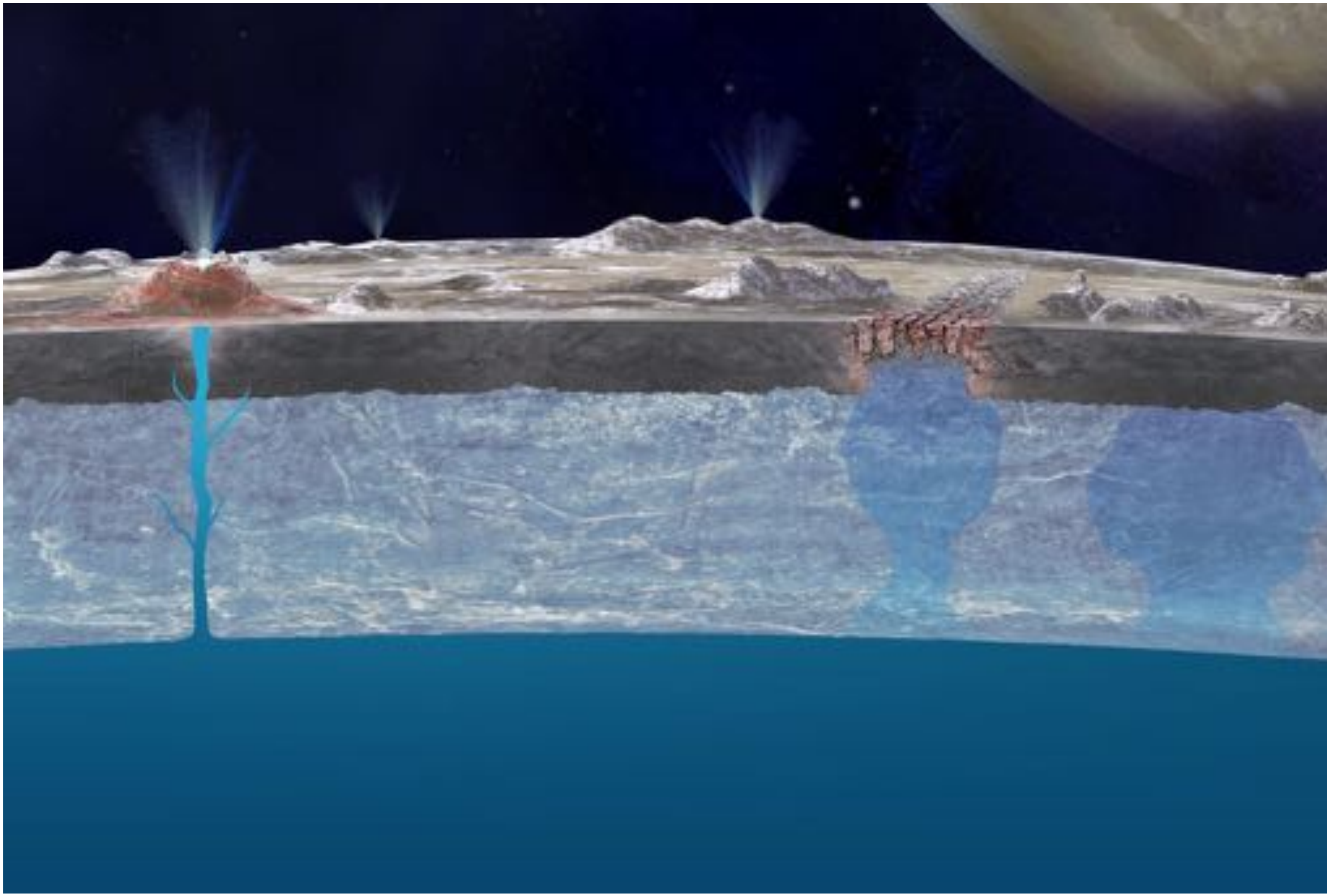


Measurement requirement:

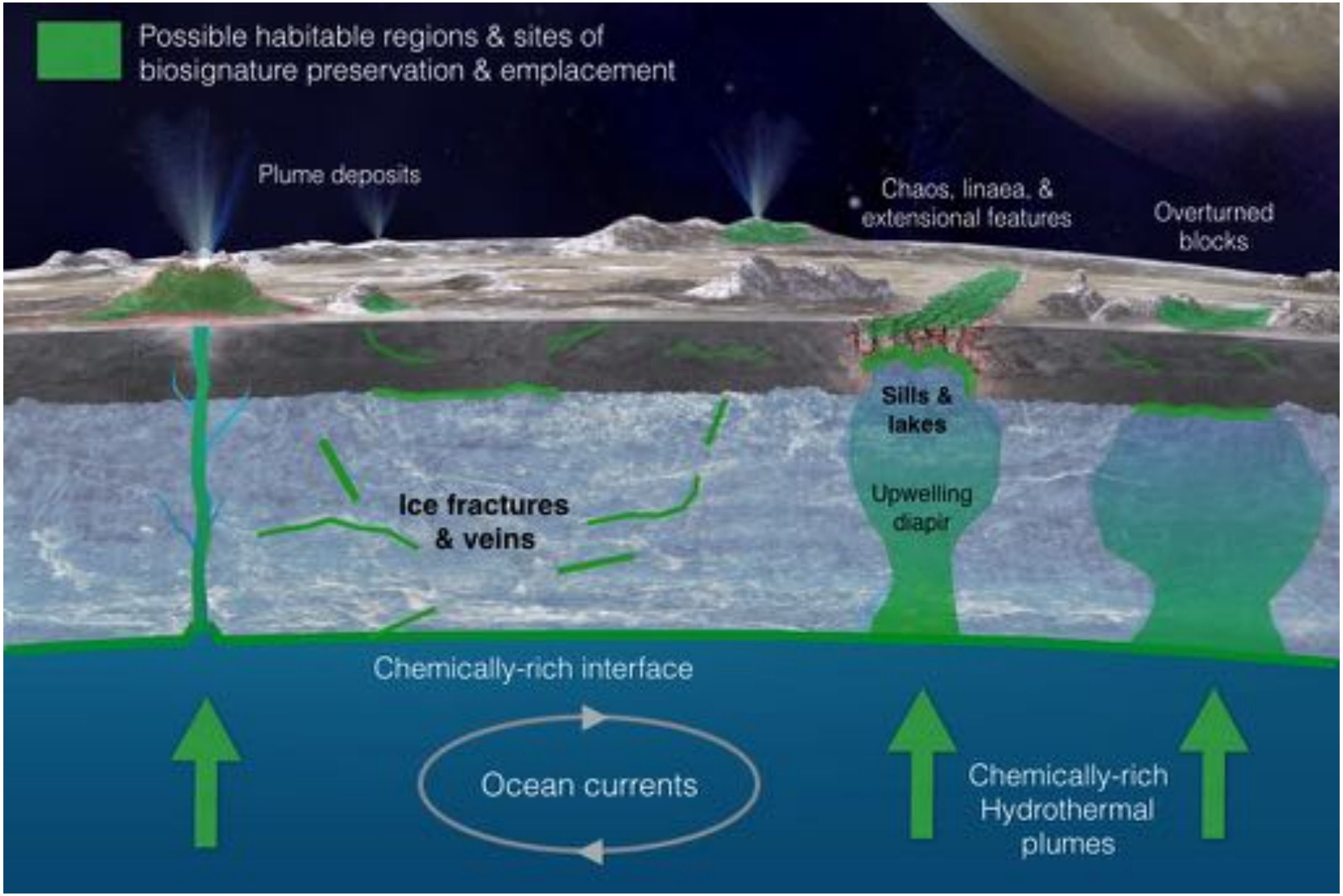
- Identify inorganic and volatile components in the sample at 10's to 100's of part per thousand level.



Provenance



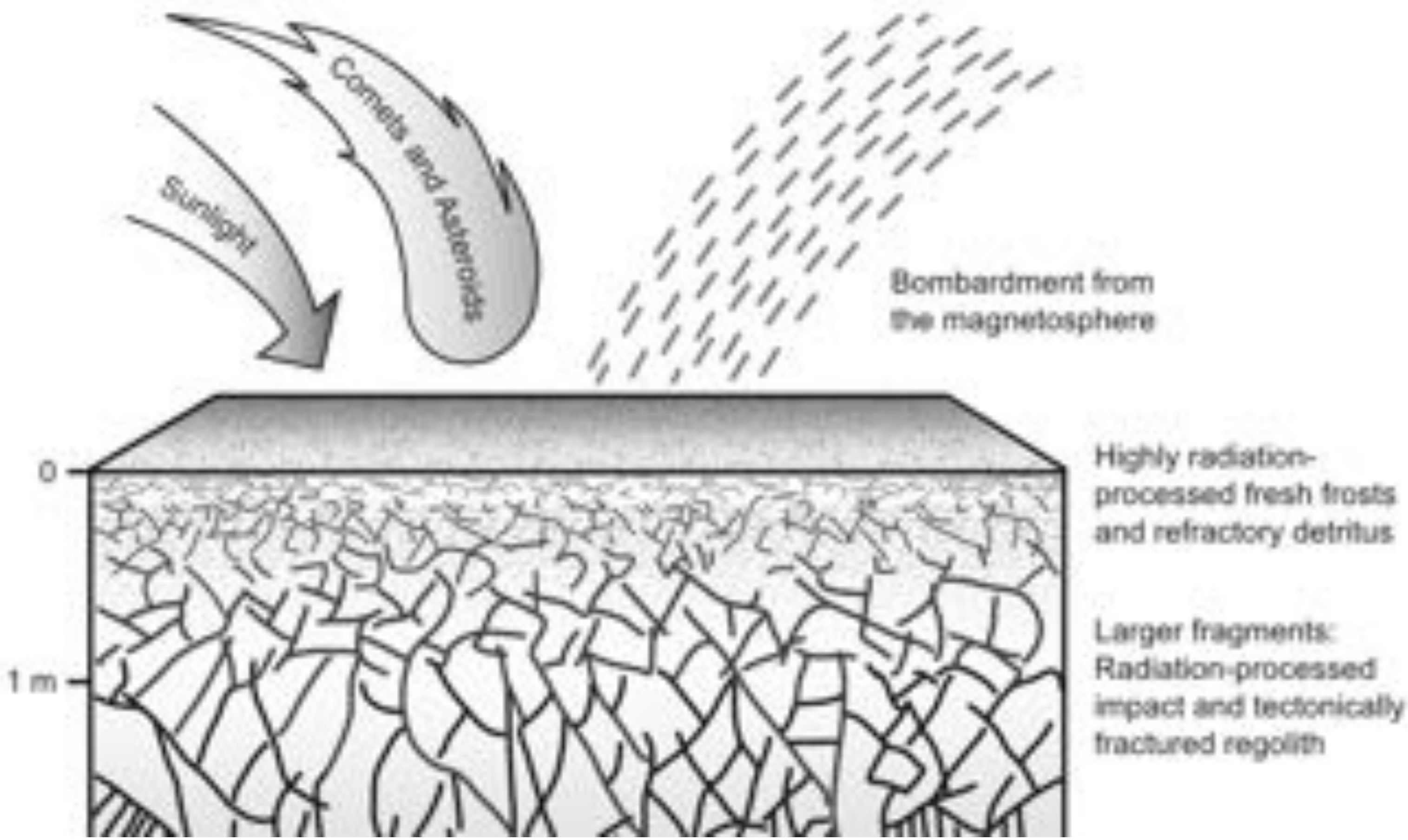
Provenance



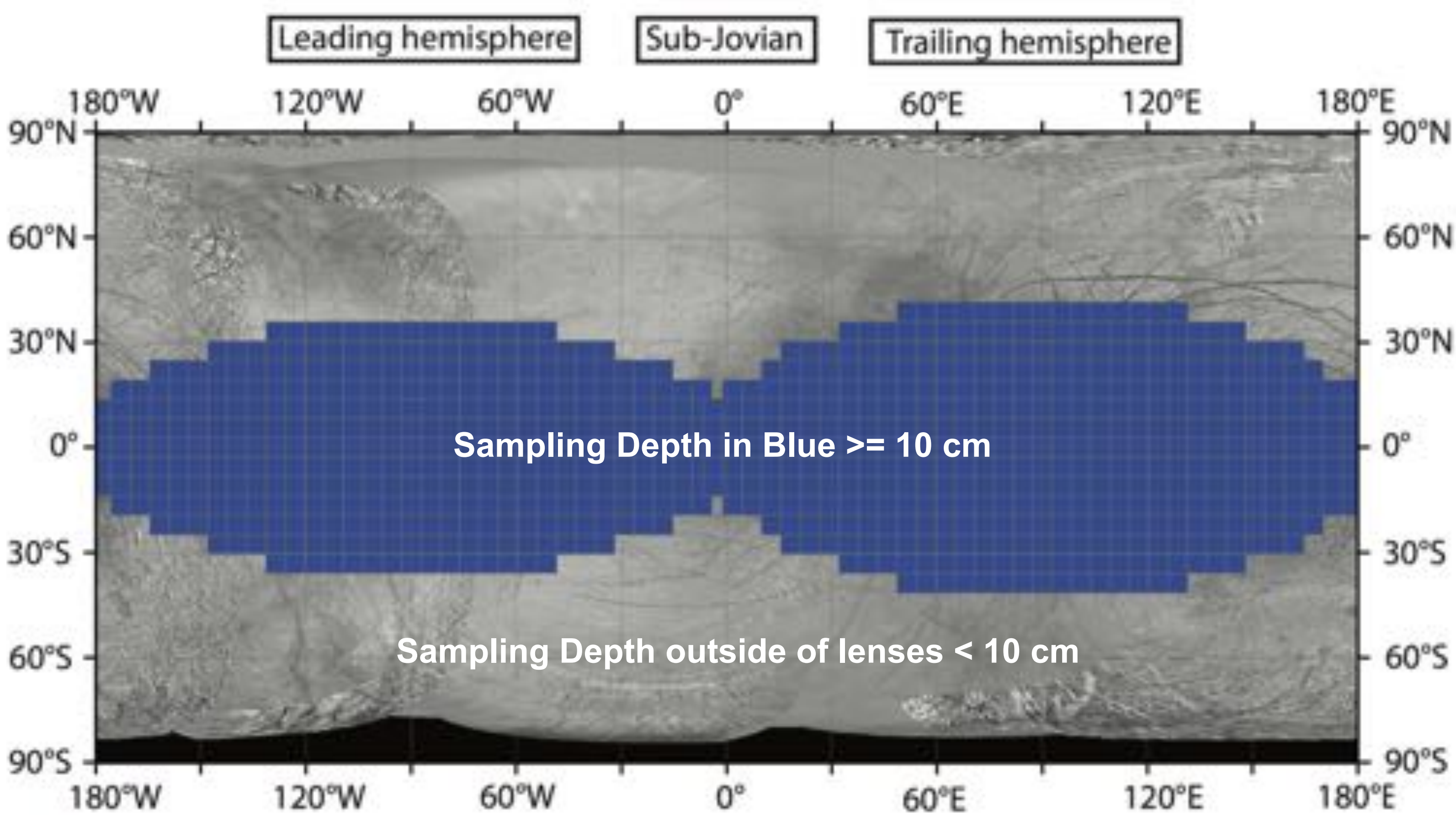
Possible habitable regions & sites of biosignature preservation & emplacement
Plume deposits
Chaos, linaea, & extensional features
Overturned blocks
Sills & lakes
Upwelling diapir
Ice fractures & veins
Chemically-rich interface
Ocean currents
Chemically-rich Hydrothermal plumes

Provenance

The Ideal Sample vs. Reality



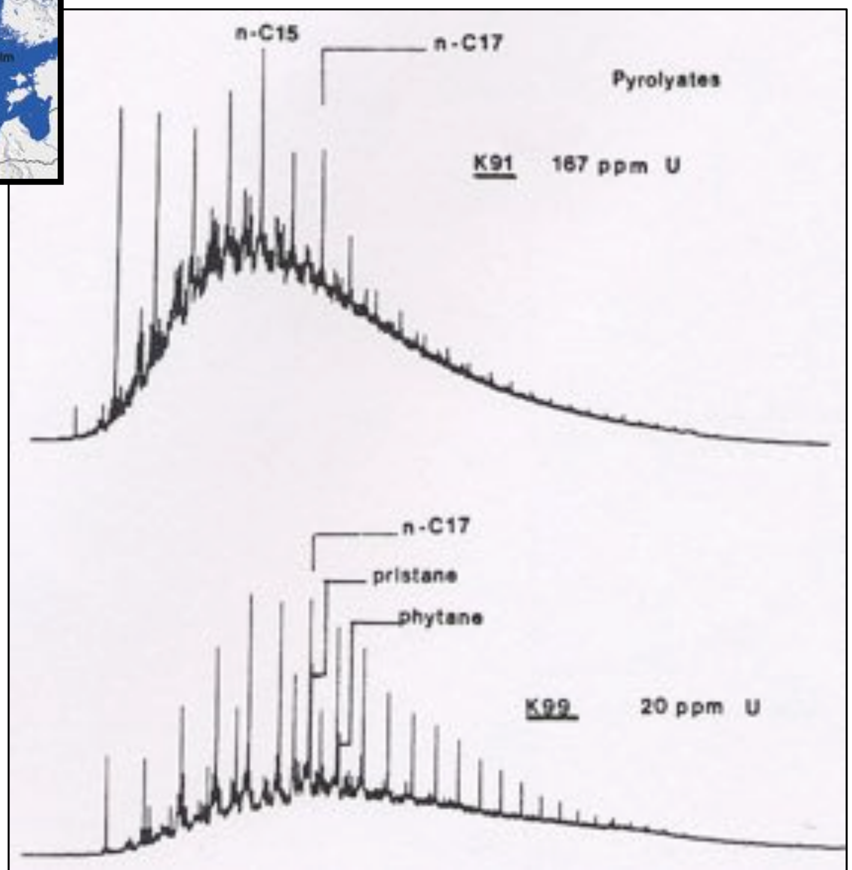
Radiation processing: Sampling depth



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.

Radiation Processing: Organic Patterns & Complexity

Irradiation Effects on Biosignatures



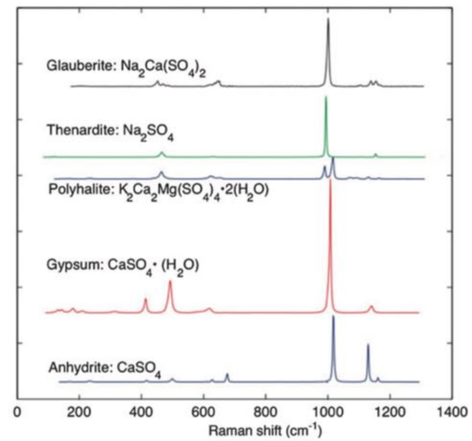
Sundararaman and Dahl (1993), Hand et al. (2009)

- 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.

Characterize Non-ice Composition

Spectroscopy reveals habitability and the effects of radiation on sampled materials

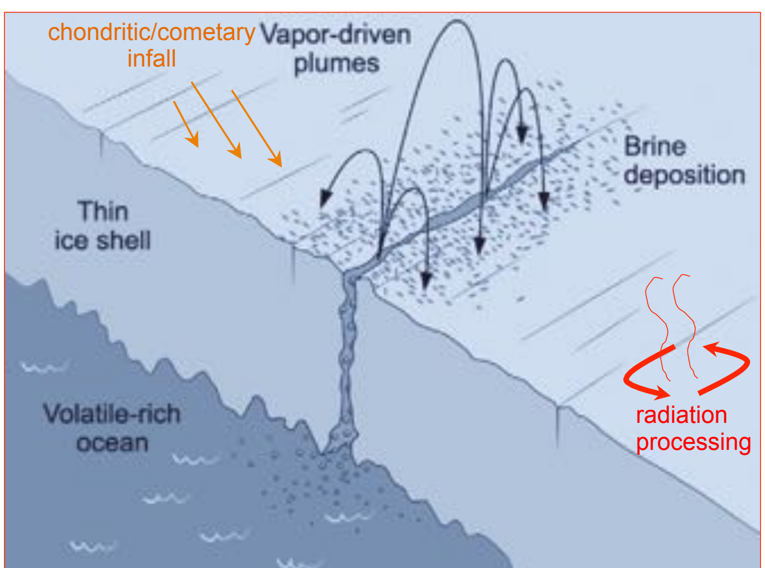
- Ocean chemistry by analyses of salts (C, Cl, S).
- Exogenous materials, which may provide nutrients to the ocean (micrometeorites, Io-sourced deposits).
- Ice grain size, which can reveal plume deposits and relative ice age.
- Radiation products, which indicate surface exposure.

