Europa Clipper

Instrument Summaries

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Europa Clipper Baseline Level-1 Science Objectives

Ice Shell & Ocean

- Map the vertical subsurface structure in regions of potential surface-ice-ocean exchange to >3 km depth along globally distributed ground tracks achieving a total cumulative length ≥30,000 km.
- Constrain our knowledge of the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to ±50%.

Composition

- Create a compositional map at ≤10 km spatial scale, covering ≥60% of the surface, sufficient to identify non-ice materials especially organic compounds.
- Characterize the composition of ≥0.3% of the surface, globally distributed at ≤300 m spatial scale, sufficient to identify non-ice materials, especially organic compounds.
- Characterize the composition and sources of volatiles, particulates, and plasma, sufficient to identify the signatures of non-ice materials, including organic compounds, in at least one of the above forms, in globally distributed regions of the atmosphere and local space environment.

Geology

- Produce a controlled photomosaic map of ≥80% of the surface at ≤100-m spatial scale.
- Characterize the surface at ≤25-m spatial scale across ≥5% of the surface with global distribution, including measurements of topography at ≤15-m vertical precision across ≥1% of Europa's surface.
- Characterize the surface at ~1-m spatial scale to determine surface properties, for ≥18 globally distributed sites.

Current Activity

- Search for and characterize any current activity, notably plumes or thermal anomalies, in regions that are globally distributed.

Correlation

- Instrument pointing and data reduction shall enable cross-correlation of all science data sets.

ECM Instrument Summary

Team Leader: Margaret Kivelson [1] **Dep. Team Leader**: Xianzhe Jia [2] **IS:** Jordana Blacksberg and Corey Cochrane [3] **IE:** TBA

[1] University of Michigan and UCLA, [2] University of Michigan, [3]Jet Propulsion Laboratory, California Institute of Technology

Instrument	Europa Clipper Magnetometer (ECM)
Primary Science Objective	Characterize Europa's magnetic induction response to Jupiter's magnetic field at two frequencies to constrain ocean and ice shell thicknesses, and ocean conductivity.
Measurement technique	Magnetic field measurements are performed at two key frequencies for each Europa flyby, corresponding to the 11 hour (synodic) and 85 hour (orbital) periods, to observe the time-varying inductive response at Europa to Jupiter's driving magnetic field. An inversion analysis of the data collected over all flybys is then performed to determine the ocean and ice shell parameters.
Sensors	The ECM uses fluxgate sensors to measure the 3-axis vector magnetic field. Specifically, the fluxgate sensors measure the magnetic field as a correction of a temporal imbalance in the oscillating magnetization state in a ferromagnetic material that is present in a finite ambient field.
Sensor configuration	Three sensors are accommodated on an 8.55-m-long, coilable boom. The outboard sensor is mounted at the end of the boom at 8.47m, in the quietest magnetic environment, furthest from the spacecraft. The middle sensor is mounted at 6.83 m, and the inboard sensor at 5.20 m. The middle and inboard sensors are positioned along the boom such that gradiometry can be performed to correct for the effects of spacecraft-generated magnetic fields.
Measurement range	Each sensor measures the magnetic field in the range of +/- 4000 nT per axis
Sampling rate	During flybys (within 18 Europa radii, or +/- 2 hours of closest approach), ECM will sample at 16 vector samples per second (high data rate). For the remainder of each orbit, background measurements will be performed at 1 vector sample per second (low data rate).
Inflight calibration	The instrument precision is maintained through periodic inflight calibrations using spacecraft rolls about the spacecraft X- and Y-axes executed outside the primary science period and nominally executed every 3rd encounter.

Mass	Mass CBE = 31 kg (includes fluxgate sensors (1.2 kg each), mag boom, and electronics unit). Note: This does not include the mass of the harness connecting the sensors on the boom to the electronics unit.
Power	16.2 W during science operations, 4.2 W non-operational power dissipation
Data Rate	Total Science Data Per Encounter for all three sensors both high and low rate = 0.359 Gbits (high data rate for science data: 1209.6 bits/second per sensor, 4 hours per 14.2 day encounter around closest approach; low data rate for science data: 81.6 bits/second, 332 hours per 14.2 day encounter) Total H&S Data Per Encounter = 1.5 Gbits (ECM H&S Data Volume: Constant Rate of 1344 bits/second, 336 hours per 14 day encounter, 100% of the time), however H&S data is decimated by a factor of 5 before transmitting to ground.

