Europa Lander Stereo Spectral Imaging Experiment (ELSSIE)

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ELSSIE is a visible/short-wave infrared (VSWIR) stereo imager and point spectrometer that would provide for Europa Lander (EL):
1) ***panoramic and workspace views to support sampling and geological analyses;***
2) ***VSWIR images and point spectra to identify and characterize enrichments in organics and non-ice phases and determine which ice is least radiation-damaged, thus supporting selection of the best samples for detailed in situ analysis;***
3) ***surveys of the landscape for morphological and spectral evidence of active surface processes.***

REFERENCES:
[1] Murchie S. et al. (2007) JGR Planets, 112, E05S03.
[2] Blaney D.L. et al. (2017) Lunar Planet. Sci. 48. #2244.
[3] Smith P.H. et al. (1997) JGR Planets, 102, 4003–4025.
[4] Hand, K. et al (2017) https://europa.nasa.gov/resources/58/europa-lander-study-2016-report/
[5] Turtle, E.P et al. (2016) Lunar Planet. Sci. 47, #1626.

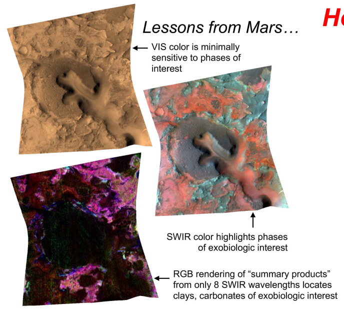
Technical Inspirations

MRO/CRISM imaging spectrometer [1]
- SWIR reveals phases invisible at 0.4-1.0 µm (VIS)
- Most information can be captured by a few colors
- "Summary images" show mineral indices

Europa Clipper/MISE imaging spectrometer [2]
- Sorting and averaging of many short exposures mitigates radiation-induced noise
- Onboard image math in the DPU

Imager for Mars Pathfinder stereo multispectral imager [3]
- Images from multiple sensors on a single focal plane; on Europa Lander cameras, enables just 1 radiation shield

Lessons from Mars…



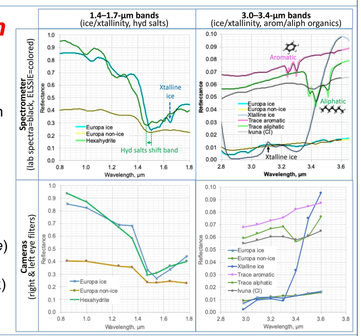
How SWIR Informs EL Sample Selection

The **signatures of an interesting sample** are:
- **Hydrated salts** indicating concentrated ocean water
- **Organics** indicating possible biosignatures
- **Fresh** ice without grains (and organics) disordered by radiation

How to find **hydrated salts**
- 1.5-µm band offset to shorter wavelengths

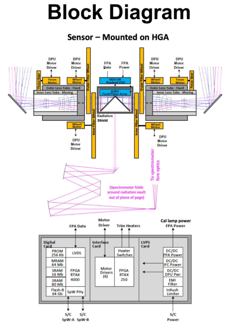
How to find & distinguish **organics**
- 3.3- to 3.4-µm band
- Longer-wavelength band for aliphatic, shorter for aromatic

How to find **fresh ice** (*using depths different wavelengths penetrate*)
- Freshest – amorphous (no 1.65-µm band, no 3.1-µm peak)
- Fresh – has crystallized (has 1.65-µm band, has 3.1-µm peak)
- ✗ Radiation damaged crystalline ice – grain rims have become amorphous (has 1.65-µm band, no 3.1-µm peak)

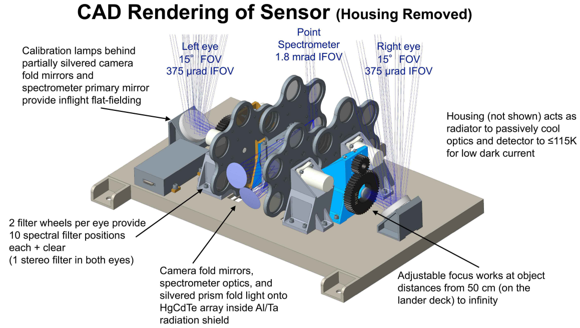


ELSSIE Concept

Block Diagram



CAD Rendering of Sensor (Housing Removed)



Science Traceability

ELSSIE science in gray boxes is enabled by SWIR wavelength coverage

Requirement met by cameras
Requirement met by both cameras & spectrometer
Requirement met by spectrometer