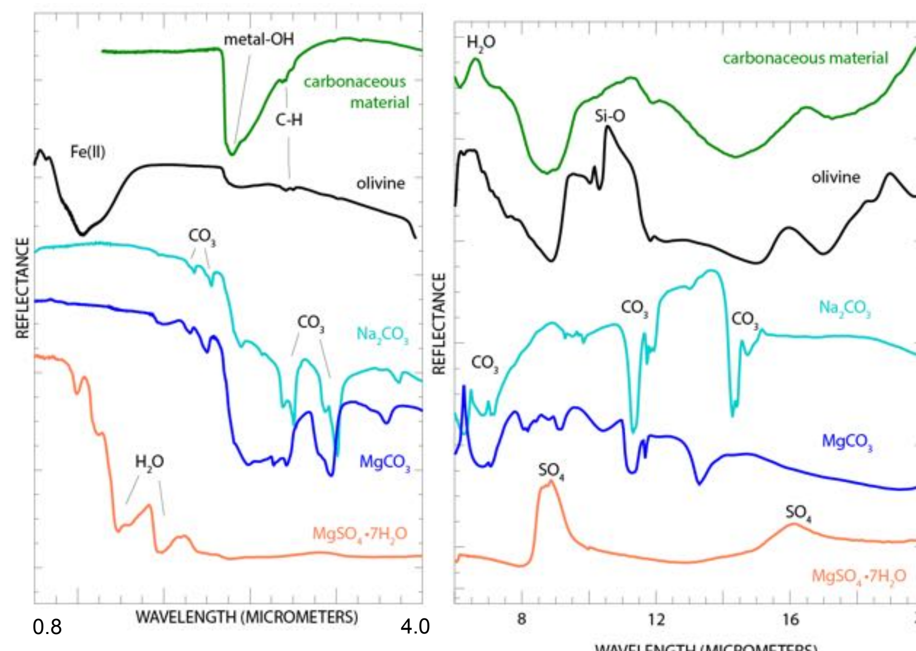


Downs (2006)

Measurement requirement:

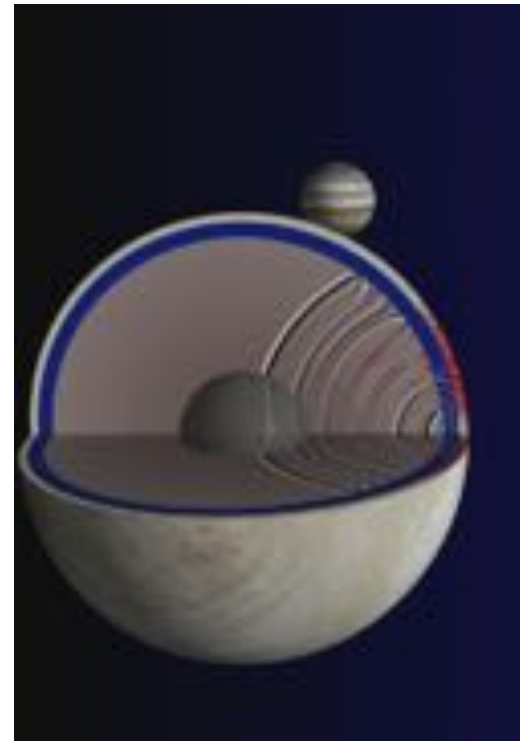
- Identify inorganic and volatile components in the sample at 10's of part per thousand level.





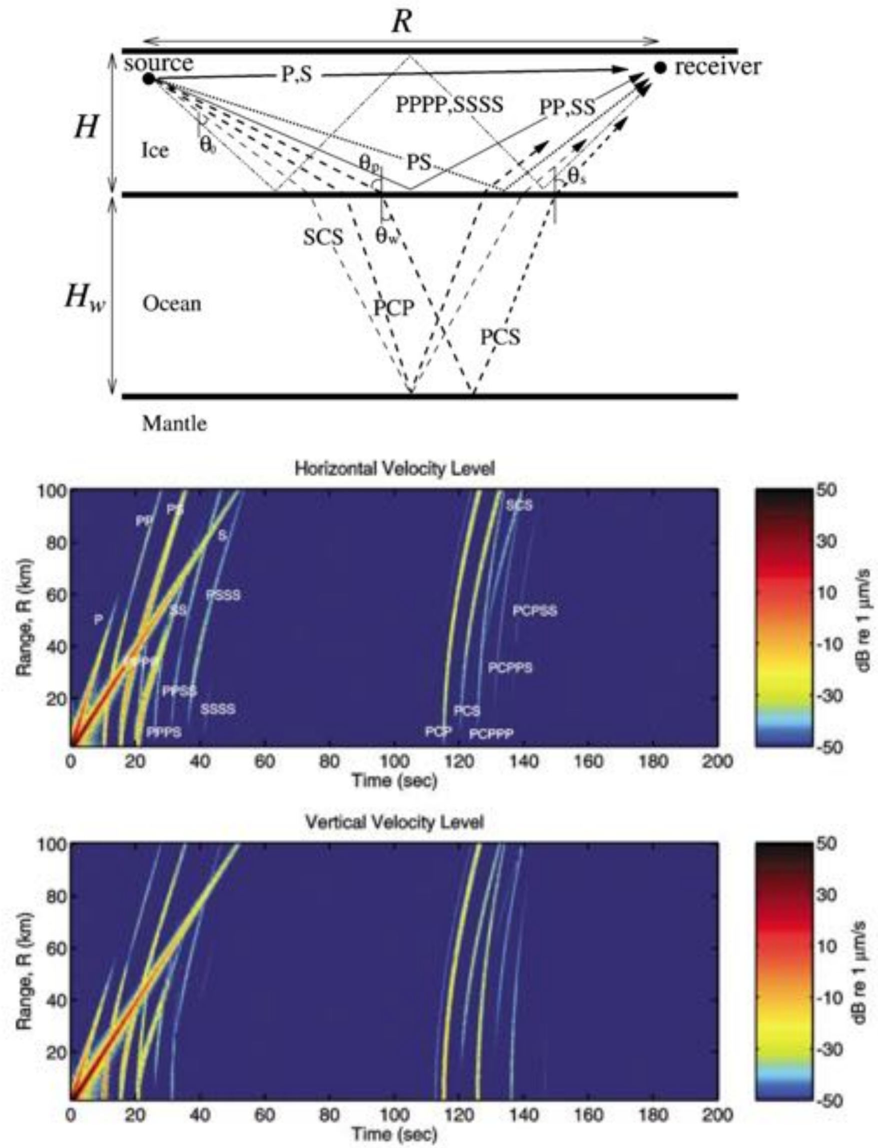
Determine the Proximity to Liquid Water

- Because the ice shell of Europa is ~10's km in thickness, and the ocean is ~100 km deep, signals of **~0.1 Hz to a few Hz** can be used to reveal ice shell thickness and mechanical properties, and possibly even seafloor depth.
- A single 3-axis geophone achieves the **Threshold** measurement, provided it can monitor Europa for at least two tidal cycles (7 Earth days).
- **Baseline** payload accommodates a broad-band seismometer that can 'listen' deeper into Europa's interior.



Determine the Proximity to Liquid Water

- A tectonic event 100 km away from the lander will generate acoustic signals that take < 3 min. to travel from source to seafloor to the lander.
- Accommodating for instrument and lander noise, a geophone could detect signals to ~25 dB re 1 μm/s.



Goal 3: Context

- Characterize surface and subsurface properties at the scale of the lander to support future exploration.
- Important whether or not life is detected by the investigations in Goals 1 and 2
- If life ***is*** detected:
  - Goal 3 will be essential in understanding how and where biosignatures, and life, could exist and be preserved.
  - Will aid future missions in accessing biosphere regions.
- If life ***is not*** detected:
  - Goal 3 will help us understand physical properties & dynamic processes at Europa's surface and whether a habitable region is/was expressed on the surface (cross-over with Goal 2).
  - Will set the stage for future exploration, more advanced search for potential biosignatures with different mission configuration.
  - Comparative oceanography: Europa is of great scientific interest independent of the search for life.

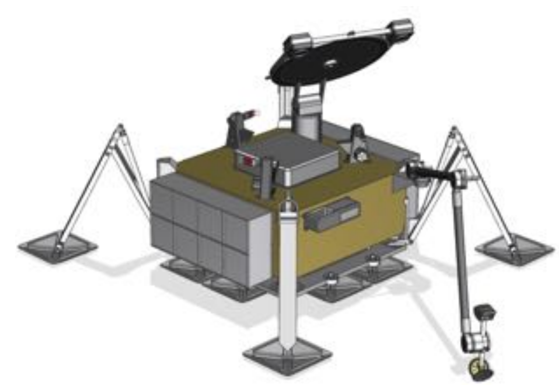
Goal 3: Science + Engineering

- Measurements that feed-forward into the future exploration of Europa
- Goal 3 science takes advantage of engineering capabilities and instruments of the Europa Lander to better understand the surface:
  - Enables synergies of engineering and scientific measurements.
  - Conducts science with engineering capabilities of DDL system, e.g. imaging of landing site during descent process.
  - Characterizes surface with robotic arm mobility sensors.
  - Assesses temperature changes and physical properties of Europa's surface through thermal monitoring.

Objective 3a: Physical Properties

- Observe the properties of surface materials at the landing site (including the sampled area) and sub-meter-scale landing hazards, and connect local properties with those seen from flyby remote sensing.

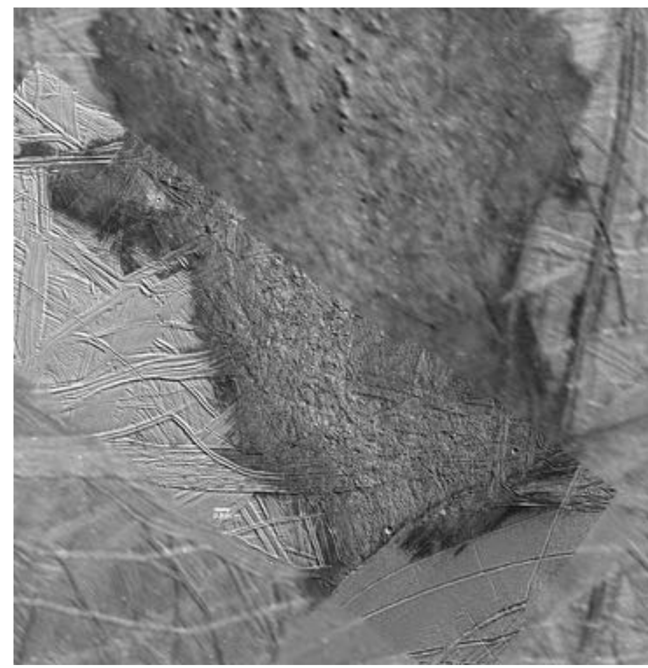
- 3a1: Characterize the physical properties of Europa's surface materials through interaction with sampling arm and landing system.
- 3a2: Identify sub-meter-scale geomorphic features and their quantitative relief (topography) characteristics in the landing zone.
- 3a3: Characterize the chemical and mineralogical properties of the surface, to inform future site selection.
- 3a4: Characterize the internal structure of Europa including ice shell thickness, depth of the ocean, and interior structure.



Objective 3b: Dynamic Processes

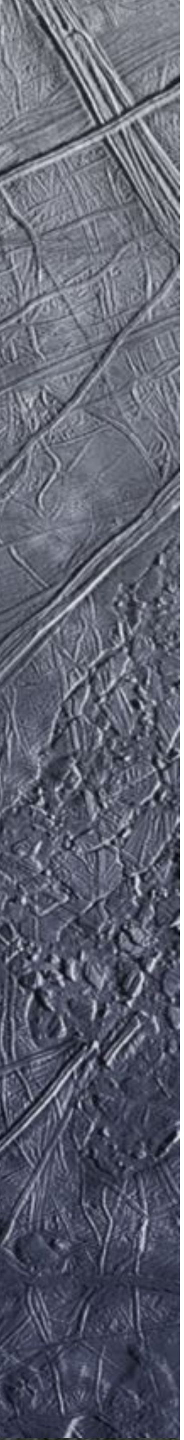
- Characterize dynamic processes of Europa's surface and ice shell over the duration of the mission to understand exogenous and endogenous effects on the physicochemical properties of surface material.

- 3b1: Characterize the physical processes that affect materials on Europa (gardening, micrometeoroid impact, tectonic and thermal degradation, etc.).
- 3b2: Characterize the chemical processes that affect materials on Europa (radiolysis, decomposition, oxidation, etc.).
- 3b3: Characterize the magnitude and effects of the thermal response at the landing site from the landing event and the lander surface operations (sampling, etc.).
- 3b4: Characterize the 3-dimensional surface dynamics of Europa and the local dynamic variability (potentially indicative of activity) at the landing site.



Use of Mission Engineering Systems to Enable Science

- **Powered Descent Vehicle ("SkyCrane") supporting Lander: Capture, store, and relay from Lander the following descent datasets:**
  - TRN nadir descent imaging sequence
  - Hazard avoidance imaging Lidar topography (DEM's)
- **Lander engineering sensing systems: Capture, store, and return to Earth (via relay):**
  - 3-axis accelerometer data during landing and after to capture the impact of the Powered Descent Vehicle as a source signal
  - Temperature probes with contact to the surface?
  - RF transponder data from Lander to Comm orbiter at 1 mm/s?
  - Motor currents during arm-based cutter operations (sampling)



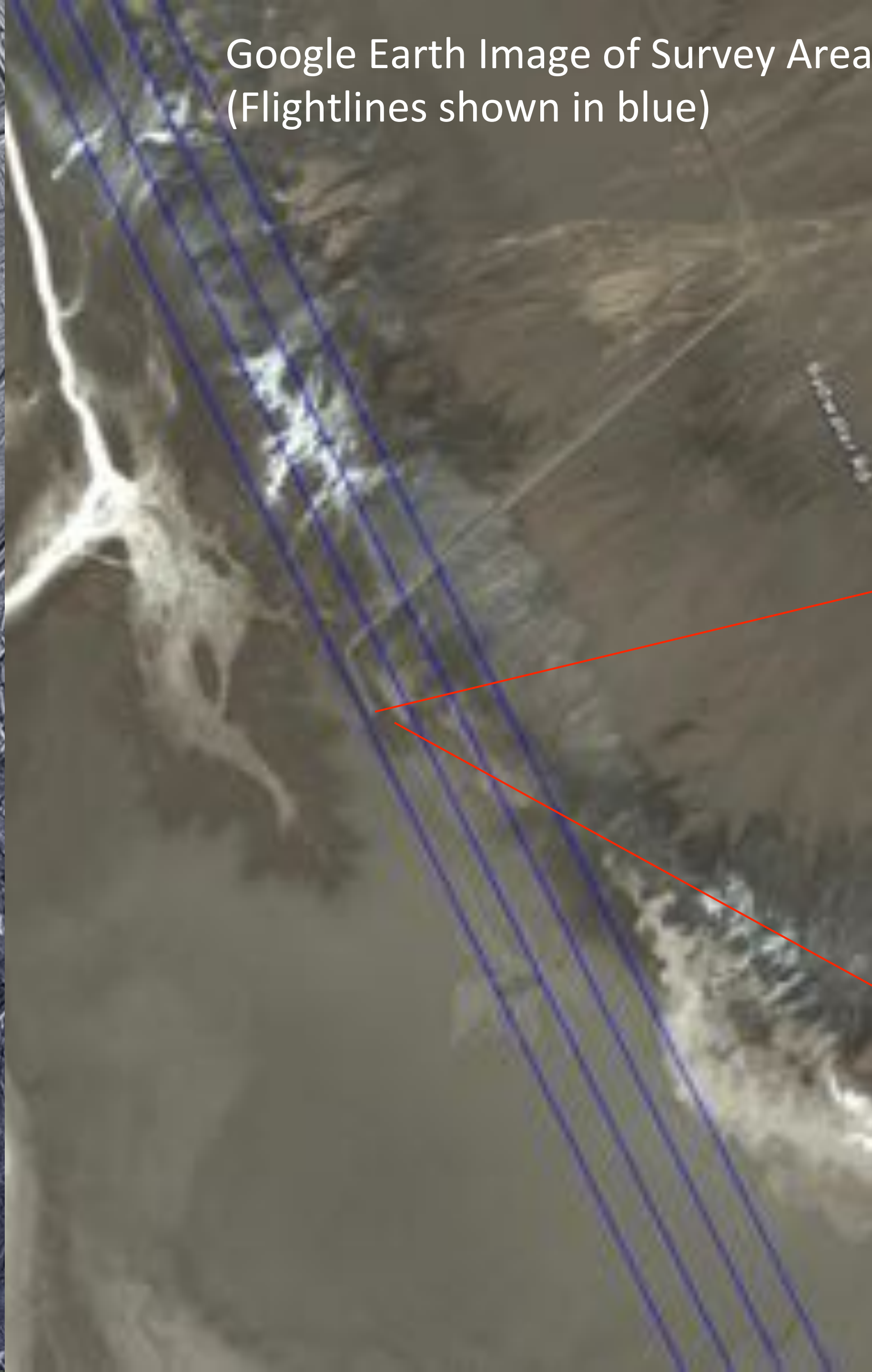
Devils Golf Course ASO LiDAR Data

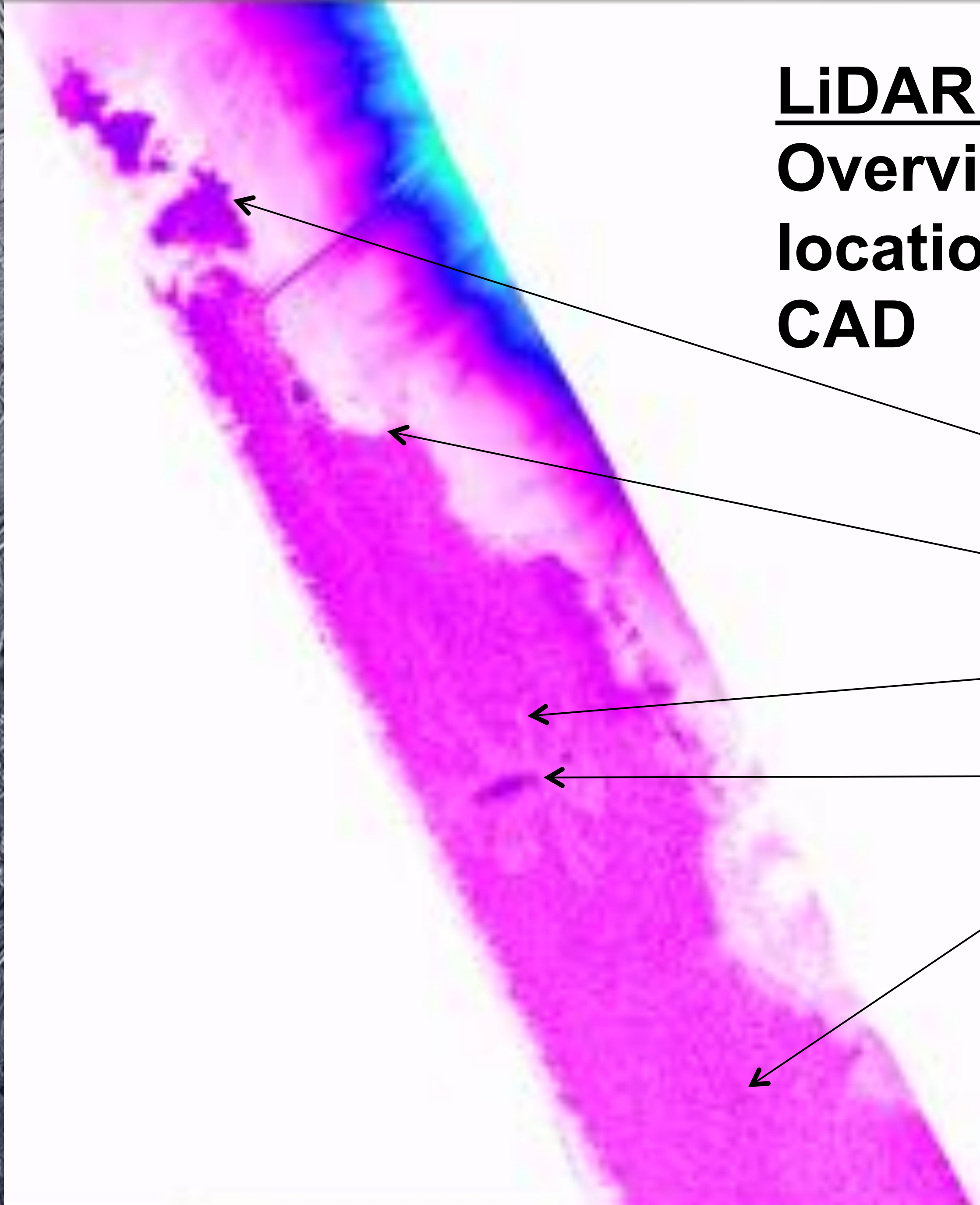
11-3-2015

Data Collection Parameters

- Riegl LMS-Q1560 Airborne Lidar
  - 2 scanner system, but only scanner 1 operating
  - 400kHz laser pulse rate, 12% power
  - 58^{o} FOV
- Flown aboard a King Air A-90 (N41J)
  - ~1000ft AGL, 180kts
  - 4 flight lines, each flown twice
  - Point density 20-60 pts/m^2
  - ASO project ID CADG20150910F1a1