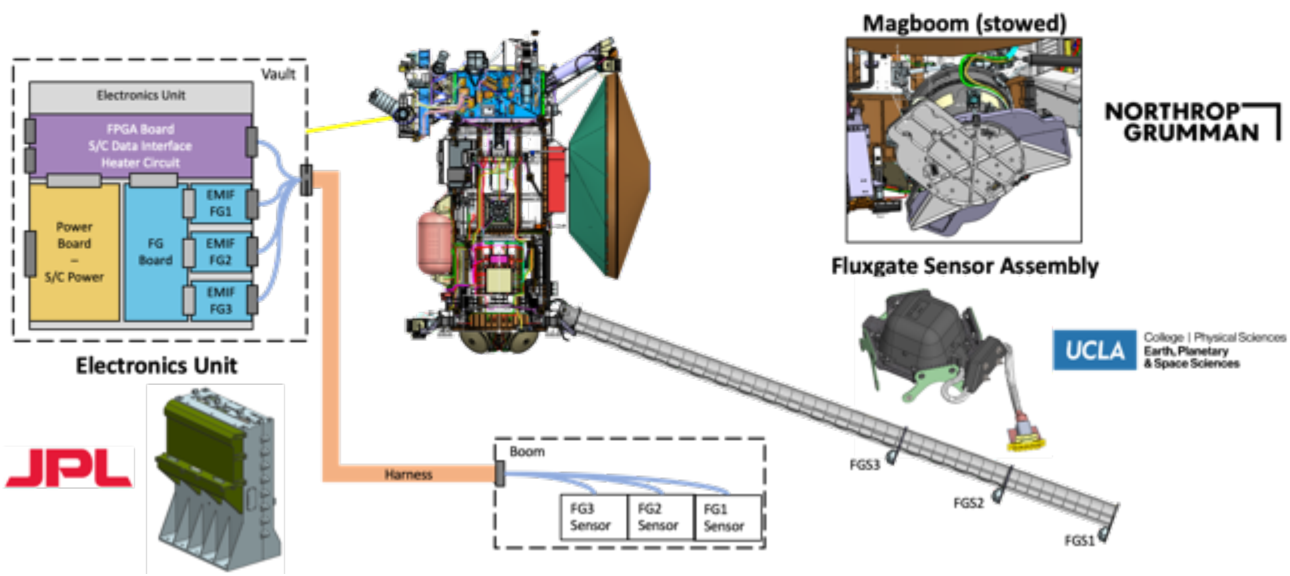


Figure: ECM Accommodation showing 3 fluxgate sensors on the Clipper MagBoom, and the Electronics Unit in the vault

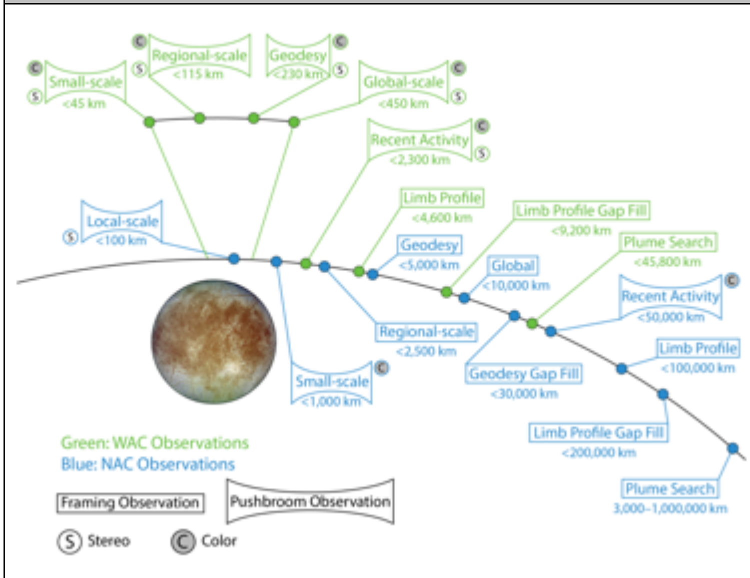
EIS Instrument Summary

PI: Zibi Turtle[1]. **IS:** Carolyn Ernst[1] and Catherine Elder[2]. **IE:** Emily Manor-Chapman[2].

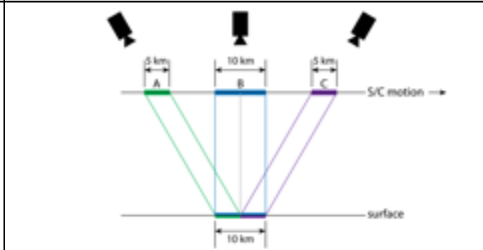
[1]Johns Hopkins University Applied Physics Laboratory, [2]Jet Propulsion Laboratory, California Institute of Technology.