EL Goal [4]	EL Objective [4]	EL Investigation [4]	ELSSIE Science Objective	ELSSIE Requirement
1. Search for evidence of biosignatures on Europa	1A. Detect any organic indicators of past or present life	1A1: Detect organic compounds in the sampled material, w/ emphasis on biogenic characteristics.	Search for organic-rich ice, variations in relative abundance of aliphatic & aromatic compounds	Camera filters & spectrometer cover 3.3-3.4 µm bands
				SNR>50
			Resolve organic-rich material in a >5 mm object @ 2.5 m	IFOV ≤1 mrad
				MTF ≥0.2 @ Nyquist
	1B. Identify / characterize morphological, textural, or other indictors of past or present life	1B2: Resolve and characterize macroscale morphological evidence for life and intermediate scale objects to bridge resolution w/ orbital data..	Resolve structures ≥1.5 mm in size, in color, @1.5 m	IFOV ≤0.5 mrad
				MTF ≥0.2 @ Nyquist
			Resolve ≥1 cm object @10 m, in filters comparable with orbital data	IFOV ≤0.5 mrad
				EIS bandpasses
			Image landscape in stereo	Stereo baseline ≥ (20 cm / (IFOV/0.5 mrad))
	1C. Detect inorganic biomarkers	1C1: Detect potential biominerals.	Detect and discriminate hydrated sulfate, carbonate, chloride, silica, oxyhydroxide, phyllosilicate	Detect 0.5-3.5 µm absorptions
				Spectrometer sampling ≤20 nm
				SNR>50, 1.4-µm hydrated sulfate band
	1D. Determine provenance of sampled material	1D1: Geological context	Resolve 1 mrad features	Satisfied for cameras by 1B2b
		1D2: Characterize chemistry to determine endogenic vs. exogenic origin of a sample & constrain radiation processing of its biosignatures	Detect entombing plume or salt deposits so promising material can be sampled	Camera filters & spectrometer cover hydrated sulfate, chloride, carbonate bands @1.4 µm
				SNR>50
				Spatial requirements same as 1A1
			Discriminate fresh vs. amorphous ice grains, coatings	Measure 1.65-µm band, 3.1-µm peak in crystalline ice
			Detect H2O2	Coverage @3.5 µm
			Detect chondritic silicates	Detect 1-3.5 µm absorptions
			Fill FOV, 1 cc sample @2 m	IFOV ≤2.5 mrad
2. Assess habitability of Europa via *in situ* techniques available to a lander	2A. Characterize the non-ice composition of Europa's near-surface	2A1: Assess habitability of ocean from non-ice materials	Detect hydrated chloride, sulfate, carbonate, silica	Satisfied for spectrometer by 1B2, IFOV by 1D2
		2A2: Identify spatial variation in composition, inform sampling	Detect variations in non-ice composition @1 mm; additional information @10 cm	Satisfied by 1A1, 1B2, 1C1, 1D2 (cameras, spectrometer)
	2B. Determine proximity to … recently erupted materials	2B2: Search for evidence of emplaced liquid water	Survey site for flow morphologies	Satisfied for cameras by 1B2
		2B3: Search for evidence of active plumes / materials	Confirm fresh vs. amorphous ice grains, coatings	Spectral sampling covering 1.65 & 3.1 µm
			Plume search @ twilight	High dynamic range using long exposures
3. Characterize surface & subsurface properties at lander scale	3A. Observe properties of surface materials & hazards. Connect w/ orbital data	3A1: Characterize physical properties of surface materials	Examine fractures, regolith, shape of sampling tailings	Same as 1B2
			Map ice grain size variations using 1.25-, 1.5-µm bands	Measurements @ 1.25, 1.5 µm and continuum
		3A2: Identify geomorphic features of landing zone	Stereo & color imaging, landscape	Satisfied by 1B2
		3A3: Characterize non-ice mineralogy	Spectroscopy, key absorptions	Satisfied by 1C1
	3B. Characterize dynamic properties of surface	3B1: Characterize physical processes that alter surface	Repeat imaging in 1.25-, 1.65-µm bands	≥2 mosaics of far field to detect changes
		3B2: Characterize chemical processes (e.g., radiolysis)	Spectral measurements before & after excavation	Satisfied by 1D2

Design & Testing in ICEE-2

ICEE-2 Development Tasks

1) Iterate sensor & DPU designs to shrink volume, mass, resource utilization, then proceed to mechanical design
2) Demonstrate compatibility of suitable detector with heat microbial reduction
3) Model radiation at FPA to verify noise within tolerance of onboard processing; iterate shielding design as needed
4) Build prototype lens cell and demonstrate performance at cryogenic temperature (leverage EIS development [5])
5) Build prototype adjustable focus and demonstrate performance at cryogenic temperature
6) Build prototype spectrometer
7) Prototype & demonstrate onboard processing algorithms