Location: Devils Golf Course (salt evaporite pillars) in Death Valley N.P., CA

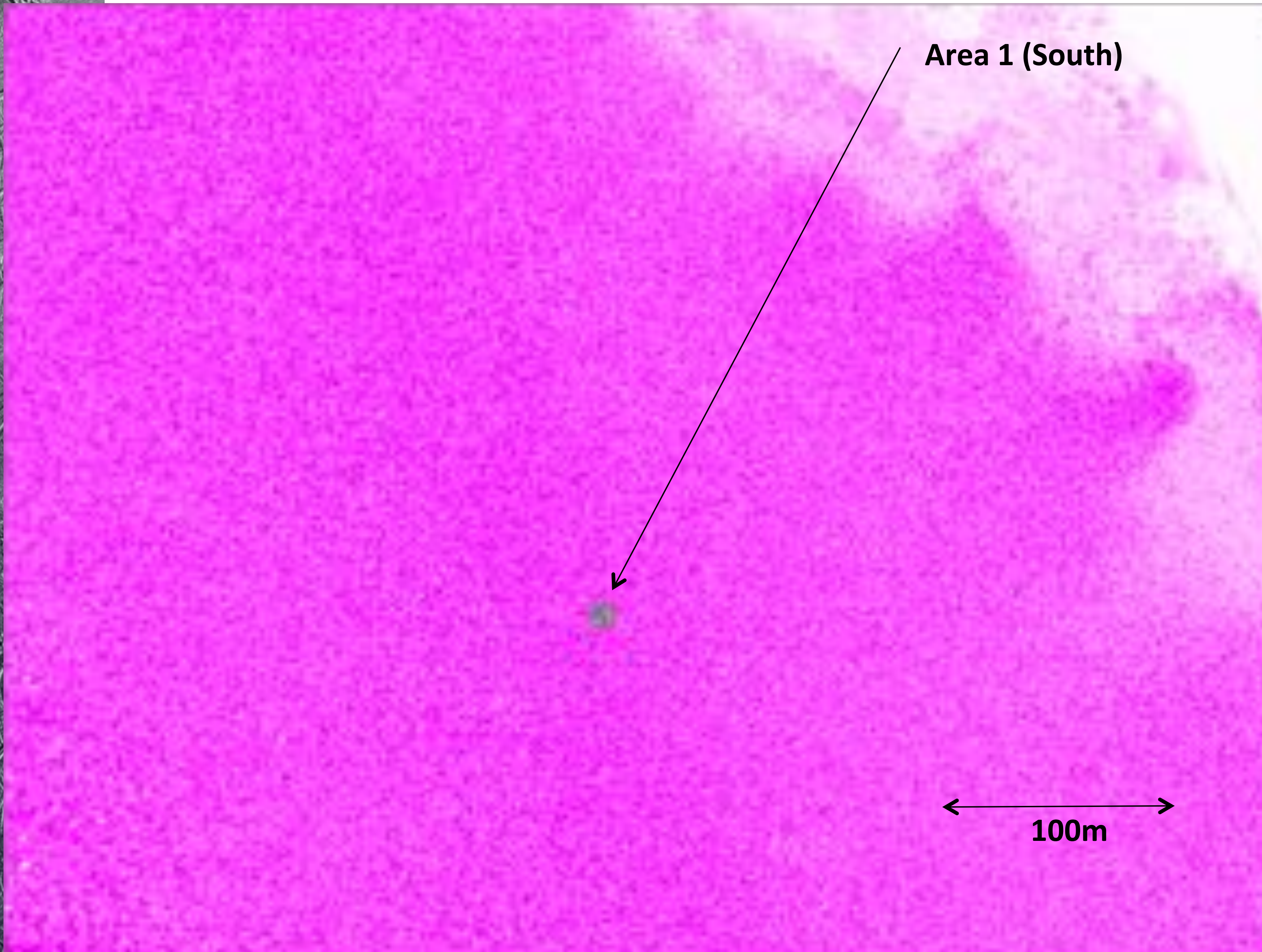


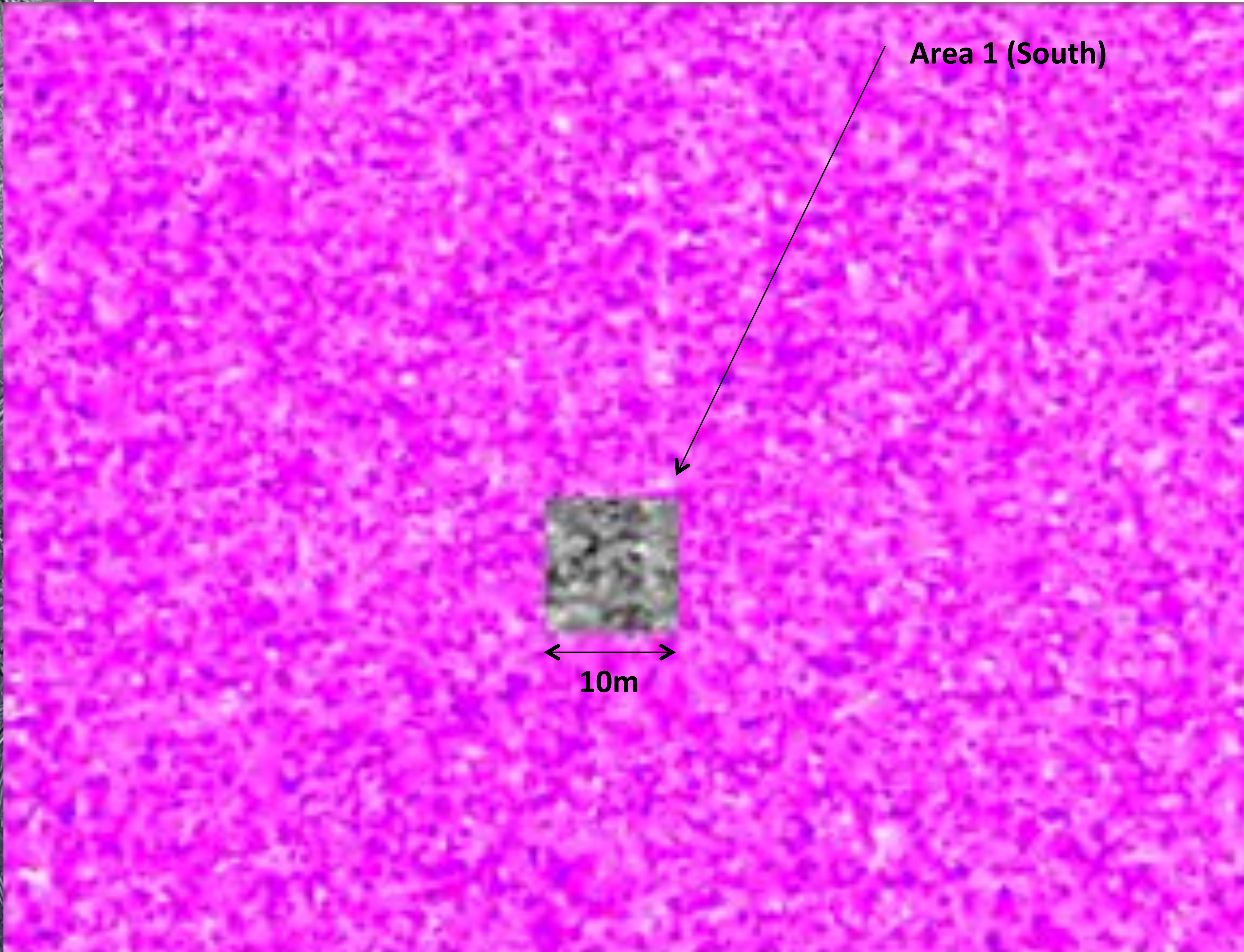


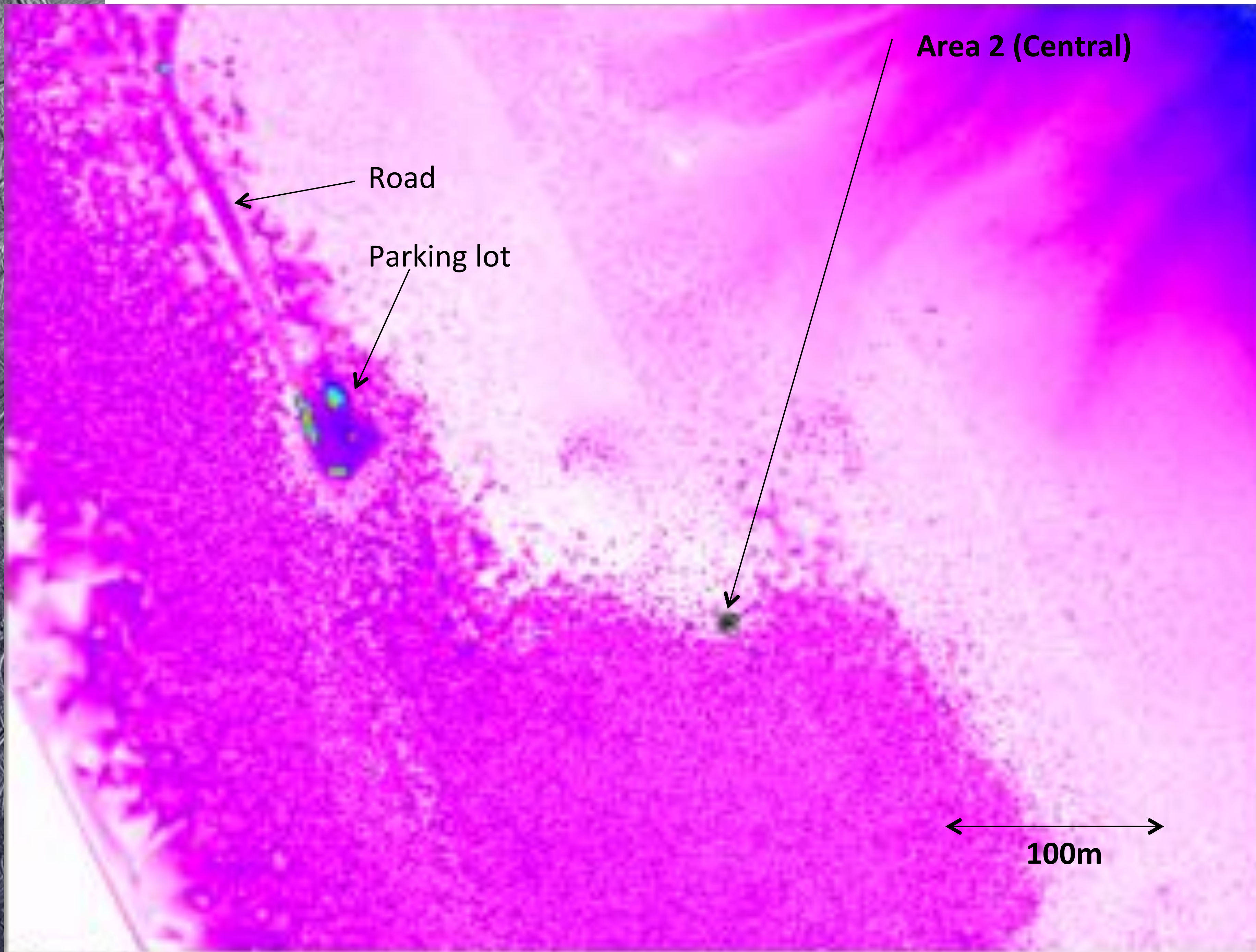
LiDAR Dataset

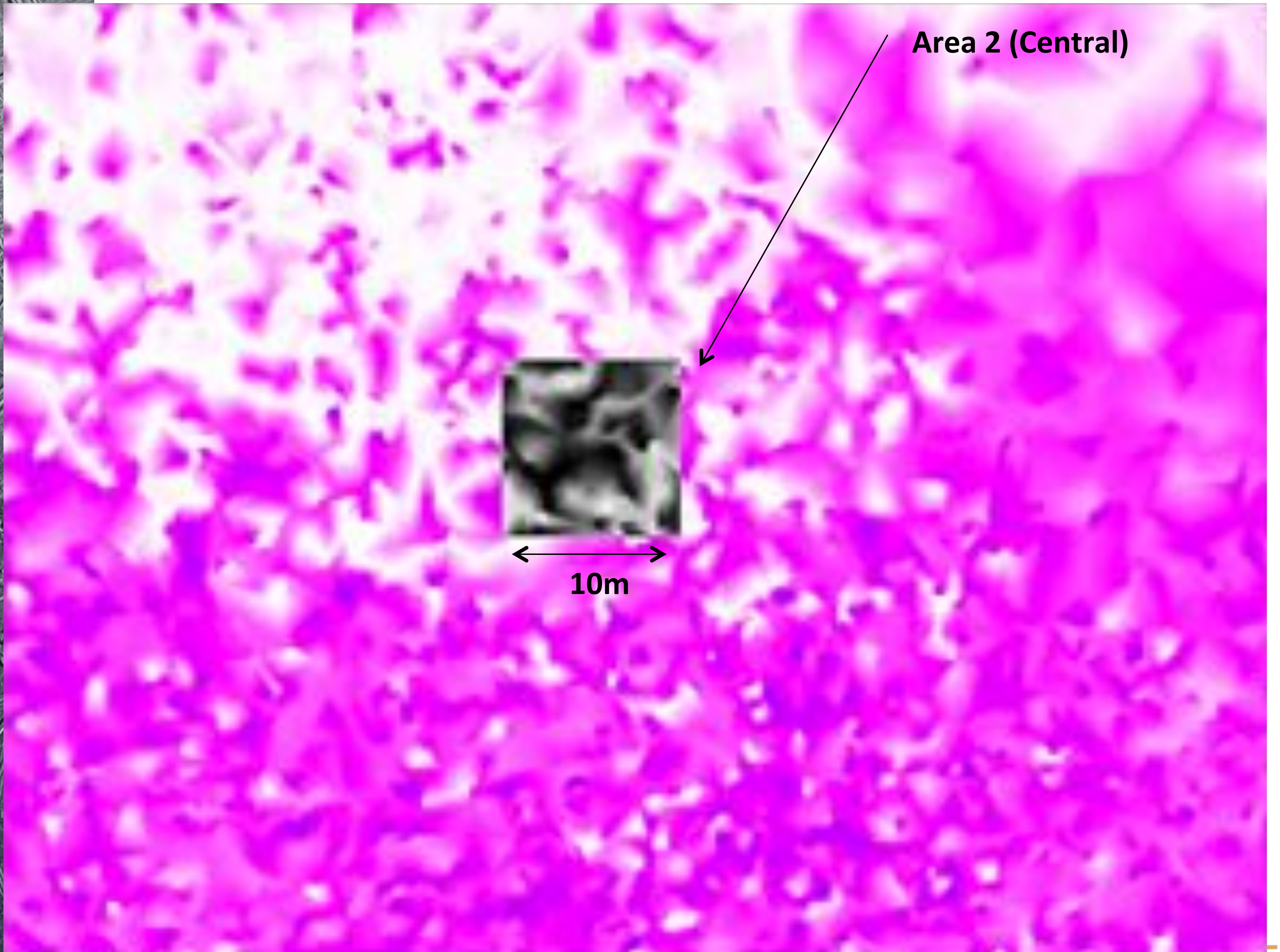
Overview showing locations chosen for CAD