Instrument Overview	
Instrument	Europa Imaging System (EIS) consists of two visible imaging cameras: • Narrow Angle Camera (NAC) • Wide Angle Camera (WAC)
Primary Science Objectives	• Characterize visible reflectance, morphology, and albedo of the surface with associated topographic coverage to address global-scale distribution of geologic landforms. (Global-scale imaging @ pixel scales ≤100 m.) • Characterize visible reflectance, morphology, albedo, and color of the surface with associated topographic coverage to address regional-scale topography of geologic landforms. (Regional-scale imaging @ pixel scales ≤25 m.) • Characterize visible reflectance, morphology, albedo, and color of globally distributed sites to address resurfacing and degradation by processes such as weathering and erosion. (Small-scale imaging @ pixel scales ≤10 m) • Characterize the visible reflectance, morphology, and albedo with associated topographic coverage to address local-scale surface properties. (Local-scale imaging @ pixel scales ≤1 m.) • Search for active plumes via forward scattering by entrained particles. • Characterize albedo and color variations to search for recent activity.
Measurement Techniques	• Framing imaging mode • Pushbroom imaging mode and digital time-delayed integration (TDI) • Color observations acquired by pushbroom imaging using six broadband filters (~350–1050 nm) • NAC stereo imaging at local scale via stereo pairs acquired in pushbroom mode using along-track gimbal; NAC stereo imaging at global and regional scales acquired via pairs of framing images with qualifying convergence angles, typically during different flybys • WAC 3-line concurrent stereo via pushbroom, with 24° convergence angle

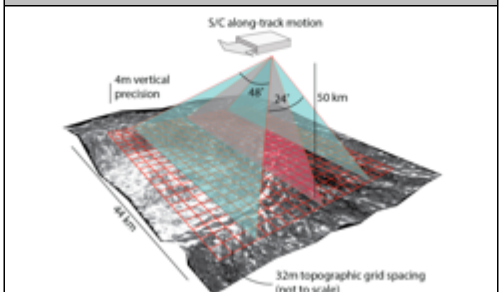
EIS Datasets



NAC local-scale stereo

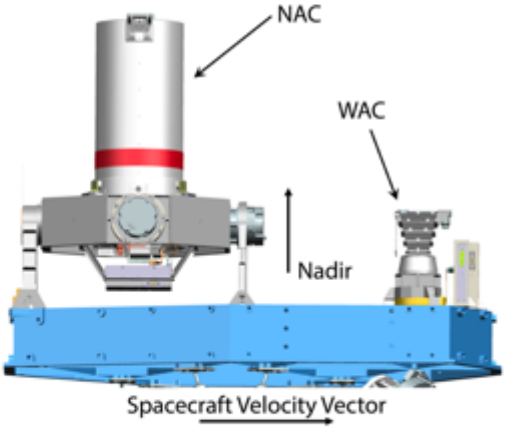
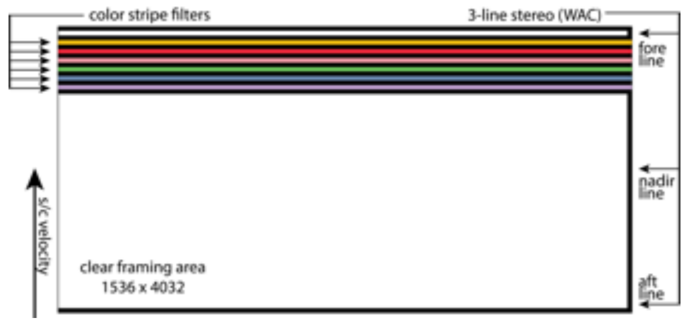
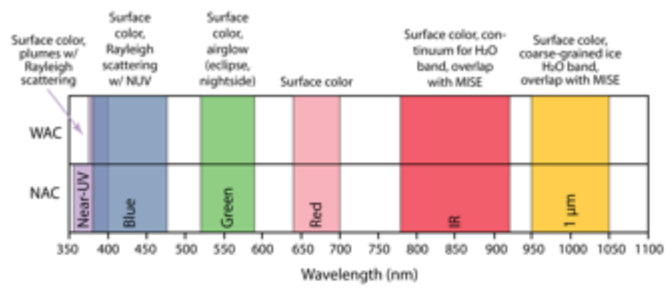


WAC 3-line stereo



Instrument Characteristics

Camera	NAC	WAC
Type	Reflective, Ritchey Chrétien telescope, 2 mirrors, 3 lenses	Refractive 8 lenses
Effective Focal Length	1000 mm	46 mm
Telescope Aperture	152 mm	8 mm
F number	6.58	5.75
Detector Type	2048 x 4096 CMOS pixel array, 10 µm pixels, frontside illuminated	
Pixels per Image (Along-track (AT) x cross-track (XT))	Framing: 1536 x 4032 Pushbroom: variable x 4032	
Field of View (AT x XT)	1.2° x 2.3°	24° x 48°
Instantaneous Field of View	10 µrad	218 µrad
Pointing	Nadir ± 30º along- & cross-track	Same as FOV
Image Properties @ 50-km Altitude	0.5 m/pixel, 2-km swath	11 m/pixel, 44-km swath
Stereo DTM Properties @ 50-km Altitude	4-m ground sample dist. (GSD), 0.5-m vert. precision	32-m GSD, 4-m vert. precision