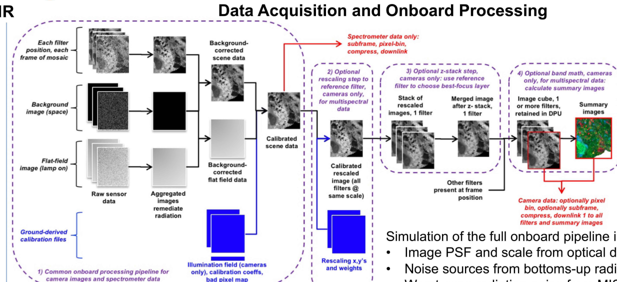
*2019 priorities

Filters / # Exposures for Radiation Mitigation, SNR

Filter Pos[1]	Name[2]	Center WL	FWHM[3]	Typical Binning[4]	Imgs taken per frame position[5]	Imgs co-added / frame, for 100% SNR margin[6]
R1	E1	428	80	None	8	3
R2	E2	555	70	None	7	3
R3	E3	670	60	None	7	3
R4	E4R	850	100	None	6	3
R5	E5	1000	100	2x2	7	3
R6	S1	1355	50	2x2	9	3
R7	S2	1475	50	2x2	10	3
R8	S3	1545	70	2x2	10	3
R9	S4/I2	1650	70	2x2	10	3
R10	S5	1780	100	2x2	10	3
L1	E4L	850	100	None	7	3
L2	I1	1250	50	2x2	7	3
L3	I3	2250	100	2x2	9	3
L4	I4	2980	100	2x2	15	5
L5	I5	3090	60	2x2	25	9
L6	I6/O0	3200	60	2x2	37	17
L7	O1	3300	100	2x2	45	25
L8	O2	3400	100	2x2	35	15
L9	O3	3500	100	2x2	35	15
L10	O4	3600	100	2x2	40	19

[1] R=right eye, L =left eye.
[2] E=EIS filter bandpasses; S=characterize 1.4-1.5 µm band due to hydrated salts and ice; I=characterize 1.65, 3.1-µm crystalline ice bands, 1.25-µm grain-size dependent band; O=characterize aromatic / aliphatic organic bands.
[3] FWHM=Full-width at half-maximum.
[4] Typical pixel binning during multispectral sequence
[5] # of images taken per filter, before onboard processing (for 115K operation)
[6] # of images coadded to improve SNR, after rejecting high values as radiation hits. The resulting single frame is compressed and downlinked or input into band math for a summary image compressed for downlink.

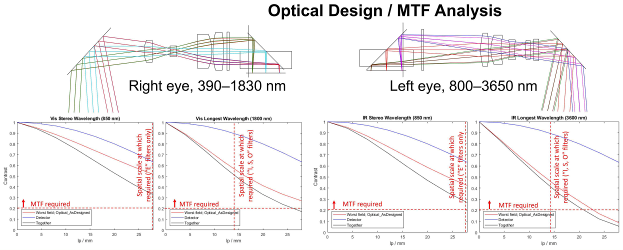
Data Acquisition and Onboard Processing



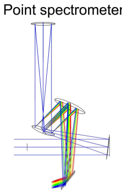
Onboard processing = MISE radiation remediation + CRISM calibration and summary product pipeline (all in the DPU)

Simulation of the full onboard pipeline includes:
- Image PSF and scale from optical design models
- Noise sources from bottoms-up radiometric model
- Worst-case radiation noise from MISE algorithm development
- Finite residuals from registration of different camera filters

Optical Design / MTF Analysis

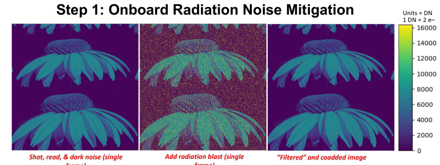


Point spectrometer



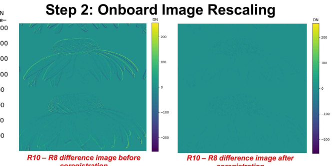
Flattened into the plane of the poster

Step 1: Onboard Radiation Noise Mitigation



- Statistical approach – acquire N frames, rank pixel values, throw out X highest, coadd remaining frames
- Based on MISE radiation statistics – 15% event probability for 0.05-s exposure

Step 2: Onboard Image Rescaling



- Due to scale differences, must co-register filters
- Image math shown before / after onboard rescaling
- Scaling matrix function ***f*** (filter, focus, T) solved onboard using telemetry; coefficients calibrated onground