- Area 4
- Area 2, 5, 6
- Area 7
- Area 3
- Area 1

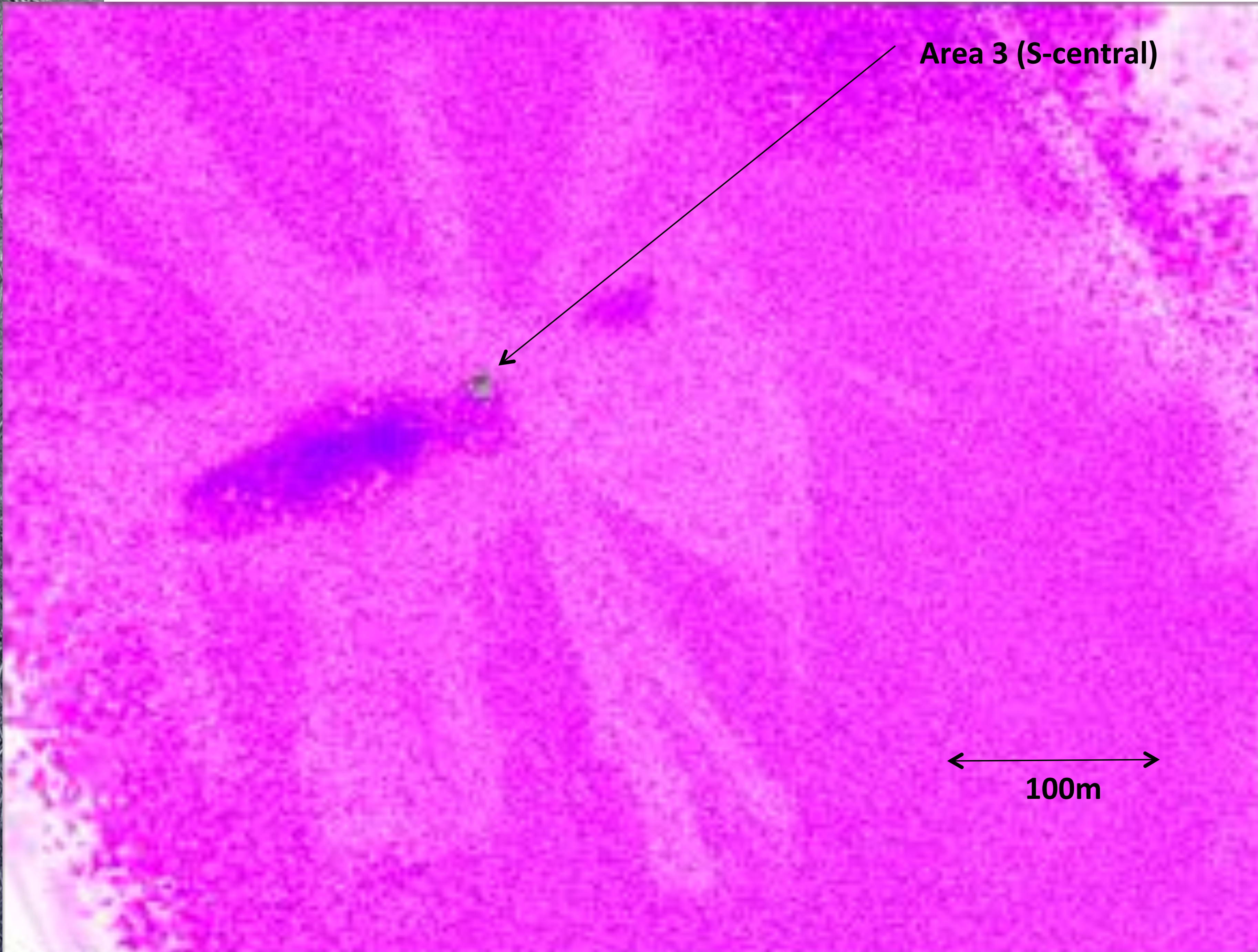

Area 1 (South)
100m

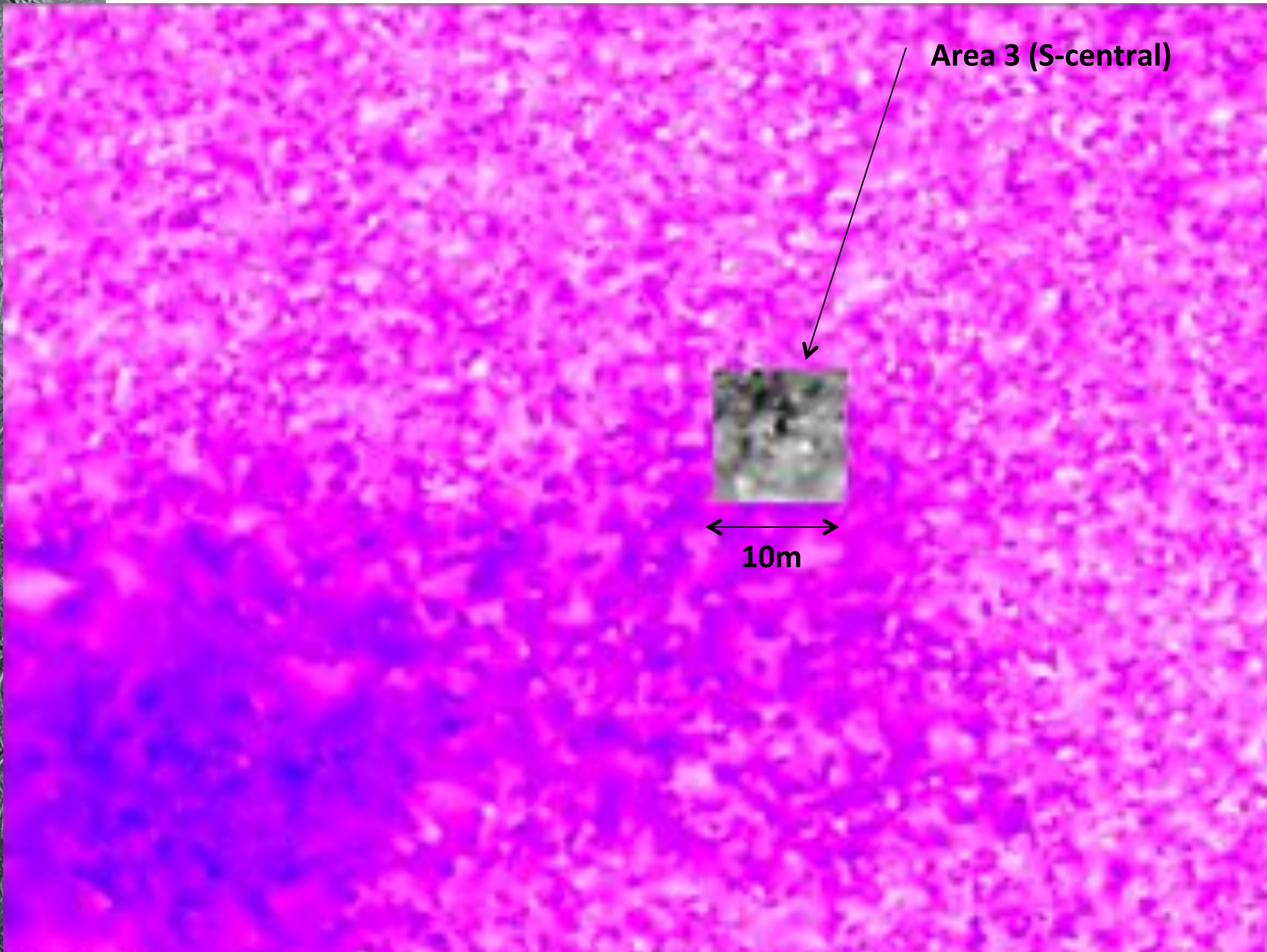

Area 1 (South)
10m

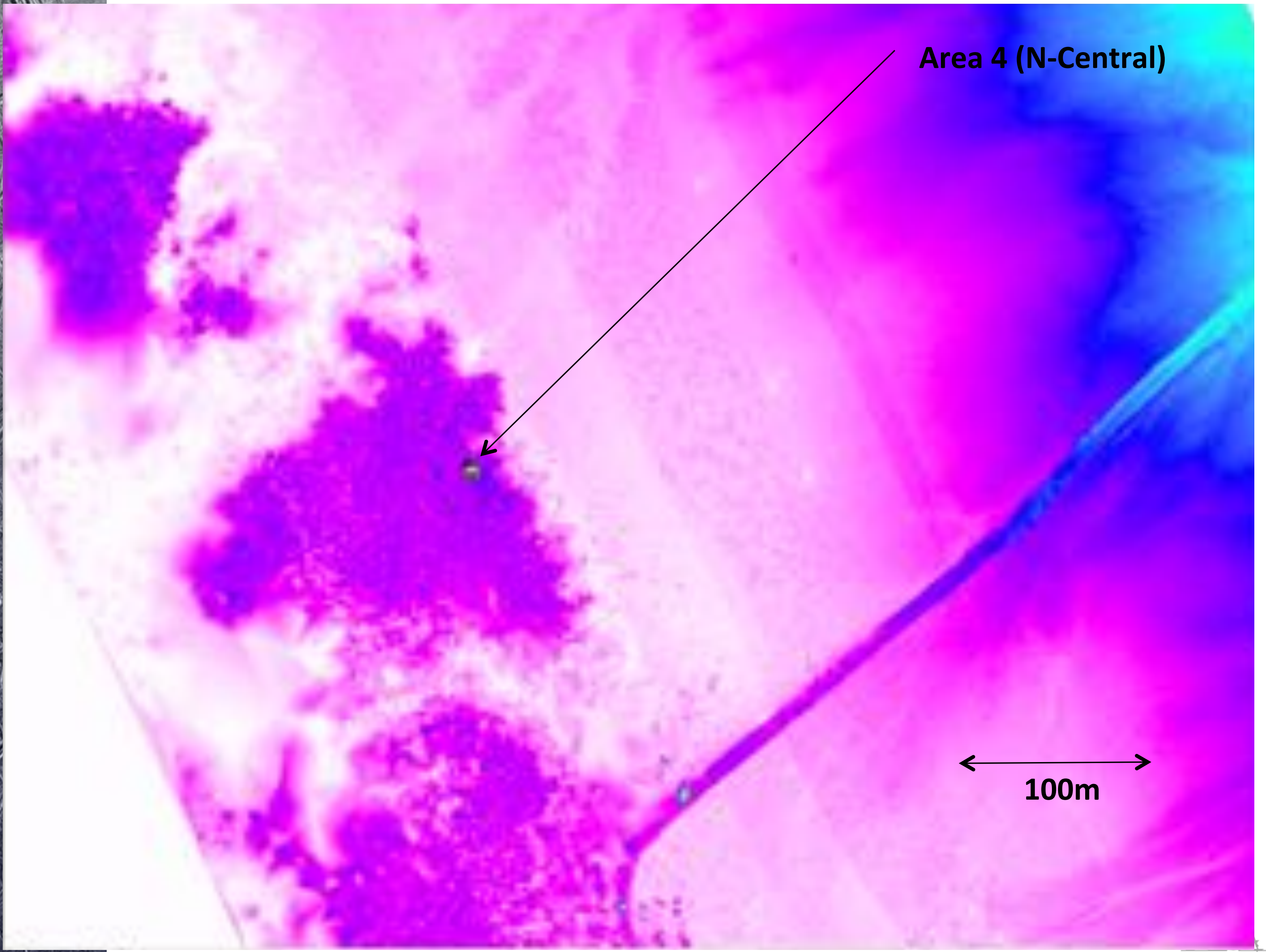

Area 2 (Central)
Road
Parking lot
100m

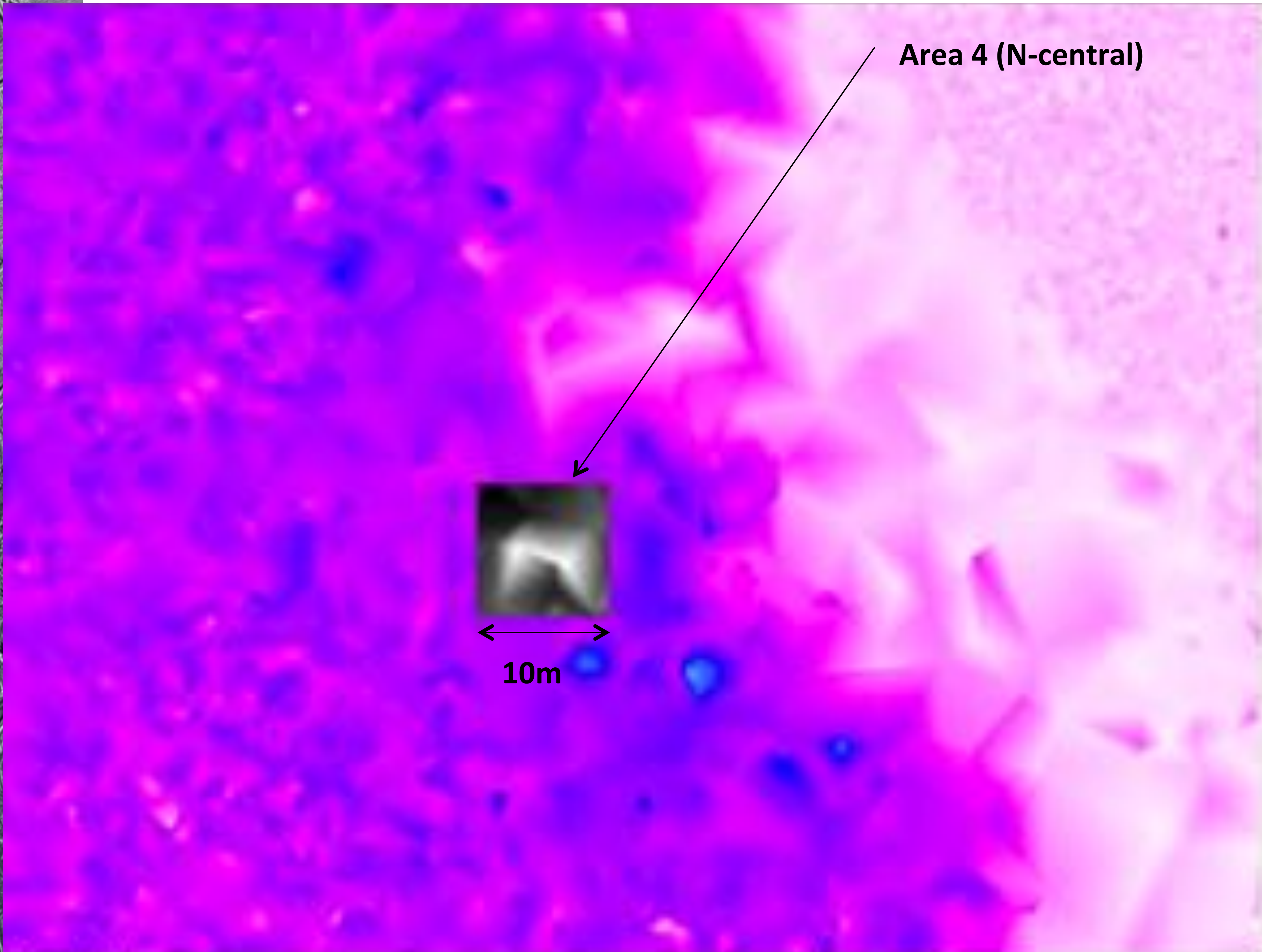


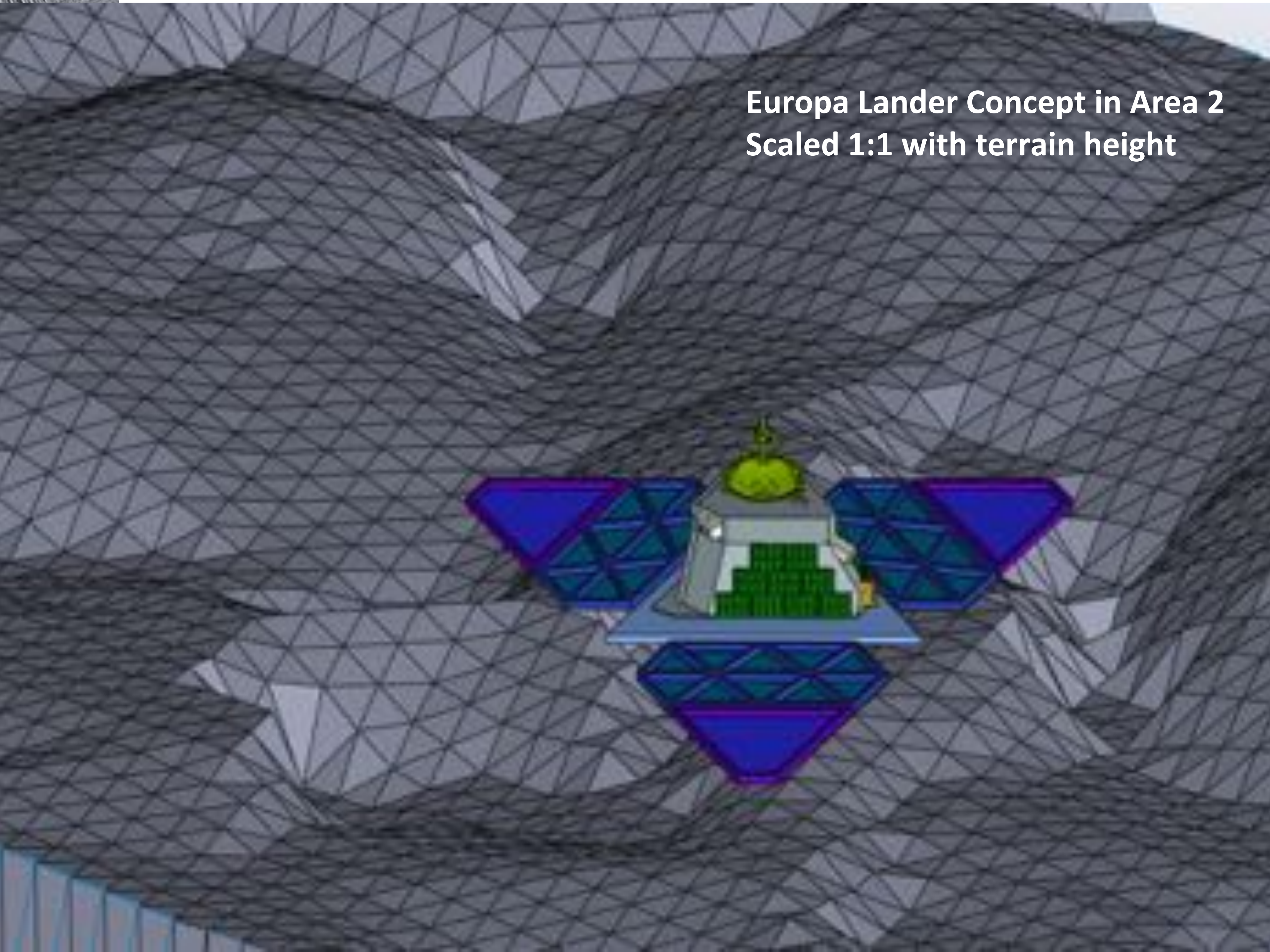
Area 2 (Central)
10m


Area 3 (S-central)
100m

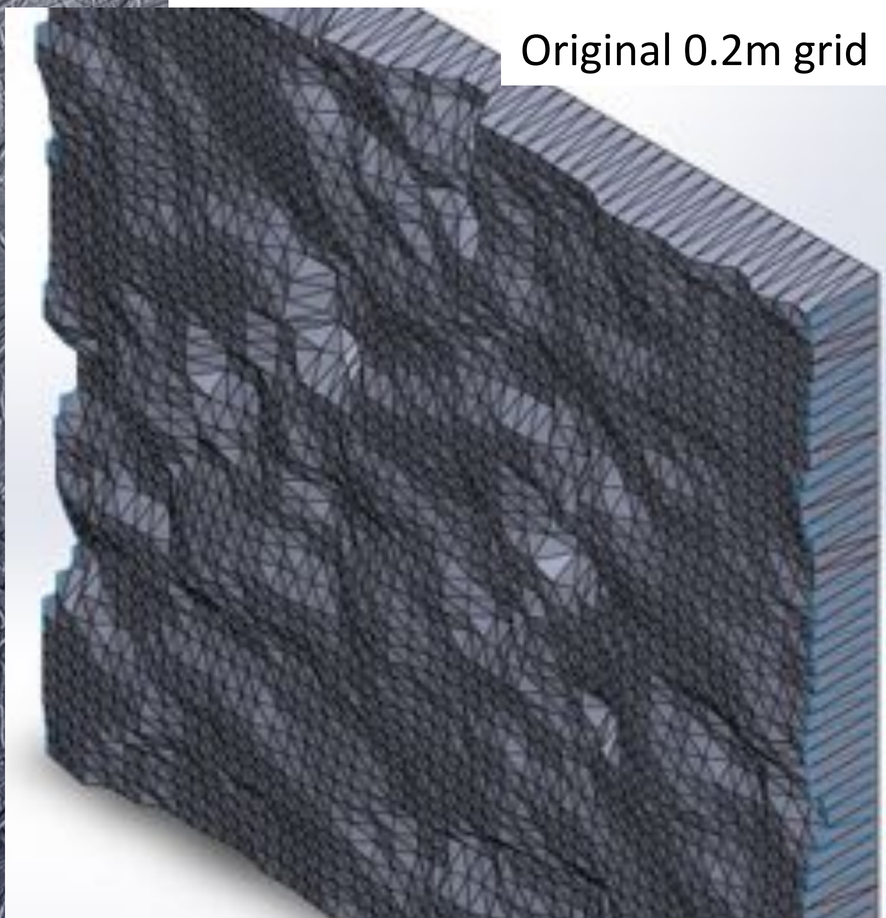

Area 3 (S-central)
10m

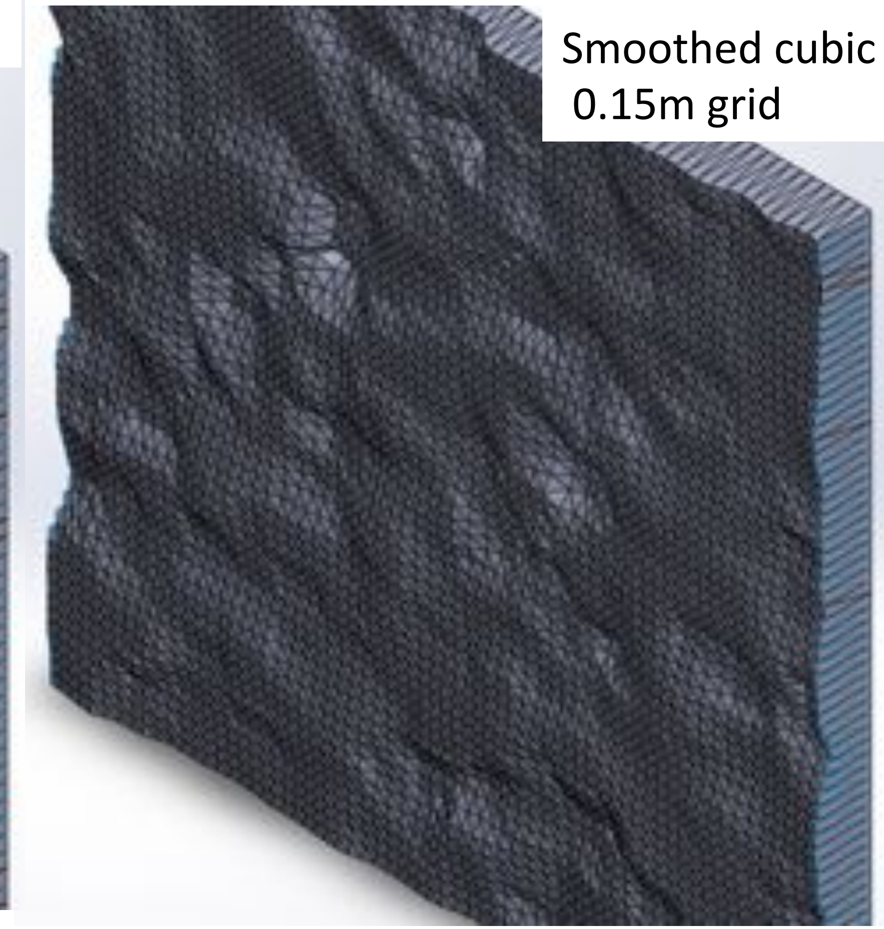

Area 4 (N-Central)
100m


Area 4 (N-central)
10m


Europa Lander Concept in Area 2
Scaled 1:1 with terrain height

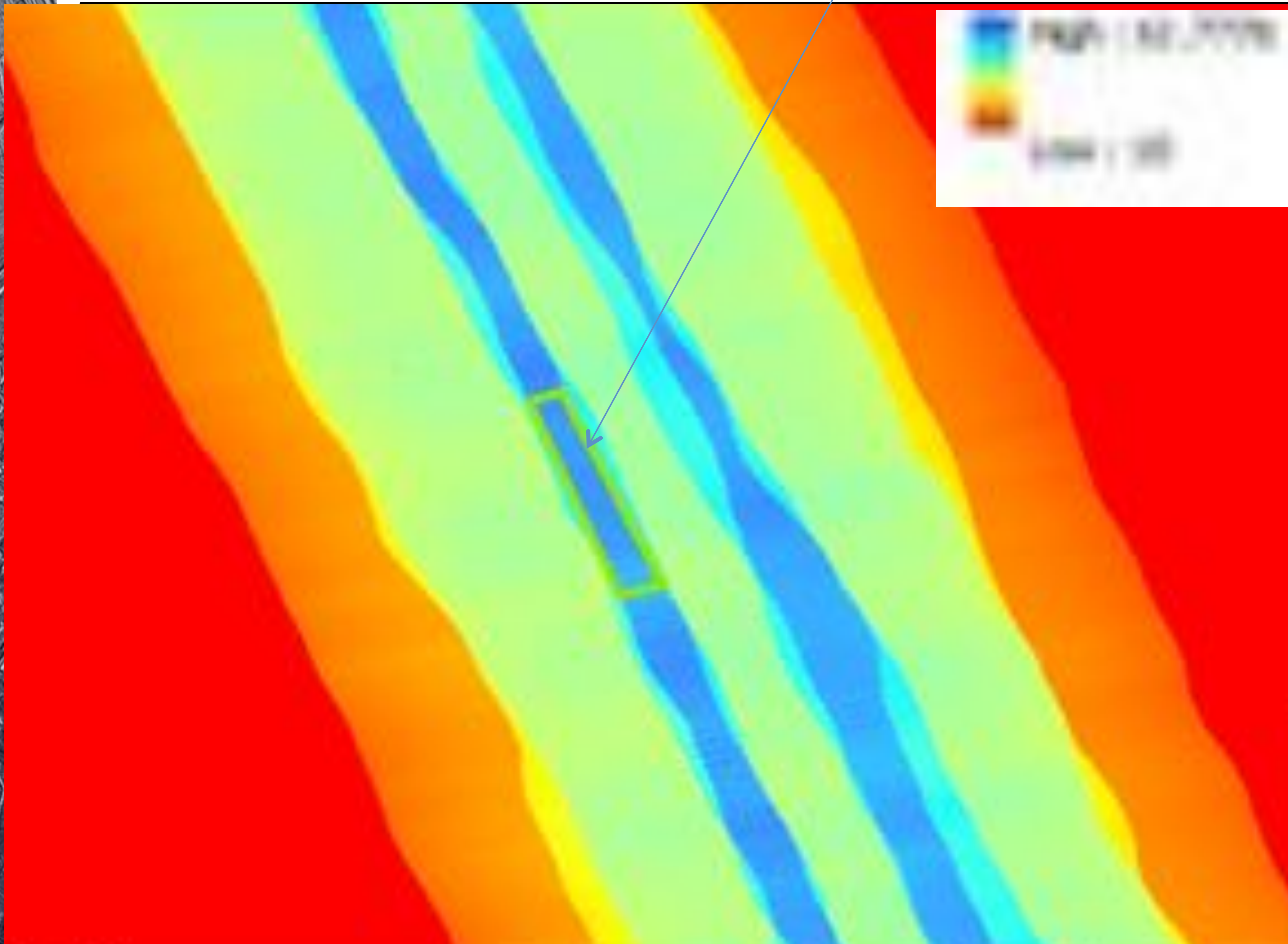
Effect of subsampling to artificially increase resolution.
Area 3 (south) Arc Resampling (smoothing) option