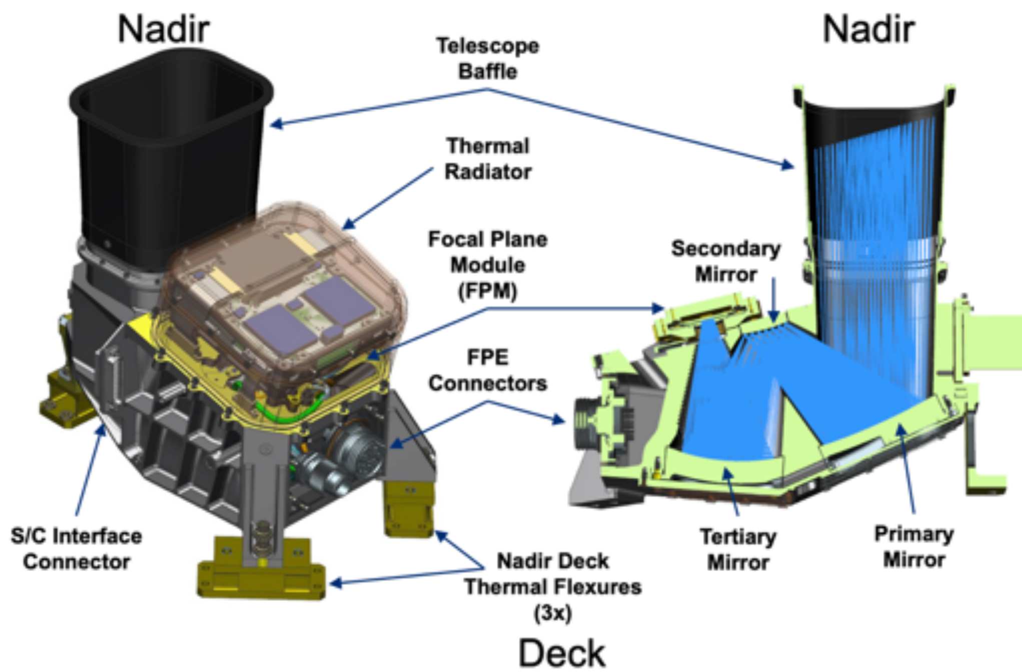
NAC and WAC	Detector Layout (Projected on Ground)
	
	Color Filters
	

E-THEMIS Instrument Summary

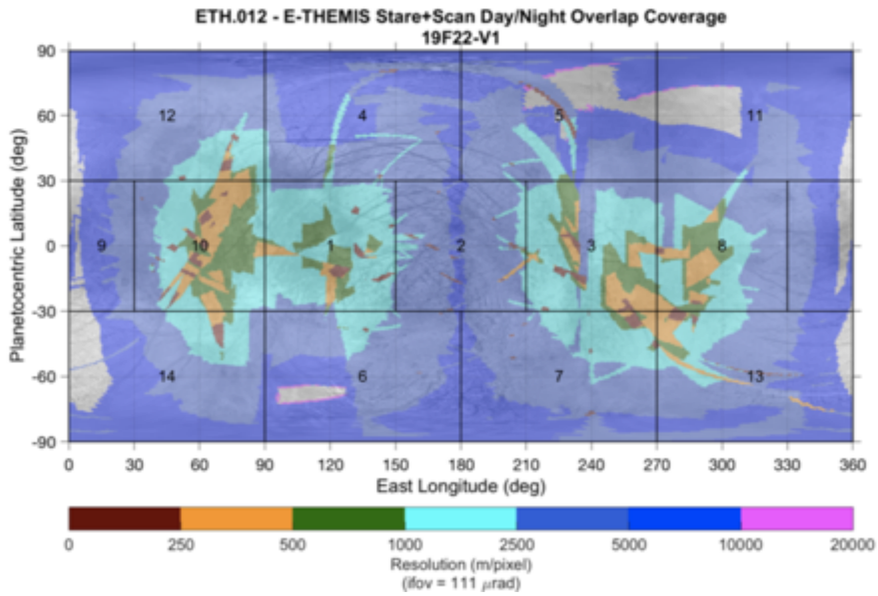
PI: Phil Christensen[1]. **DPI**: John Spencer[2]. **IS**: Sylvain Piqueux[3]. **IE**: Melora Larson[3].

[1] Arizona State University, [2]Southwest Research Institute, [3]Jet Propulsion Laboratory, California Institute of Technology

Instrument	E-THEMIS: Europa Thermal Emission Imaging System
Primary Science Objectives	• Map daytime or nighttime temperatures to characterize the thermophysical properties indicative of erosion and deposition processes • Map daytime and nighttime temperatures to characterize the thermal state of the ice shell and identify heat flow anomalies, regolith depth, and block abundance.
Detector	1280 x 1200 pixels uncooled microbolometer array
Acquisition Modes	Framing during global joint scans, and above ~2000 km of Europa Time Delay Integration when < ~2000 km of Europa
Spectral Range	Band 1: 7-14 μm Band 2: 14-28 μm Band 3: 28-50+ μm
Radiometric Performance	Band 1: @ 130K = 0.4 K 0.5s exposure time Band 2: @ 90K = 0.5 K 0.5s exposure time Band 3: @ 90K = 0.5 K 0.5s exposure time
Spatial Sampling	111 μrad pixels, binned x3 in Band 1, x4 in Band 2, x5 in Band 3 Corresponding Resolution (@1000 km): 0.4 km, 0.5 km, 0.6 km Corresponding Image Width (@ 1000 km): ~100 km
Uncompressed data volumes	Joint Scans: 0.6 Gb per encounter (10% duty cycle) Flyby: 2.7 Gb per encounter (10% duty cycle) Compression (x1.7) performed by S/C
Size, Mass, Power	23.7 cm x 31.8 cm x 29.8 cm, 19.1 kg, 42.6 W (Survival: 10.6 W)
Optics	Three mirror anastigmat telescope 69-mm effective aperture f/1.1

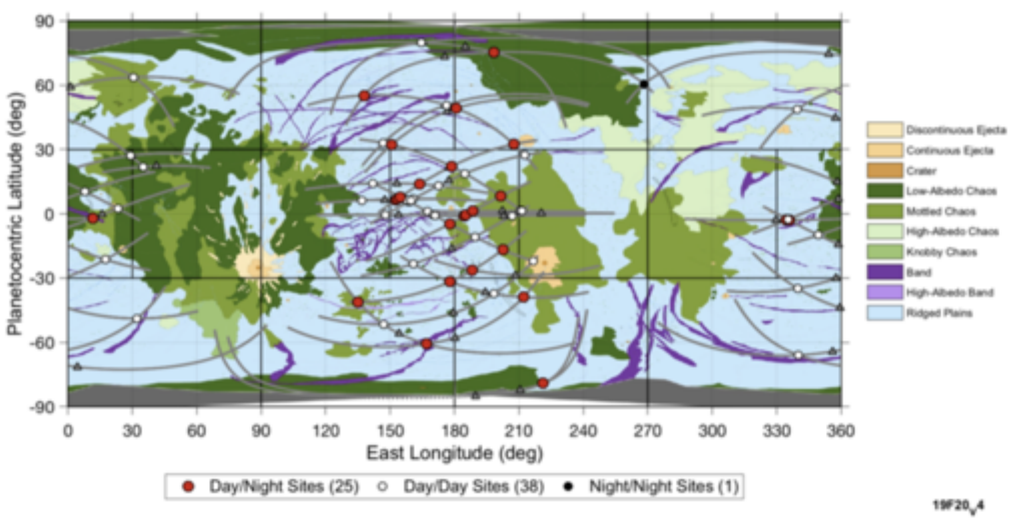


- Over the course of the primary mission, E-THEMIS generates ~200 Gbits of surface temperature observations on Europa;
- E-THEMIS observes Europa in framing mode during joint scans (two scans per encounter) to generate full disk surface temperatures from ~40,000 km or less, with a surface resolution of 25 km or better;
- E-THEMIS observes the surface during a flyby in framing and then push broom mode near closest approach, where it can generate up to 8 Gbits of data;
- E-THEMIS measures the surface cooling during and after solar eclipses by Jupiter, and constrains the surficial regolith properties (thermal conductivity, density, typical grain sizes) over the top few mm to cm;



E-THEMIS generates nearly complete day/night coverage at a surface resolution of 25 km or better. The analysis of Day/Night data yields thermal inertia, and points to heat flow anomalies.

Over the course of the primary mission, E-THEMIS observed a number of sites at high spatial resolution (hundreds of meters per pixels or better). Day/Night sites cover a wide range of surface types (see map below), and will be best suited to deconvolve thermal inertia, heat flow, and block abundance.

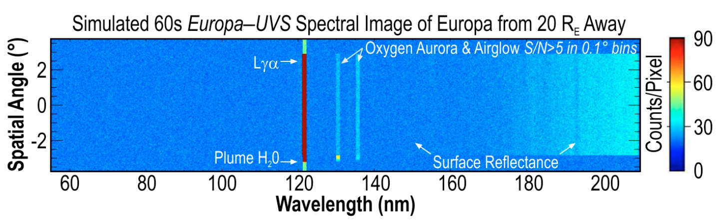


Europa-UVS Instrument Summary

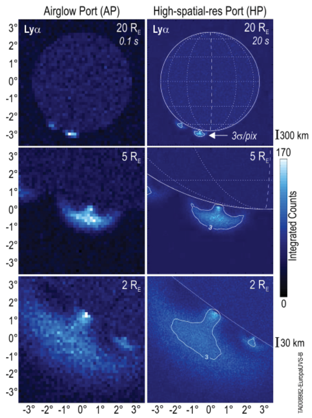
PI: Kurt Retherford[1] **DPI**: Randy Gladstone[1] **IS:** Shawn Brooks[2] **IE:** Anne Marinan[2]