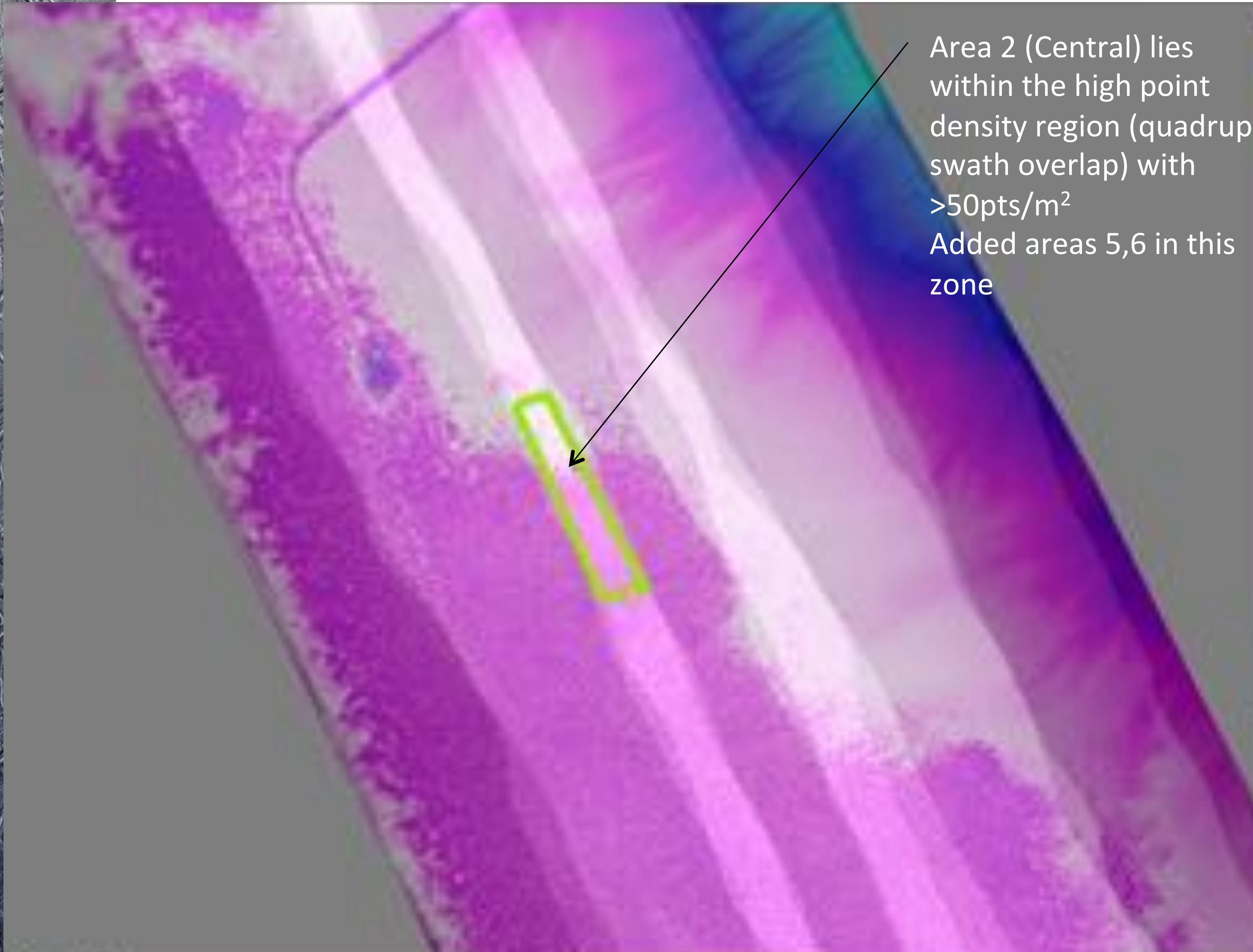




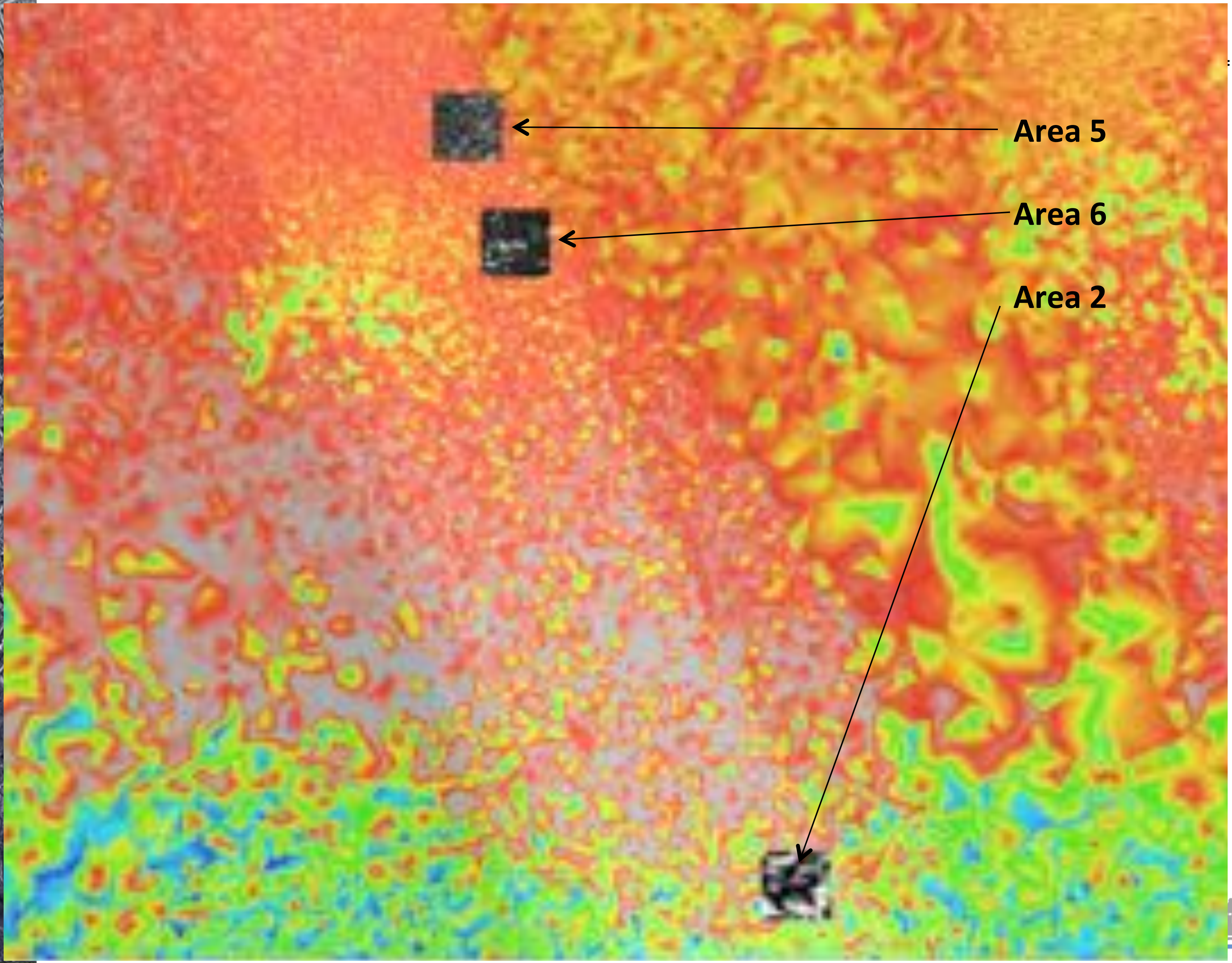
LiDAR Point Density (pts/m2)

Areas of quadruple swath overlap have very high point density. It is possible to generate a higher resolution DEM here.

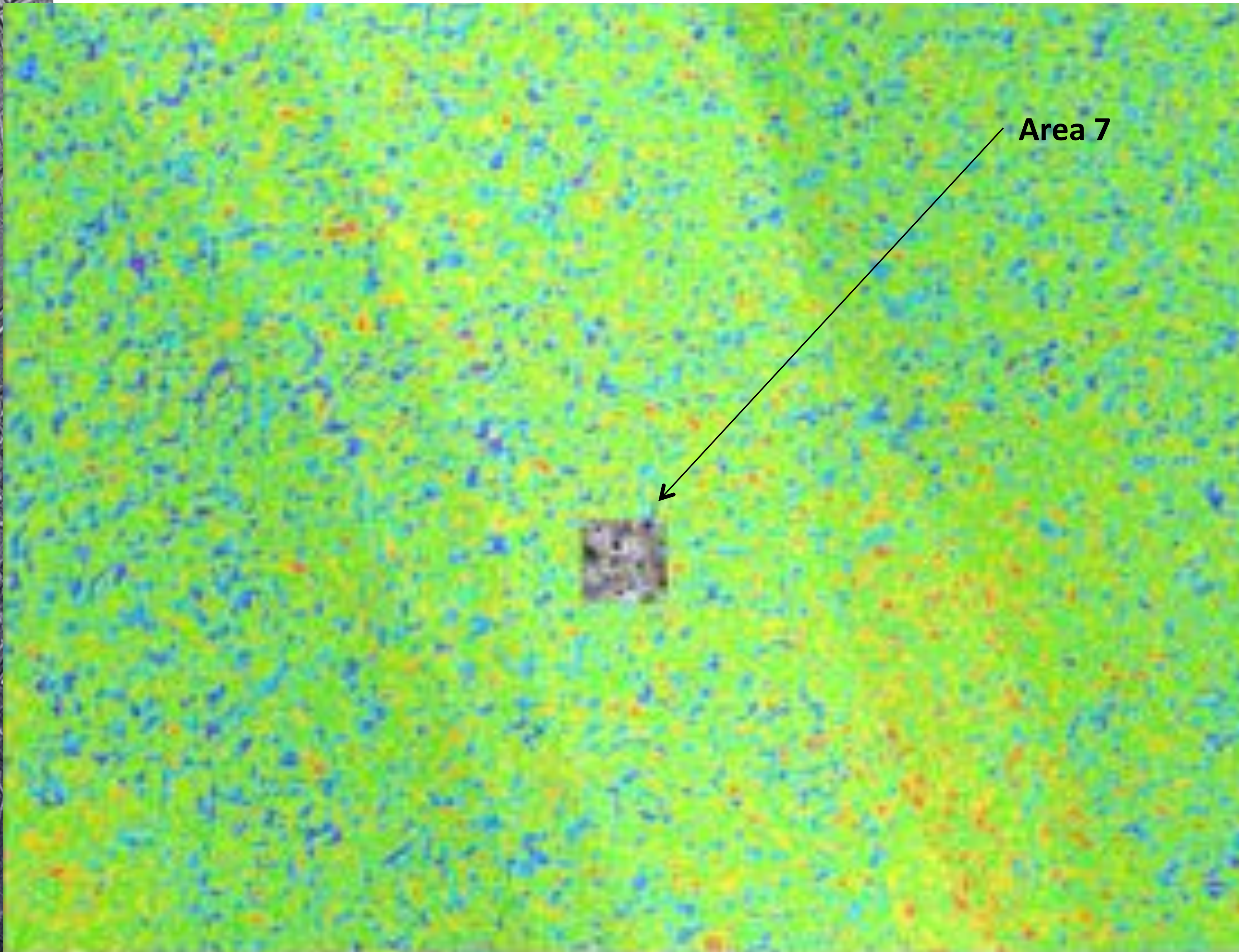



Area 2 (Central) lies within the high point density region (quadruple swath overlap) with >50pts/m^2
Added areas 5,6 in this zone

Fine-Scale Terrain in High-Resolution Zone

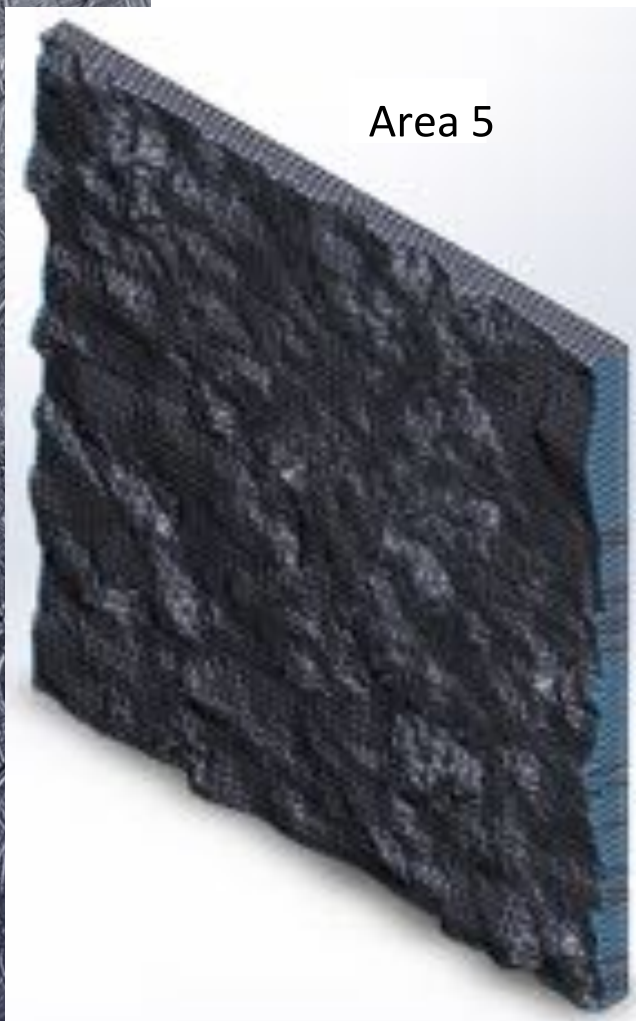


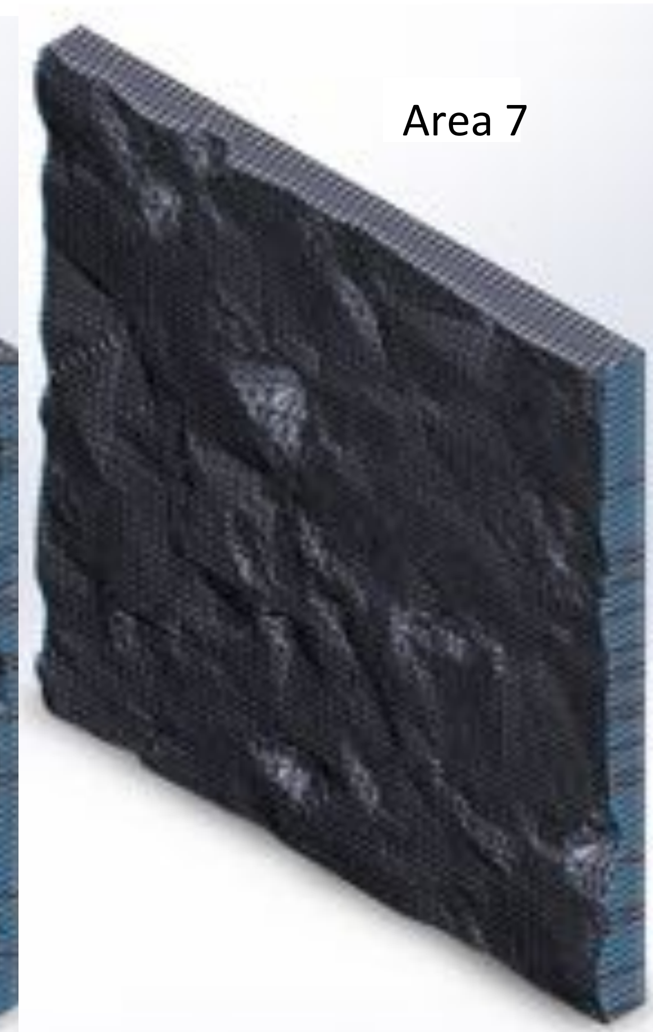
Fine-Scale Terrain in High-Resolution Zone – further south

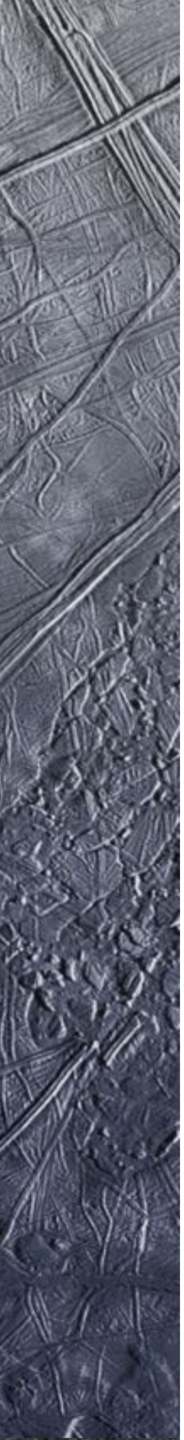


Area 2-central, surface generated with true 0.15m grid vs. 0.2m grid. LiDAR point density in this region is ~60pts/m2, which corresponds to 0.13m best real resolution.

Other 0.15m grid areas



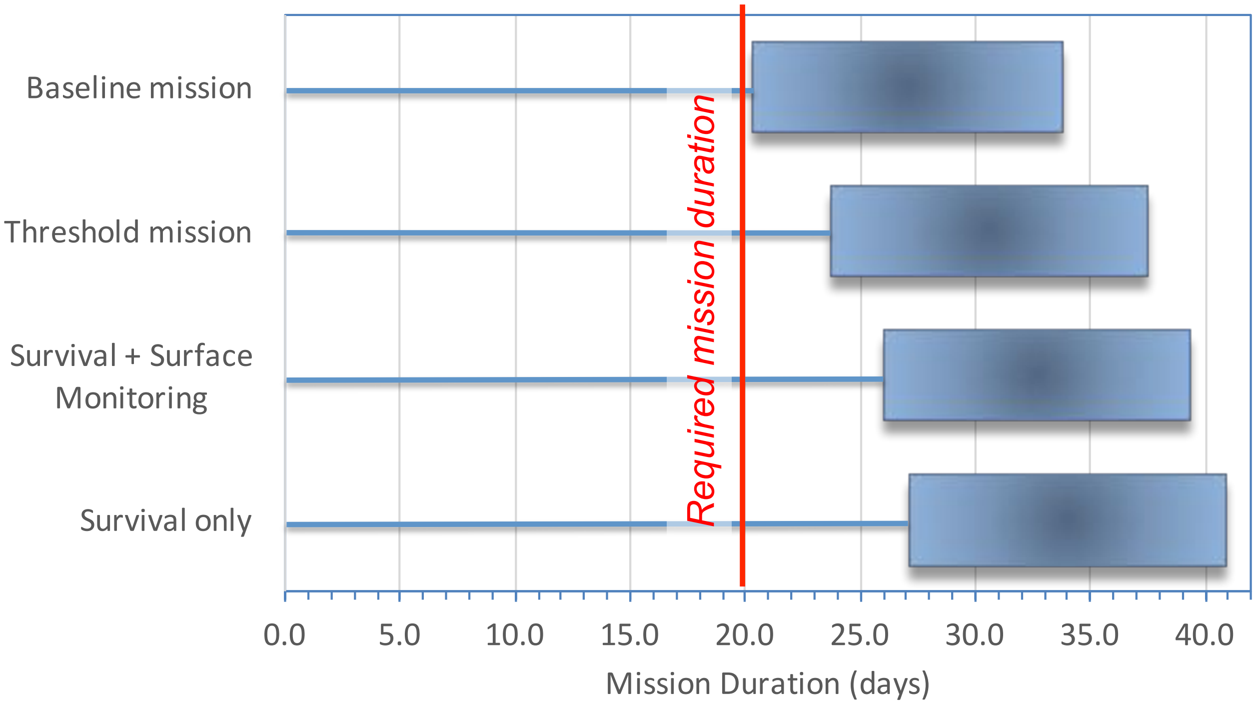




Framework for Life Detection

Mission duration:
Do not think in terms of days,
think in terms energy.

Mission Duration is Governed by Lander's 45 kWh of Stored Battery Energy



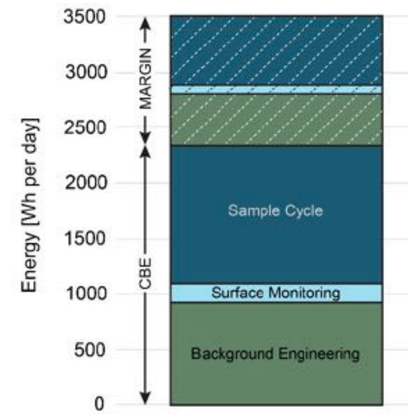
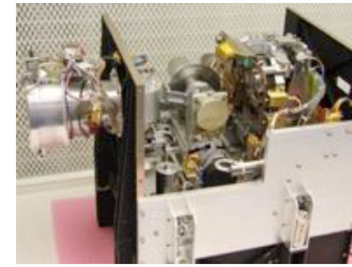
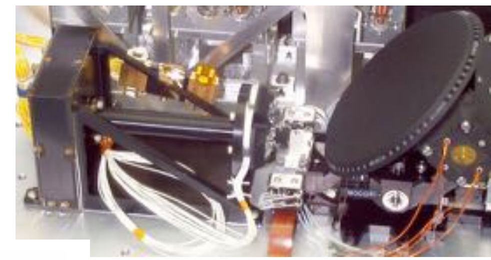
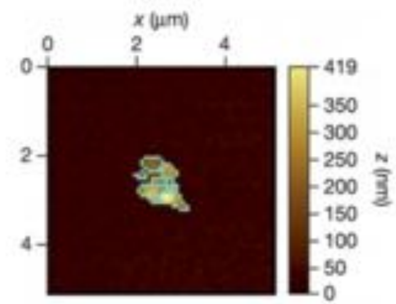


Figure 9.1. Surface mission energy allocation by function for an example sampling tal.

Model Payload Represents Viable Example of Notional Instrument Suite

- **42.5 kg (with margin) for instruments**
- **Inside the Lander "Vault" (for radiation protection):**
  - Gas Chromatograph-Mass Spectrometer
  - Microscope (0.2 micron/pixel resolution)
  - Raman/IR spectrometer
  - 3-axis geophone

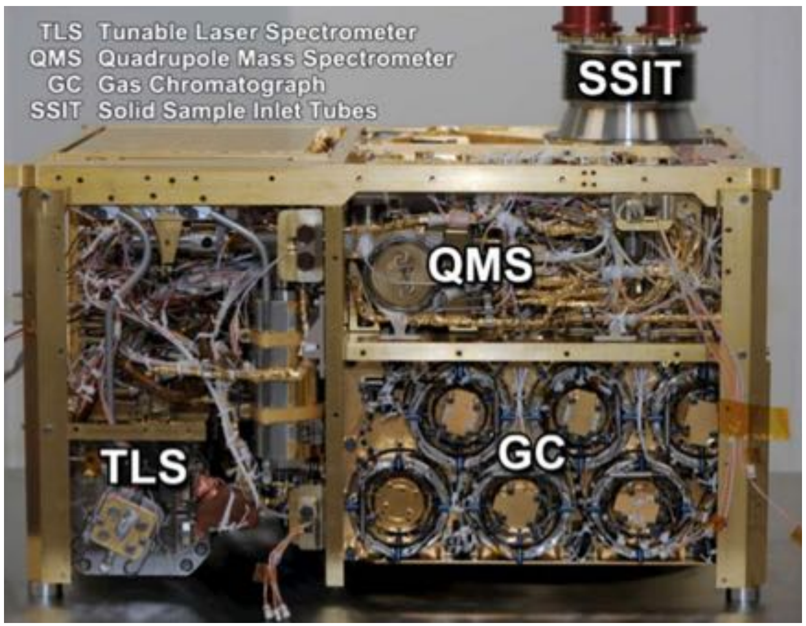



- **External to the vault (mounted on Lander's High-Gain Antenna):**
  - 2 identical visible wavelength, fixed focus cameras at approx. one meter height above surface, with optical "heads" separated by 20+ cm.

Model Payload Represents Viable Example of Notional Instrument Suite

Gas Chromatograph-Mass Spectrometer

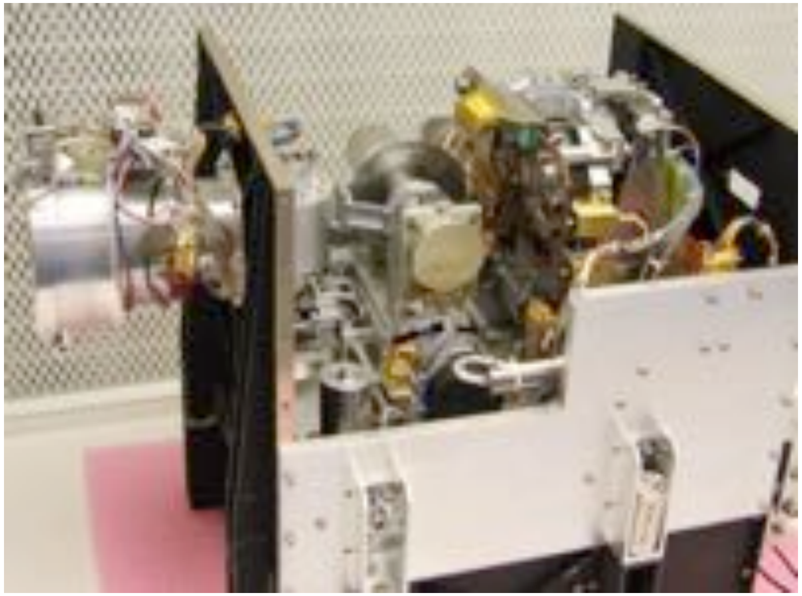


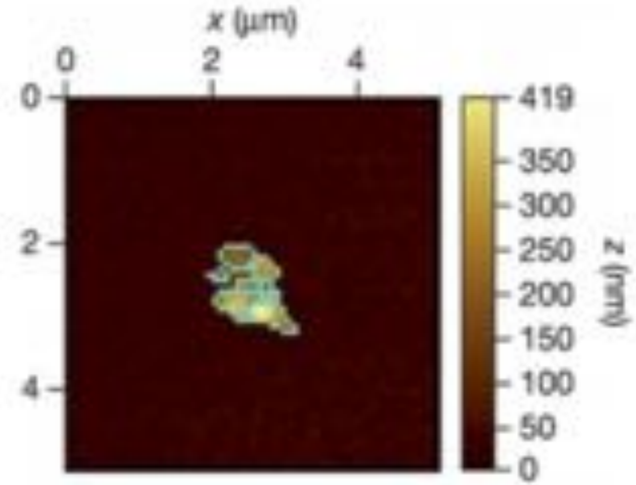
Model Payload Represents Viable Example of Notional Instrument Suite

Raman/IR spectrometer

Model Payload Represents Viable Example of Notional Instrument Suite

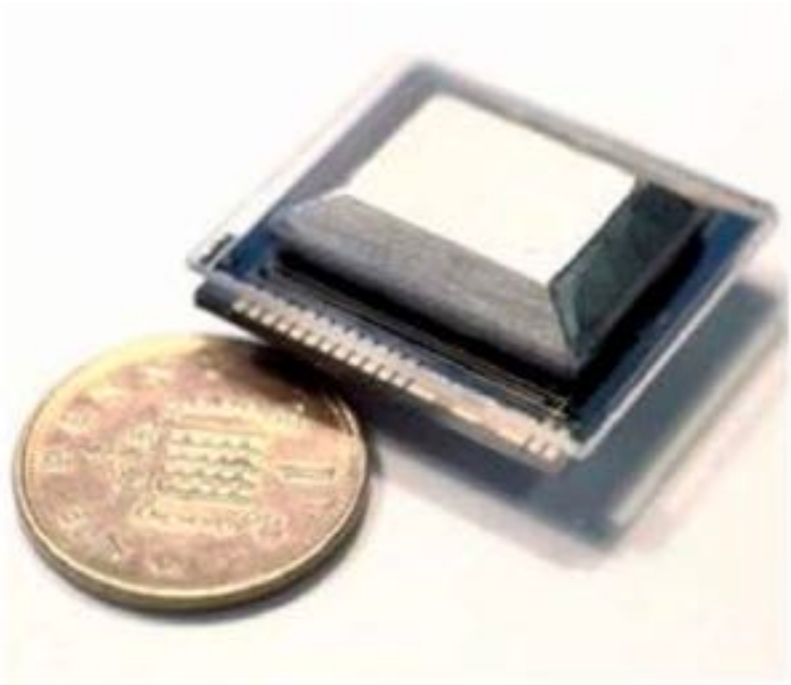
Microscope





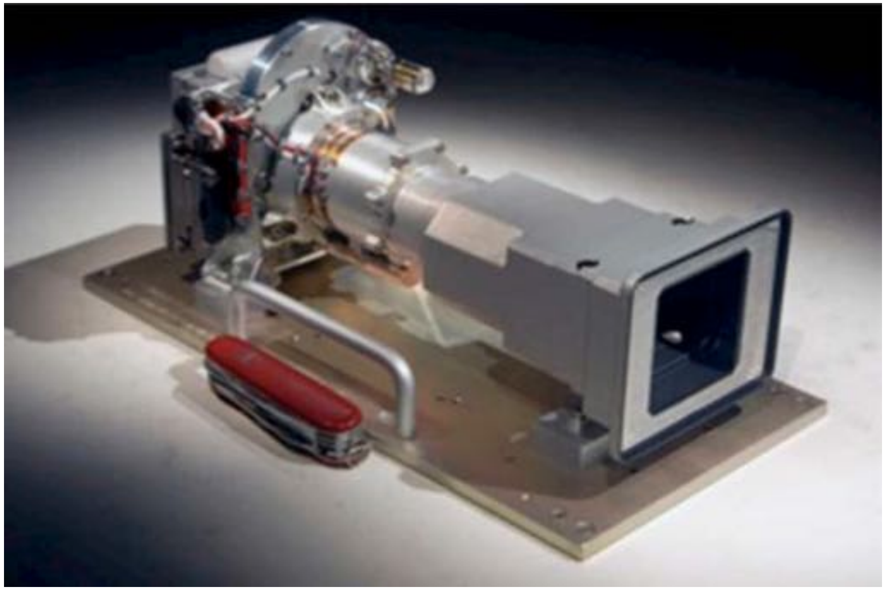
Model Payload Represents Viable Example of Notional Instrument Suite

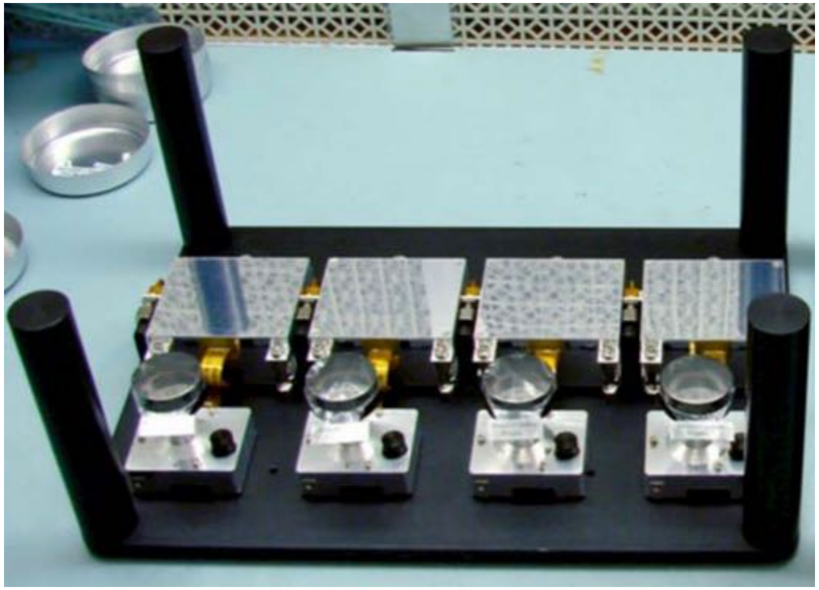
3-axis geophone



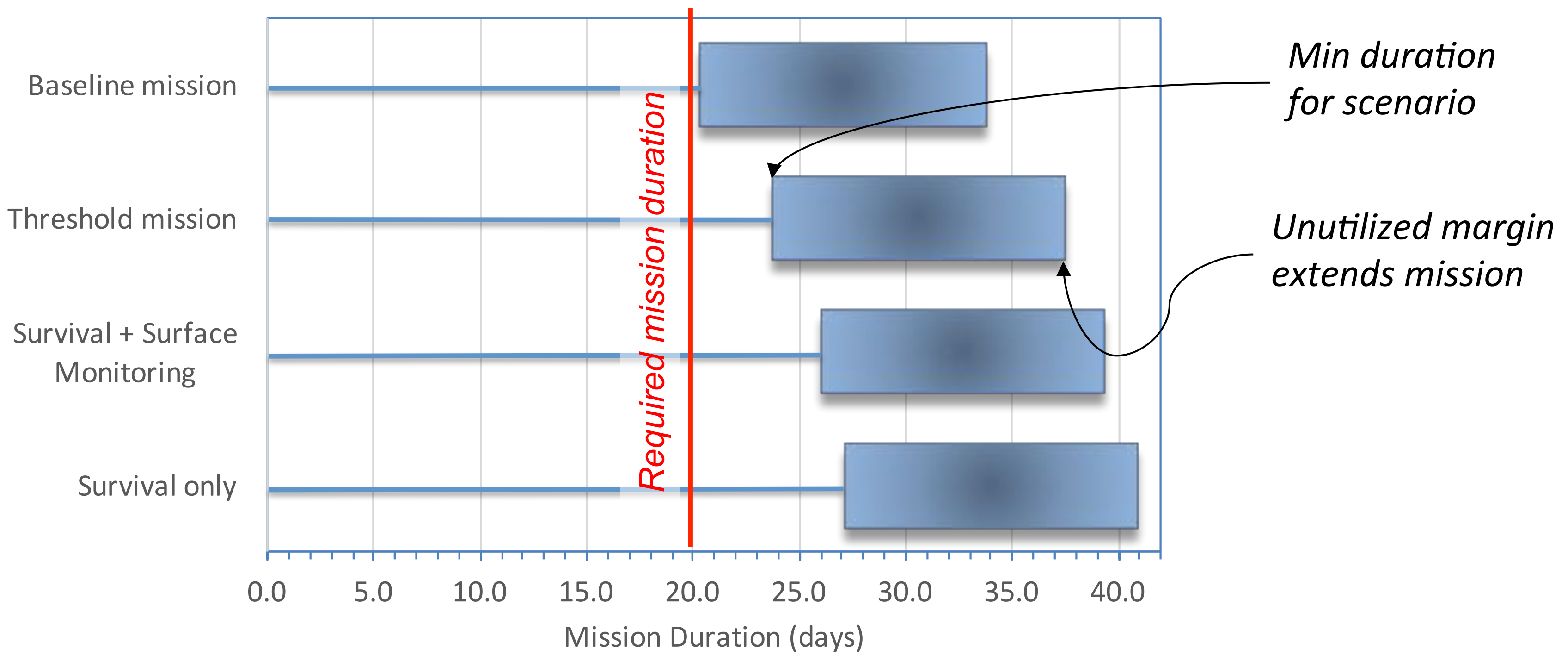
Model Payload Represents Viable Example of Notional Instrument Suite

Context Remote Sensing Instrument





Mission Duration is Governed by Lander's 45 kWh of Stored Battery Energy

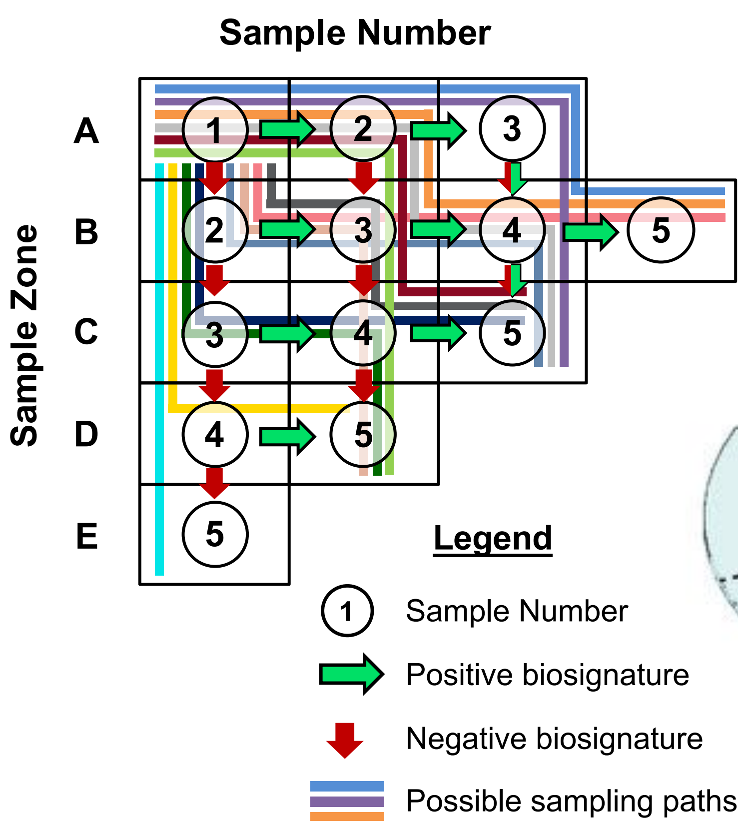


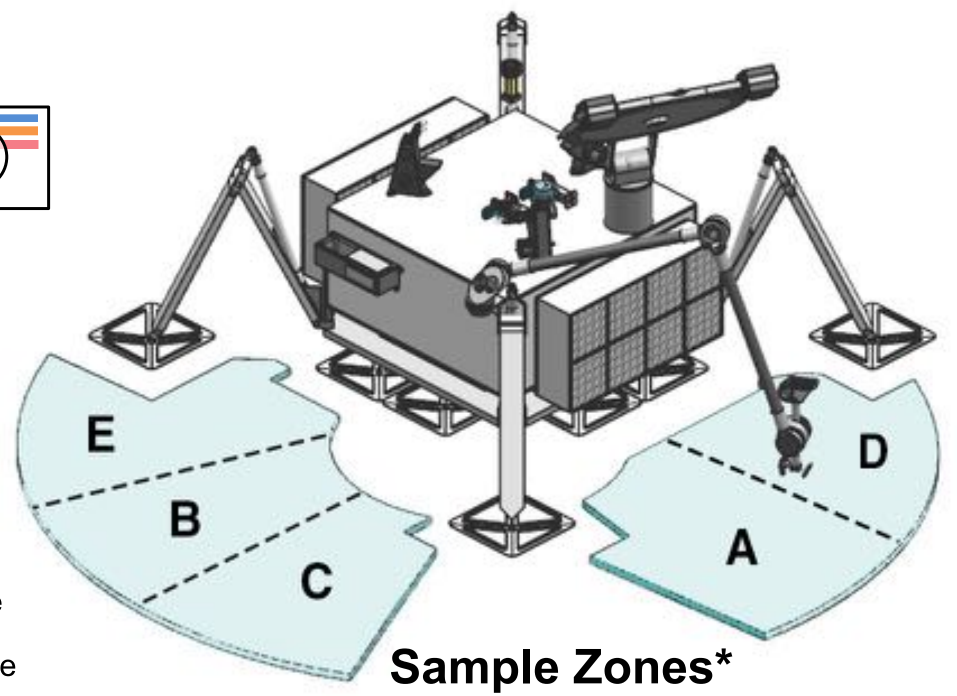
Mission scenario	# Samples	Monitoring tals	Survival tals
Baseline mission	5	continuous	0
Threshold mission	3	7	remainder
Survival + monitoring	0	continuous	0
Survival only	0	0	continuous

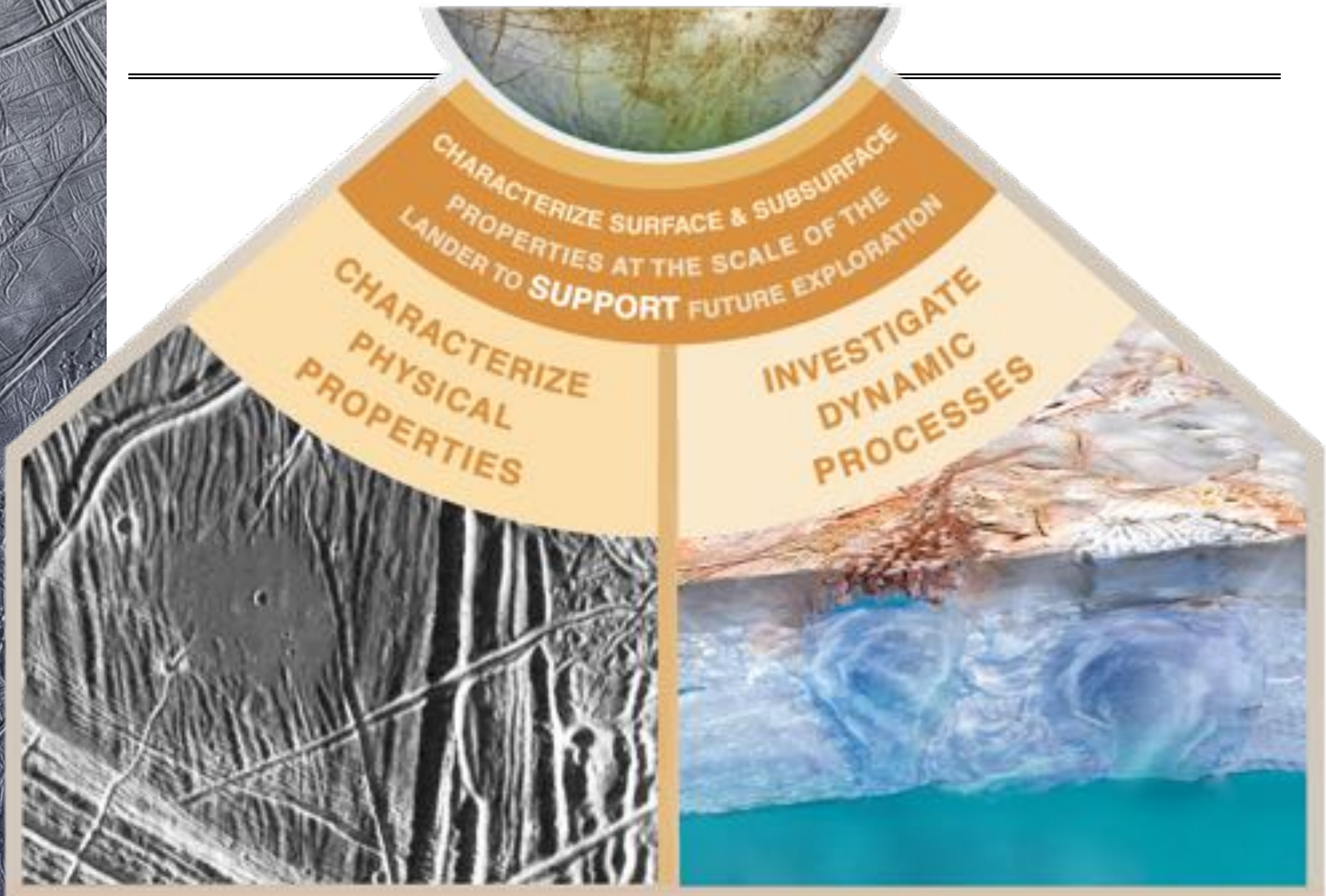
Sampling and Measurement Sequence can be Designed Ahead of Time for Rapid Execution

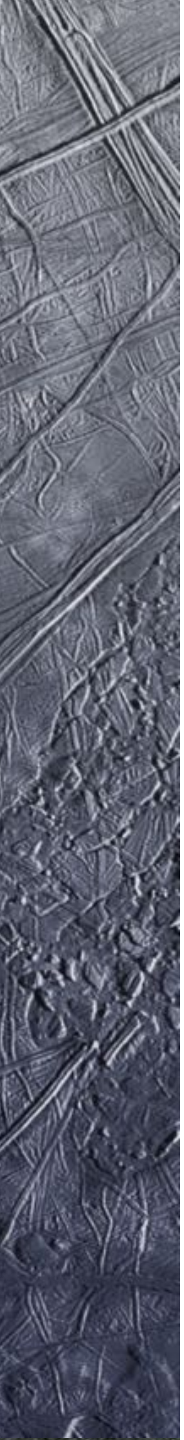
Five Samples Provide Sufficient Measurement Set to Sample Multiple Work Areas and Identify Biosignatures

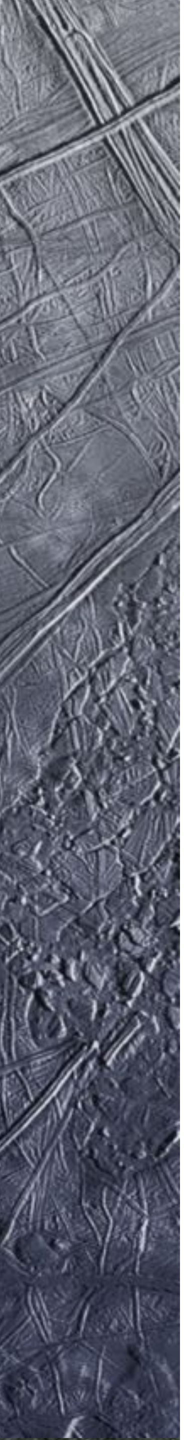
- 3 samples to detect and confirm any biosignatures (triplicate standard)
- Can choose up to 3 different zones, followed by 2 more samples for confirmation

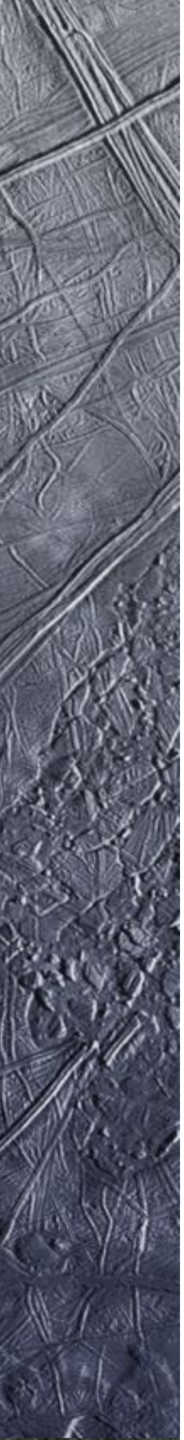





CHARACTERIZE SURFACE & SUBSURFACE PROPERTIES AT THE SCALE OF THE LANDER TO SUPPORT FUTURE EXPLORATION
CHARACTERIZE PHYSICAL PROPERTIES
INVESTIGATE DYNAMIC PROCESSES