[1]Southwest Research Institute, [2]Jet Propulsion Laboratory, California Institute of Technology

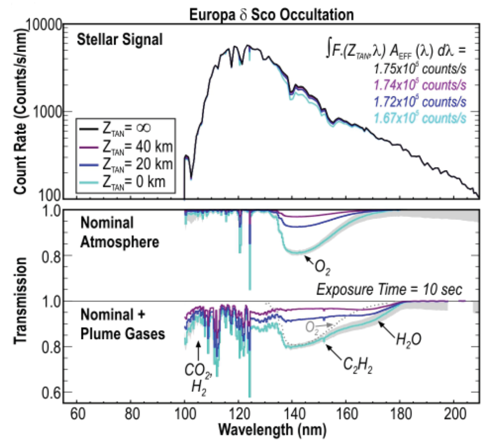
Instrument Overview	
Instrument	Europa-UVS (ultraviolet spectrograph) takes observations through one of three apertures: • Airglow Port (AP) • High-spatial-resolution Port (HP) • Solar Port (SP)
Primary Science Objectives	• Enable mapping of atmospheric vertical structure and composition. • Search for and characterize the vapor composition of any plumes.
Measurement Techniques	• Surface, airglow, and aurora stares and scans at global, regional, and local scales • Stellar and solar occultations • Jupiter transit imaging • Neutral cloud and torus stares



Excellent signal-to-noise ratios in Europa-UVS observations are expected despite the high radiation background.

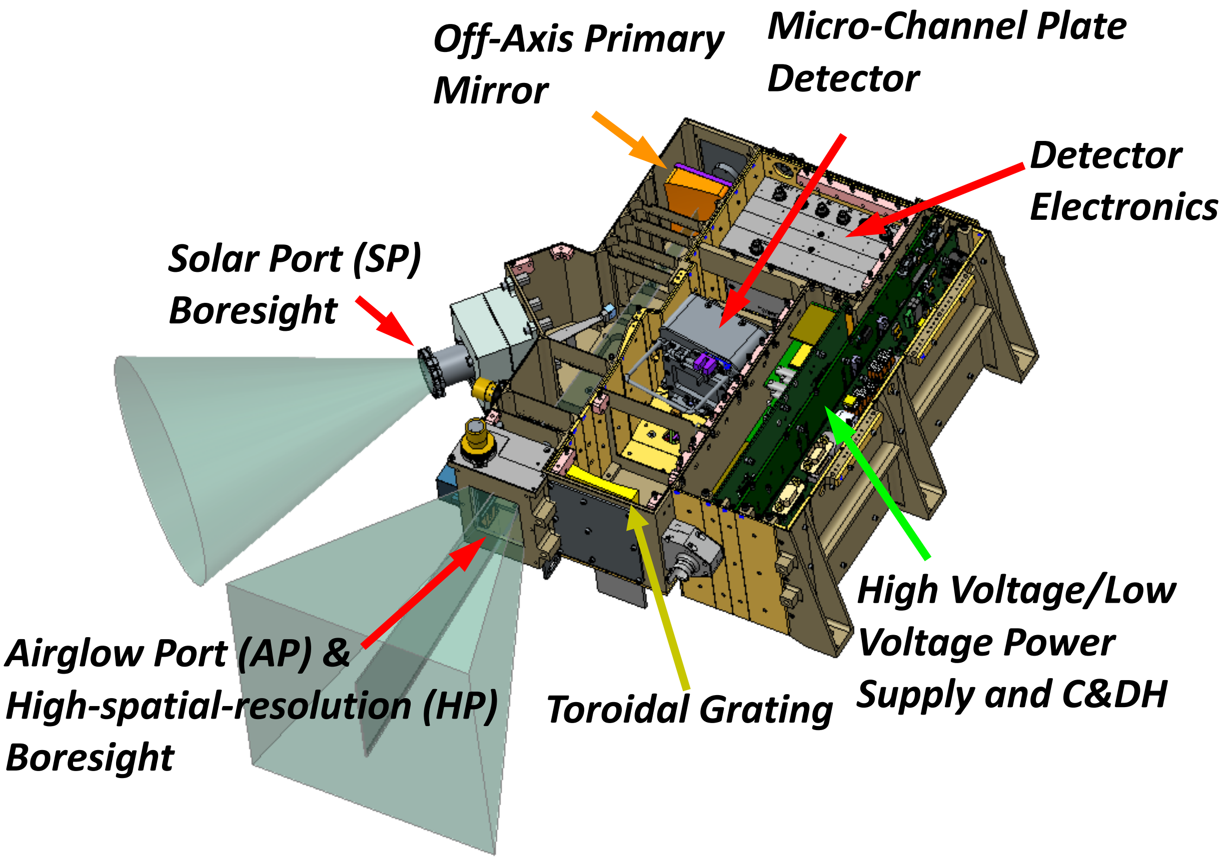


Europa-UVS will be used to scan the disk of Europa to search for plumes. Lyman-α emissions will reveal the presence of large plumes.