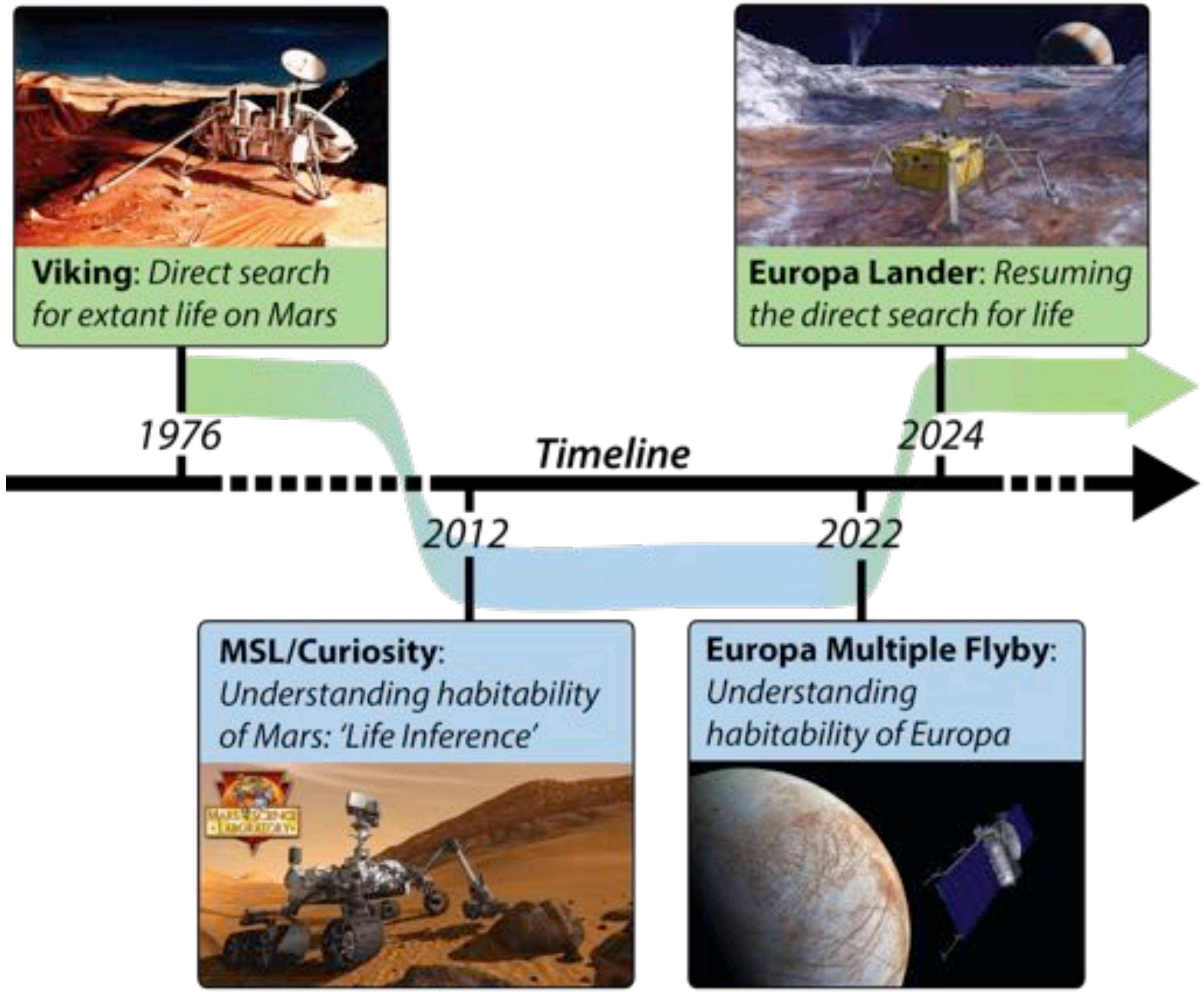
Extras

Introduction and Discussion Topics

- Lander Pre-project Introduction (S. Thurman)
- Science Definition Team (K. Hand)
  - Leverages prior 2012 Europa Lander SDT
  - Use of Europa Clipper data for landing site selection
  - Model Payload Instruments Defined
- Mission Concept Summary (S. Thurman)
  - Separate launch from Europa Clipper
  - Dedicated telecomm relay asset (Clipper backup)
  - Propulsive descent and landing
- Next Steps (All)
  - Completion of SDT report (Jan. 2017)
  - Mission Concept Review (Jun. 2017)

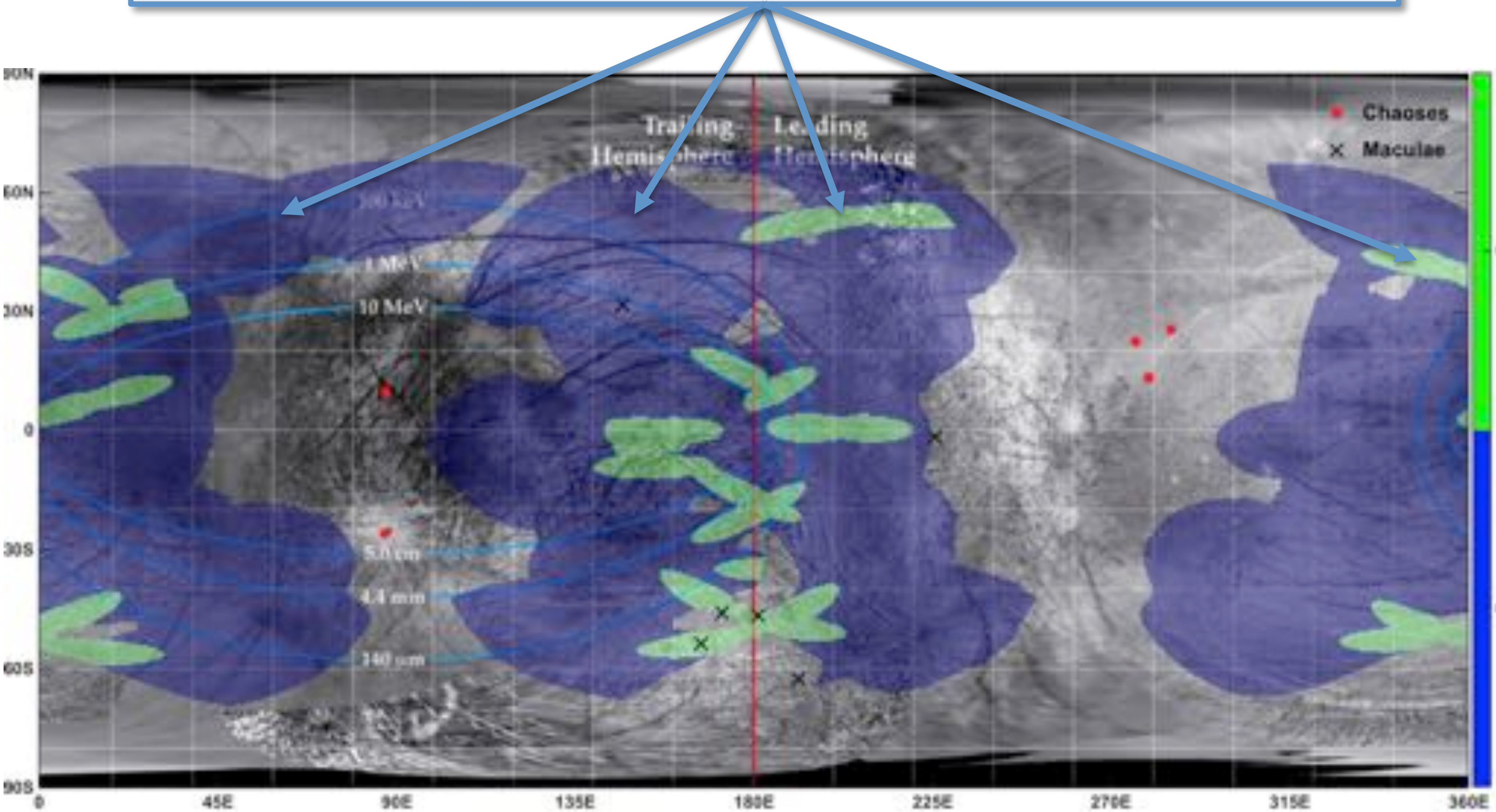
Why Europa?

Europa Lander in Context



Europa Clipper Science Data Can Meet Lander Site Selection Needs

Blue/Green shaded areas represent potential Clipper data with sufficient coverage and resolution for landing site characterization



Resolution < 0.3 m

Resolution < 6 m

Europa Lander Conceptual Framework: Informed by Science Objectives

Key Pre-Phase A Mission Parameters:

- Lander would be launched as a separate mission.
- Target launch: 2024 using SLS launch vehicle.
- Mission would carry its own communication relay (Multiple Flyby can only be used as a backup).
- Battery powered mission: 20+ day surface lifetime.
- Spacecraft provides 42 kg allocation for science payload (with reserves).
- Baseline science includes analyses of 5 samples (3 samples for Threshold) from 10 cm depth or deeper, with a volume of at least 7 cubic centimeters each.

Europa Lander **Science Objectives**

Earth Benchmark Environments Used to Define Life Detection Approach and Measurements

	Lake Vostok (Subglacial)			Lake Vida (Salty)		Winter Circumpolar Deep Water (Deep Ocean)
	Accretion Ice (Type I)	Accretion Ice (Type II)	Glacial Ice	Brine	Ice	
Organic carbon levels (mM)	65	35	16	64,700	n.a.	**38-42**
Microbial abundance (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	**0.4 - 1**
Citation	Christner et al. **2006** L&O	Christner et al. **2006**	Christner et al. **2006**	Murray et al. **2012** PNAS	At 20 m Dugan et al. **2015**; Kuhn et al. **2015**	Yuan et al. (in review)

Europa measurement objectives:

- **Organic Carbon:** Determine presence, identities & relative abundance (**1 picomole in a 1 gram sample**). Molecular weight distribution to at least 550 dalton (Threshold) and bulk structural characteristics of any organics to **1 picomole in a 1 gram sample**.
- **Cell abundance**: Sufficient spatial resolution to **infer cells at ~ 100 cells mL^{-1}** and other microstructures in the sample that have an average diameter of **0.5 µm, in a 5 cc sample**.

Science Trace Matrix Developed to Define Notional Instrument Suite

Goals		Objectives	OCA	MLD	VS	CRSI	GSS	LISS
BIOSIGNATURES	1. Search for evidence of life on Europa.	**1a.** Detect and characterize any organic indicators of past or present life.						
		1b. Identify and characterize morphological, textural and/or other indicators of life.						
		1c. Detect and characterize any inorganic indicators of past or present life.						
		1d. Determine the provenance of sampled material.						
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 and determine whether there are indicators of chemical disequilibria and other environmental factors essential for life.						
		2b. Determine the proximity to liquid water and recently erupted materials at the lander's location.						
CONTEXT	3. Characterize surface and subsurface properties at the scale of the lander to support future exploration.	**3a.** Observe the properties of surface materials at the landing site, including the sampled area, and sub-meter-scale landing hazards, and connect local properties with those seen from flyby remote sensing.						
		3b. Characterize dynamical processes of Europa's surface and ice shell over the duration of the mission to understand exogenous and endogenous effects on the physicochemical properties of surface material.						

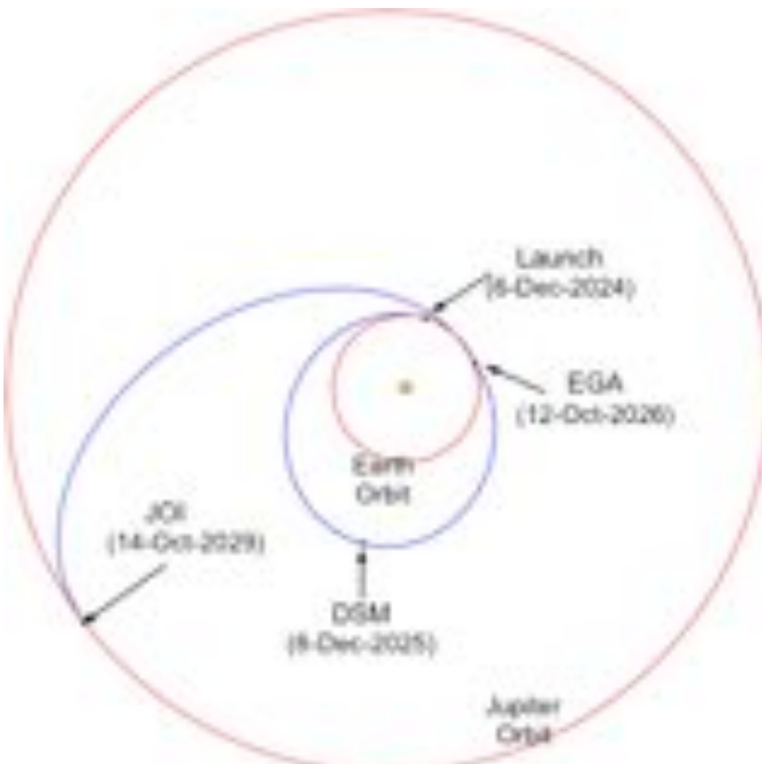
Instruments: Organic Compositional Analyzer (OCA), Microscope for Life Detection (MLD), Vibrational Spectrometer (VS), Context Remote Sensing Imager (CRSI), Geophysical Sounding System (GSS), Lander Infrastructure Sensors for Science (LISS).

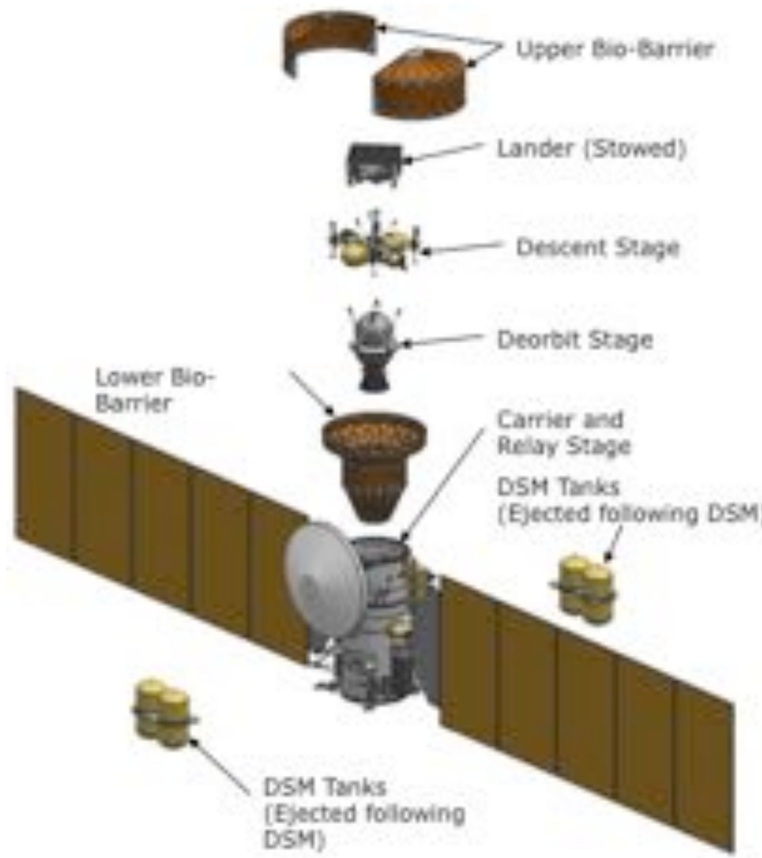
Gray = Baseline Only; Green = Engineering Payload

Signs of Life: Minimizing Ambiguity in Life Detection Experiments

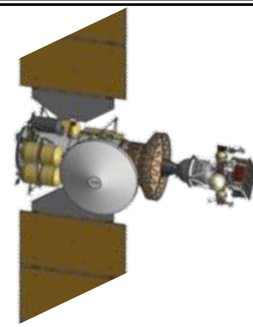
- By End of Mission:
  - Determination of the presence or absence of a suite of potential biosignatures at a level comparable to subglacial Lake Vostok.
  - Determination of the presence or absence of carbon-containing compounds down to a concentration of ~0.1 ppb, which is approximately **six orders of magnitude** better than remote sensing capabilities.
  - In the event of at least three samples yielding a positive life detection, on Day 20 of the mission we will ***NOT*** announce life detection (it will take months to complete analyses and deliberations!)

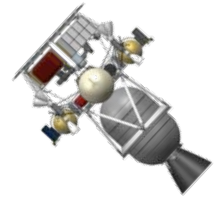
Mission Concept Summary

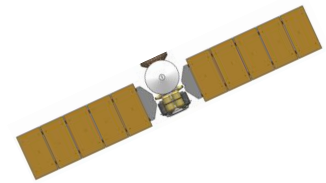




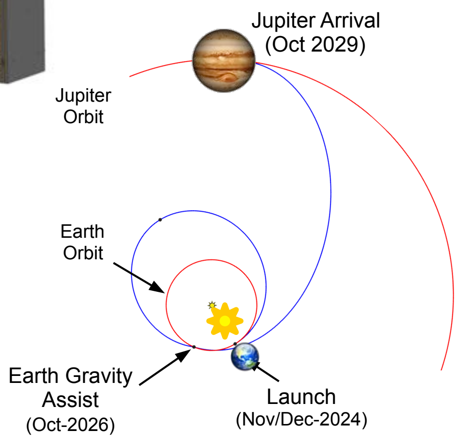
Viable Lander/Carrier Mission Concept Defined from Trade Studies Completed





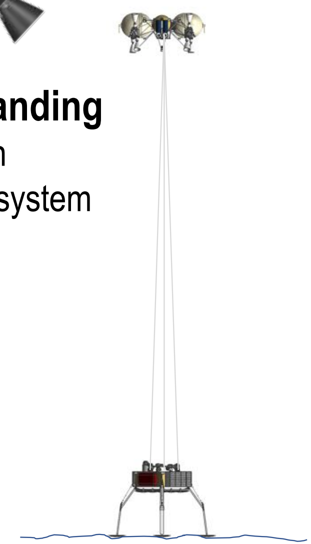


Cruise/Jovian Tour
- Jupiter orbit insertion Oct 2029
- Earliest landing on Europa: Apr 2031



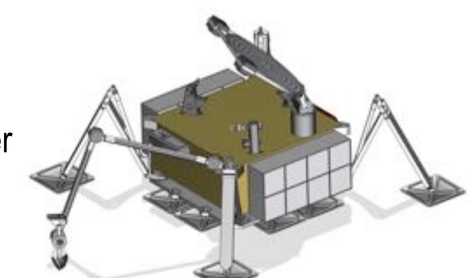
Launch
- SLS Block 1B
- Nov/Dec 2024

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

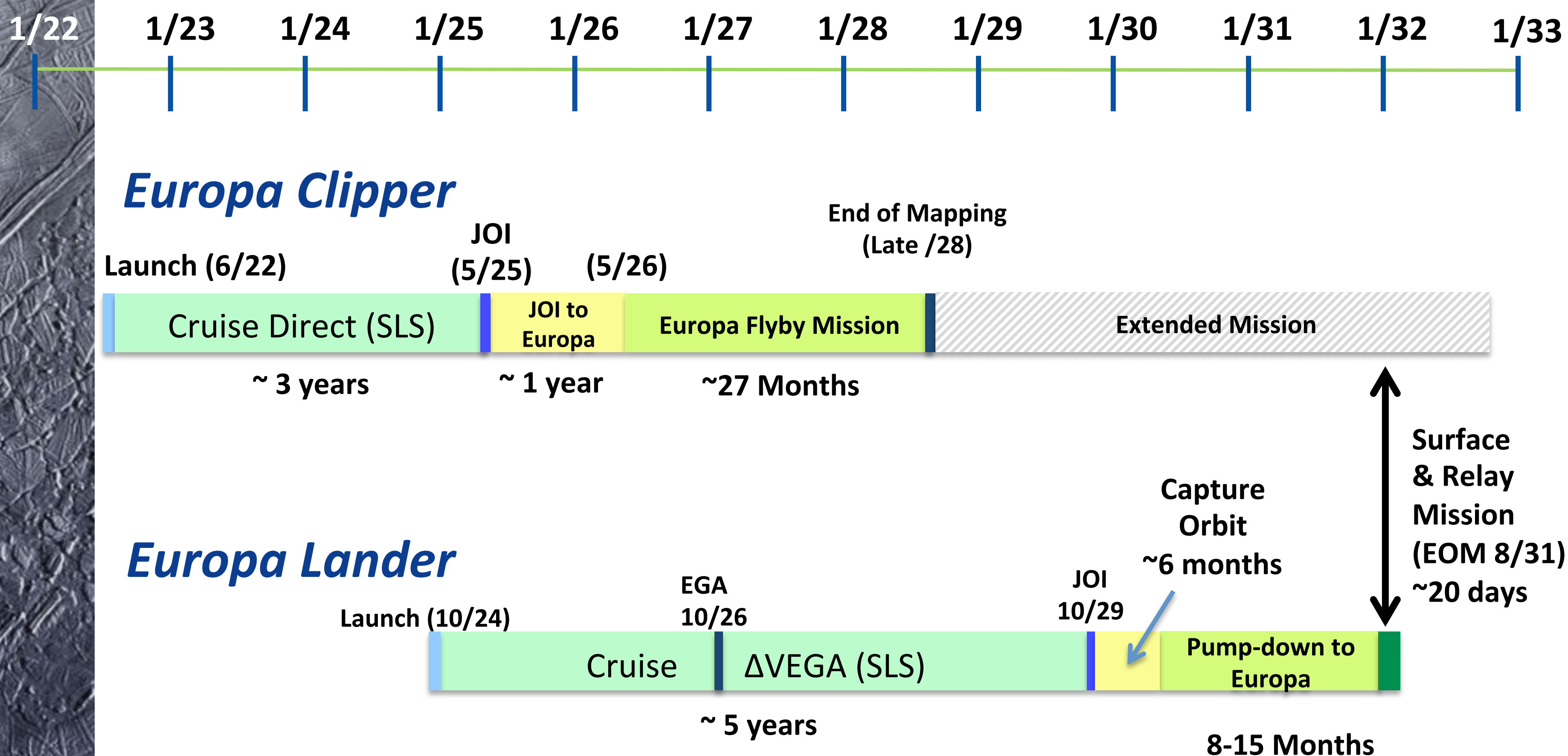


Carrier Relay Orbit
- 24 hour period
- >10 hours continuous coverage per orbit
- 2 Mrad radiation exposure

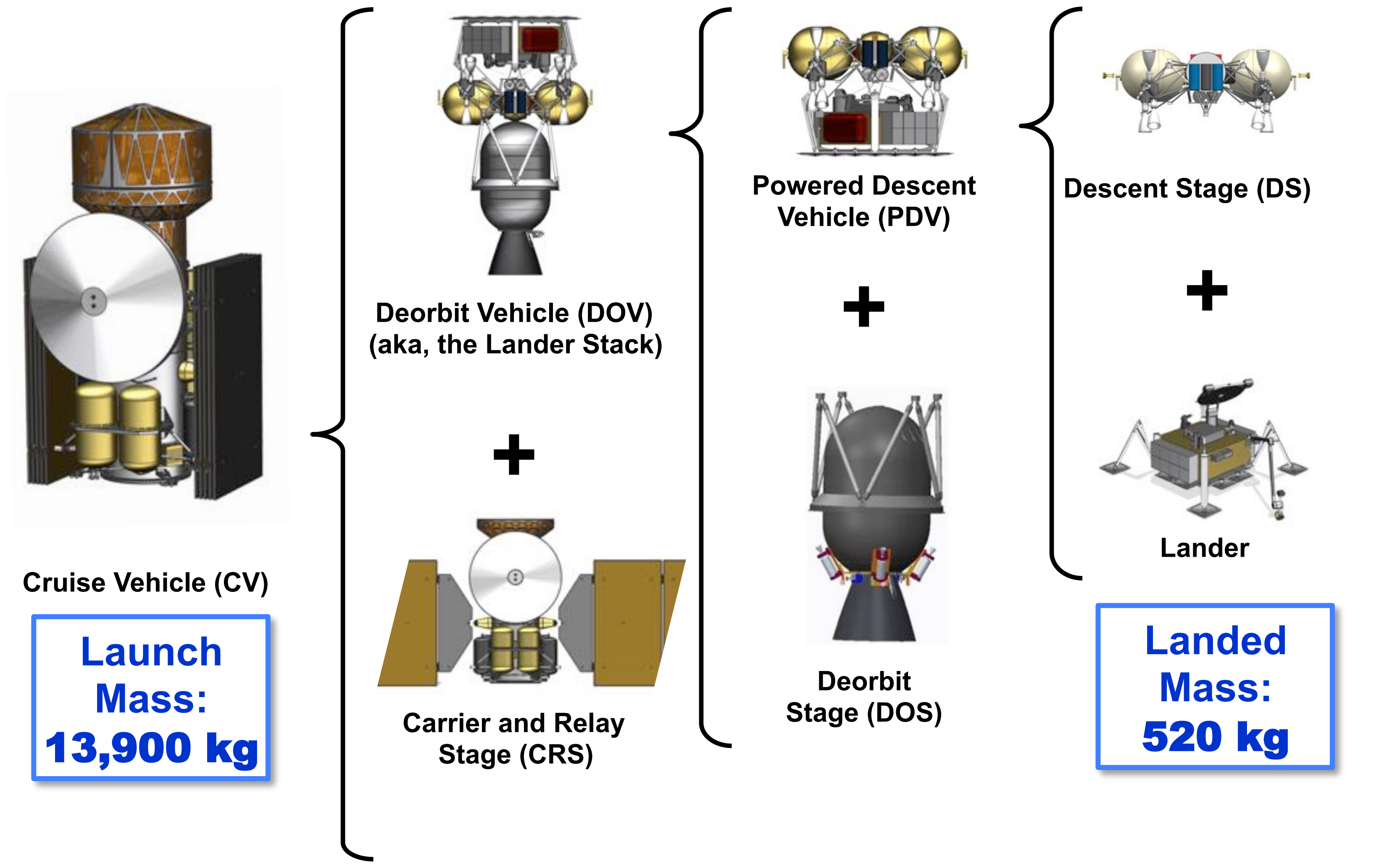
Surface Mission
- 20+ days
- 5 Samples
- Relay comm through Carrier or Clipper (backup)
- 3-4 Gbit data return
- 45 kWh battery
- 1.5 Mrad radiation exposure



Europa Clipper and Lander Timelines Support Site Selection Using Clipper Data



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



Backup Material

Science Definition Team Charter and Composition

- SDT Chartered with mission 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.
- Diverse, cross-cutting team formed
  - Co-chaired by Murray (UNV/Reno), Garvin (GSFC) and Hand (JPL)
  - Team members spanning academia, NASA, and other institutions

Science Definition Team Composition

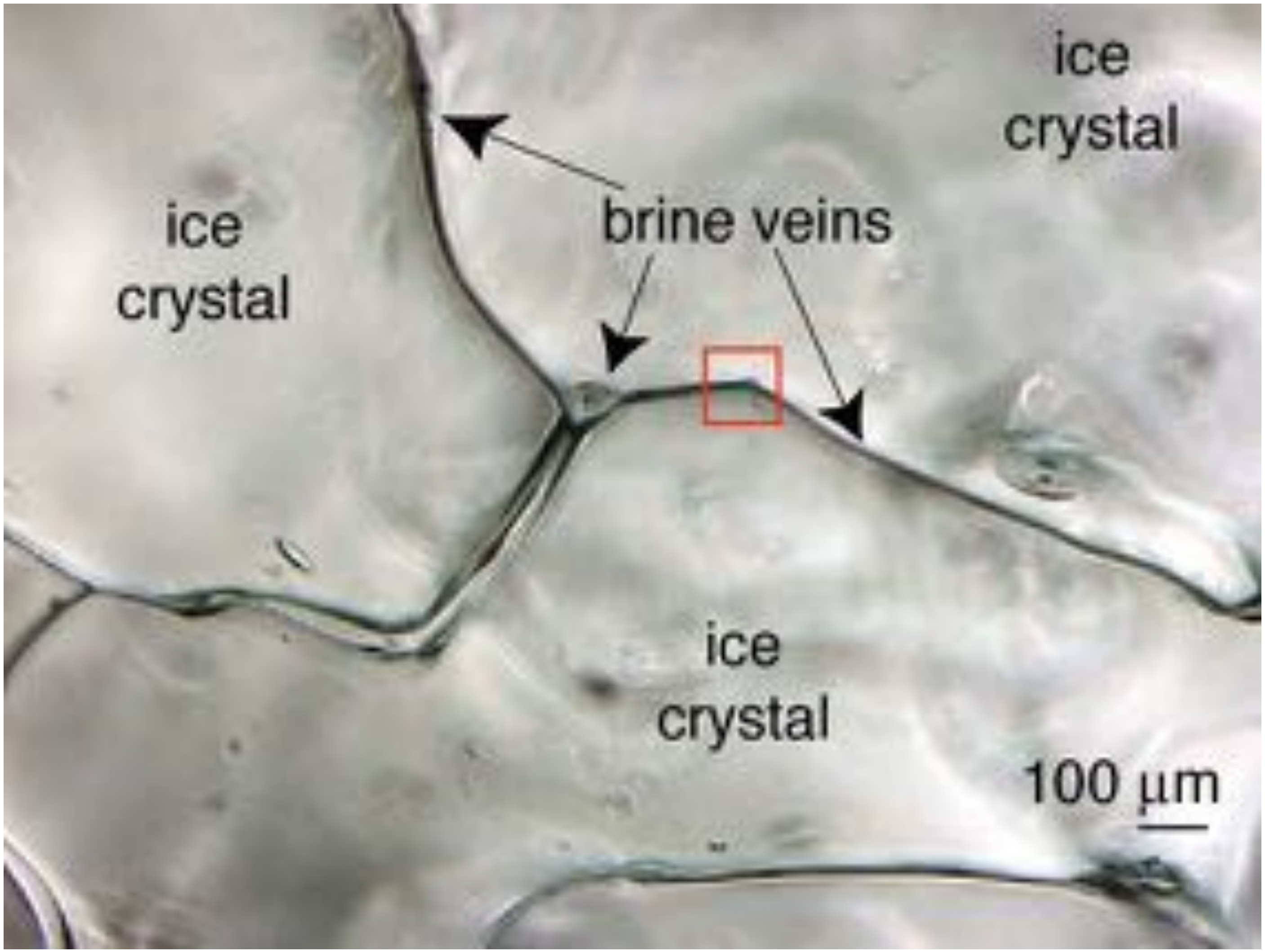
Co-Chairs: Alison Murray, DRI/Univ. NV Reno, Jim Garvin, NASA GSFC; Kevin Hand, NASA JPL

- Ken Edgett, MSSS
- Bethany Ehlmann, Caltech
- Jonathan Lunine, Cornell
- Alyssa Rhoden, ASU
- Will Brinkerhoff, NASA GSFC
- Alexis Templeton, CU Boulder
- Michael Russell, NASA JPL
- Tori Hoehler, NASA Ames
- Ken Nealson, USC
- Sarah Horst, JHU
- Peter Willis, NASA 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 and Ocean Scientists, Microbiologists, Geochemists, Geologists

Europa Lander Project Science Team: Cynthia Phillips, NASA JPL; Morgan Cable, NASA JPL; Kate Craft, APL

Glacial ice triple junctions and veins harbor liquid water and life



Model Payload Formulated via Survey of Example Instruments and Prototypes

Instrument Class	STM Goal	Instrument Example(s)	Flight/Brassboard Example(s)
Organic Compositional Analyzer (OCA)	Goal 1	Gas Chromatograph-Mass Spectrometer (GC-MS)	SAM (MSL), MOMA (ExoMars 2020)
Microscope for Life Detection (MLD)	Goal 1, Goal 3	AFM with Optical Microscope; with Deep UV fluorescence and Raman spectroscopy	Optical Microscope (Phoenix), MIDAS-AFM (ROSETTA)
Vibrational Spectrometer (VS)	Goal 1, Goal 2, Goal 3	Raman or FTIR Spectrometer	SHERLOC (M2020)
Context Remote Sensing Imager (CRSI)	Goal 1, Goal 2, Goal 3 *(external to vault)*	Stereo Camera (possibly with filters or point spectrometer for composition)	EECAMS (M2020), MastCam (MSL)
Geophysical Sounding System (GSS)	Goal 2, Goal 3	Geophone (or 3-axis seismometer)	JPL Seismometer (MGN Decadal Study)
Lander Infrastructure Sensors for Science	Goal 1, Goal 2, Goal 3	Descent Imager, LIDAR, Gravity Tracking	MARDI (MSL), X-band Radio

Model Payload Mass Allocations Developed with Lander Engr. Team

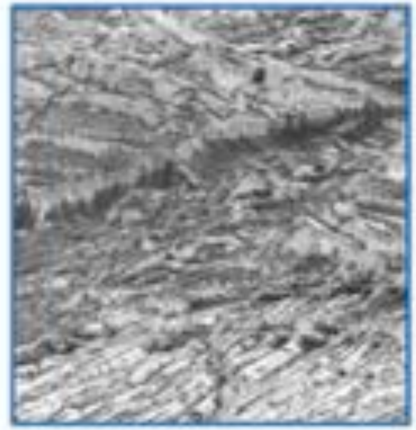
Model Payload Instrument	Threshold			Baseline		
	Allocation	Margin	MEV	Allocation	Margin	MEV
Organic Compositional Analyzer (GC-MS)	**16.40**		**21.6**	**16.4**		**21.6**
Microscope	**5.0**		**6.6**	**5.0**		**6.6**
Instrument	*3.0*		3.9	3.0		3.9
Sample Handling	*2.0*		2.6	2.0		2.6
Vibrational Spectrometer (Raman)	**5.4**		**7.1**	**5.4**		**7.1**
Geophone	**0.8**		**1.1**	**1.2**		**1.6**
Context Remote Sensing Instrument on HGA	**2.2**		**2.9**	**2.8**		**3.7**
Instrument on HGA	1.0		1.3	1.6		2.1
CRSI Vault Electronics	1.2		1.6	1.2		1.6
Radiation Shielding	1.5		2.0	1.5		2.0
Total	**31.3**	*32%*	41.2	**32.3**	***32%***	**42.5**

Relay Orbit Comparison Summary (prelim. based on initial analysis)

Mission Parameter	Carrier w/ Low-Energy Relay Orbit	"Free-Flyer" Ref. (Clipper Relay)
Carrier ΔV to achieve	300 m/s	30-50 m/s
Carrier/Lander Rad dose (TID) to Lander separation	1.1 Mrad	150 krad
Carrier Rad dose (TID) for relay support	1.0 Mrad	N/A
Lander coast time following separation	30 hr.	6 hr.
Lander de-orbit ΔV	1,900 m/s	2,300 – 2,900 m/s
Time from Jupiter Orbit Insertion to Lander delivery	21 months	16 months
Total Science Data Return	3 GB	< 0.5 GB

Europa Surface has Many Potential Hazards

Current knowledge cannot exclude possibility of ubiquitous landing hazards

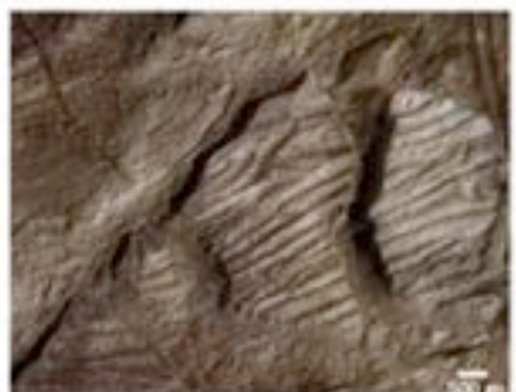


1 m/pixel

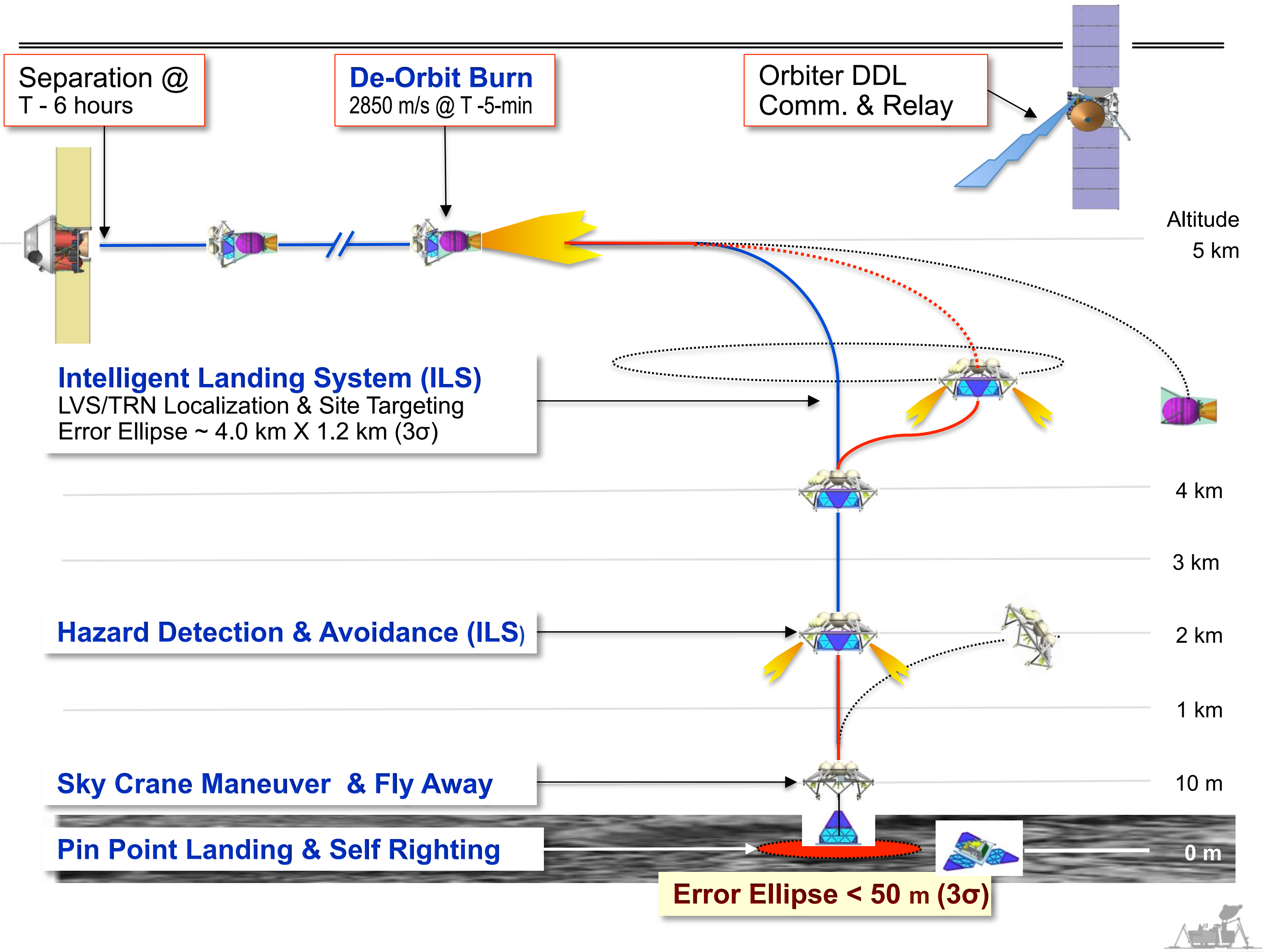
Earth glacier surfaces

Europa at 12 m/pixel and 10 m/pixel

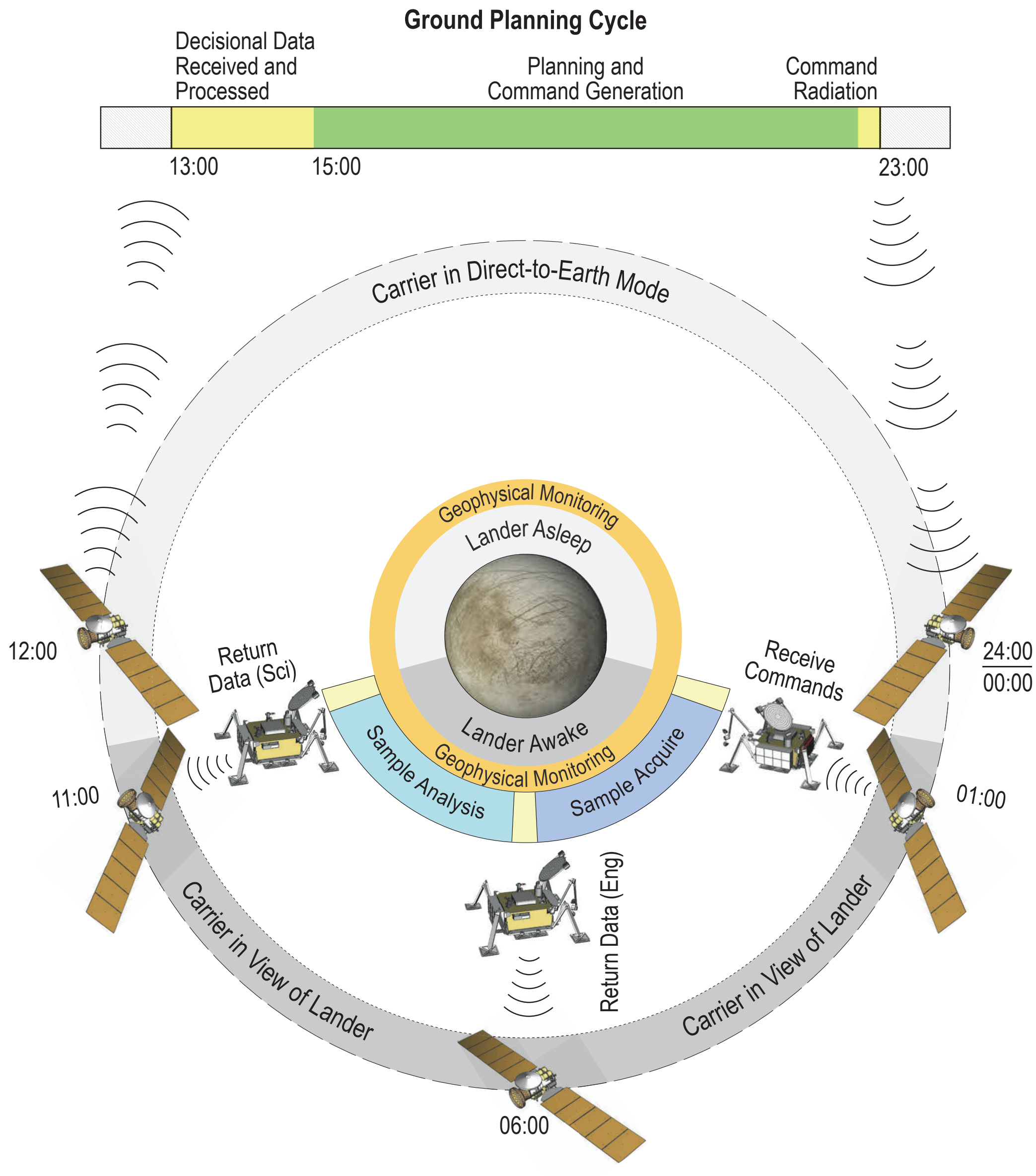
Devil's Golf Course – Death Valley



De-Orbit , Descent & Landing (DDL) Flight Path



Surface Mission Provides for Ground-in-Loop Capability



Representative Surface Timeline