Molecular and atomic species expected at Europa have significant absorption cross sections in the UV. Stellar occultations observed by Europa-UVS will provide a powerful means of detecting them.

Instrument Overview	
Spatial Resolution	• ~0.15° (AP) near 130 nm at slit center (0.29° for slit-edge and <60 nm) • ~0.12° (HP) near 130 nm, <0.2° full bandpass
Spectral Range	• 55-206 nm
Spectral Resolution	• ~0.6 nm (point source), ~1.2 nm (extended source); λ/Δλ = 220
Field of View	• 0.1° x 7.3° + 0.2° x 0.2° (7.5° full length)
Detector Type	• two-dimensional micro-channel plate • solar-blind cesium iodide (Csl) photocathode • cross-delay-line readout • read-out anode array coordinates (oversized) at 4096 spectral x 4096 spatial x 256 pulse height distributions
Spectral Cube Size	• active cube size 1927 x 1192, with 7.5° long slit illuminated coverage of 1837 spectral x 1009 spatial pixels, and up to 1 ms time resolution



Europa-UVS schematic and the instrument field of view (inset rectangle) and keep out zones (grey-green cones)

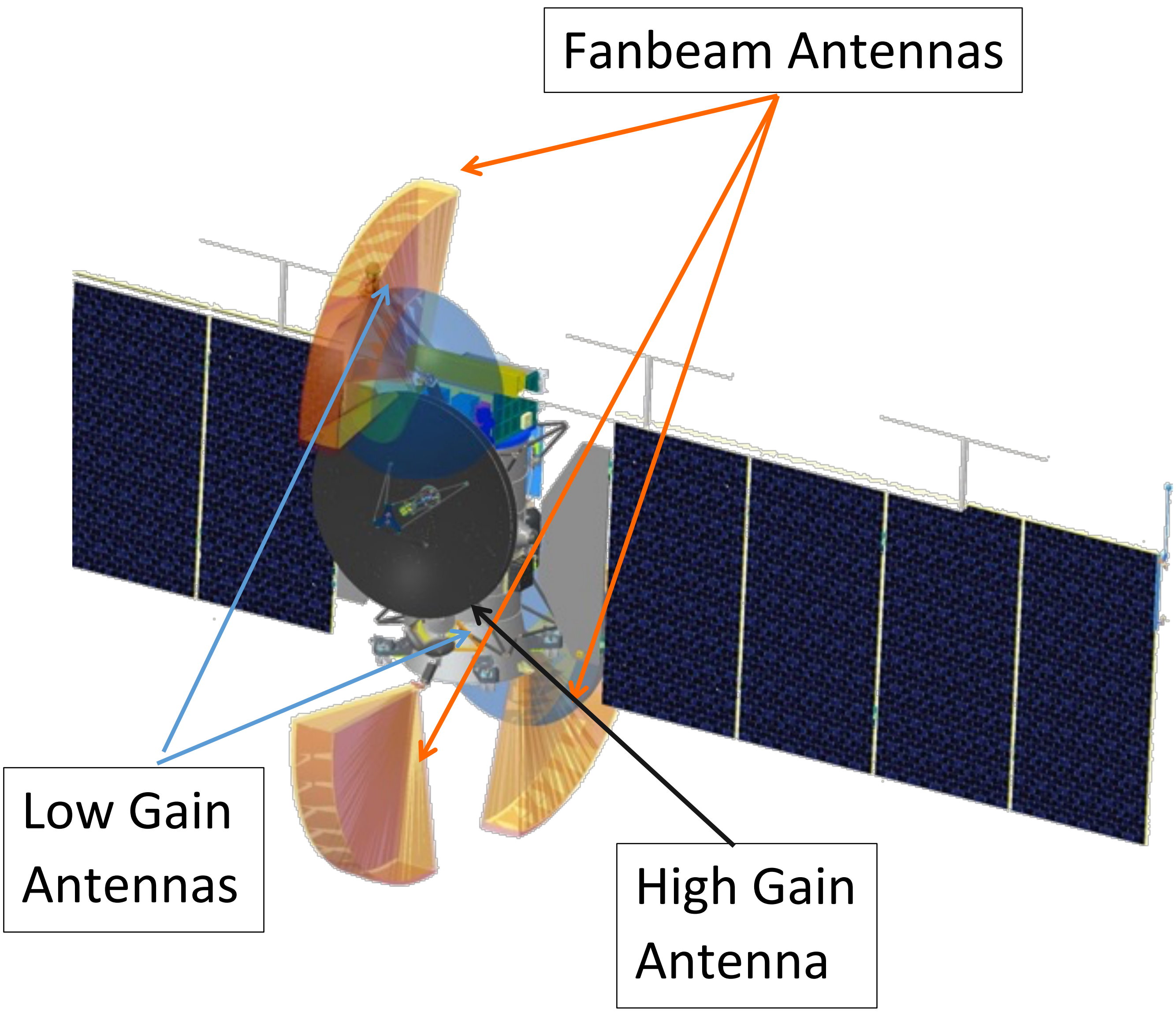
Gravity and Radio Science Instrument Summary

TL: Erwan Mazarico[1] **IS:** James Roberts[2] **IE:** Peter Ilott[3]

[1]NASA Goddard Spaceflight Center, [2]Johns Hopkins University Applied Physics Laboratory, [3]Jet Propulsion Laboratory, California Institute of Technology

Instrument	Gravity and Radio Science (RF subsystem, in conjunction with NASA Deep Space Network)
Primary Science Objective	Collect a data set, on a best effort basis, conducive to performing Doppler radio science near Europa.
Measurement technique:	Radiometric tracking (Doppler, Sequential Ranging) Radio occultation
Instrument type	Three Fanbeam Antennas Two Low-Gain Antennas One High-Gain Antenna
Radio Frequency	X-band (7.2 GHz uplink / 8.4 GHz downlink) Ka-band (31.9 GHz downlink only)
Doppler Accuracy	0.1 mm/s (SEP > 27°)
S/C transmitter	+40 dBm power
Field of view	Fanbeam Antennas: ±50° along track / ±15° cross track Low-Gain Antennas: Gaussian with peak at 7.5 dB and 42° width High-Gain Antenna: half-power beamwidth of ±7 mrad X-band / ±1.7 mrad Ka-band
Radio Link	Coherent X-band 4 dB-Hz link budget
General Operations concept:	Track line-of-sight velocity of spacecraft using DSN open-loop receiver recording within ±2 hr of closest approach; at ingress and egress of occultations by Europa; and regularly during occultations by Io Plasma Torus. Track radio range of s/c before and after Europa flyby.

Figure: Spacecraft antenna configuration. Orange slices denote the three fanbeam antenna fields of view. Blue hemispheres mark the two Low-Gain Antenna fields of view. Gray dish indicates high-gain antenna that may be used for radio occultations. Other antennas (MGA) not used for gravity science.

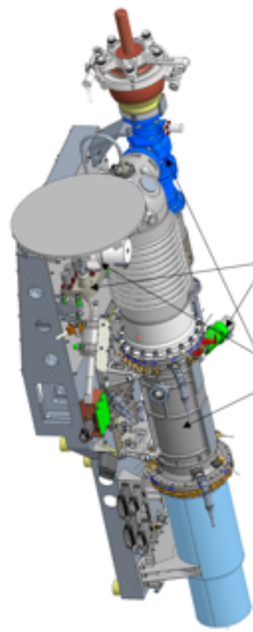


MASPEX Instrument Summary

PI: Jim Burch[1] **DPI**: Tim Brockwell[1] **IS:** Mathieu Choukroun[2] **IE:** David Conroy[2]

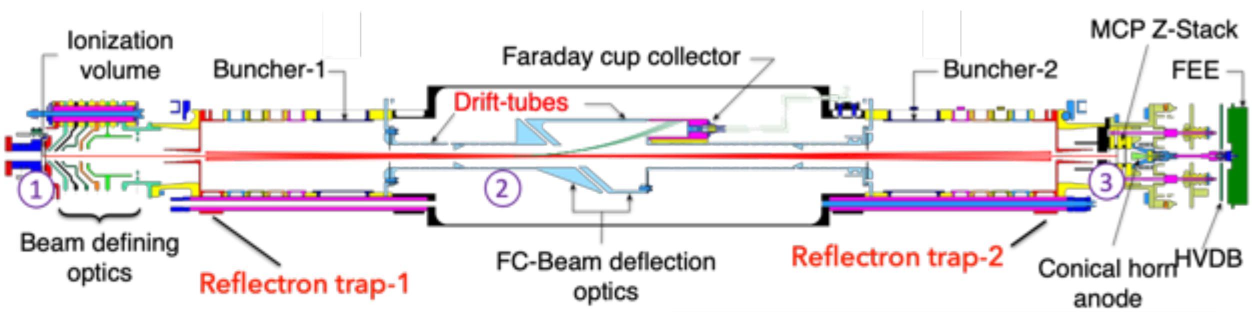
[1]Southwest Research Institute, [2]Jet Propulsion Laboratory, California Institute of Technology

Instrument:	MASPEX: MAss Spectrometer for Planetary EXploration
Measurement type:	Multi-bounce time-of-flight mass spectrometry of neutral volatiles
Science objective:	• Identify the global distribution of major volatiles in the atmosphere and local space environment and resolve key organic compounds, their sources, and their relative abundances. • Measure the composition of volatiles to characterize any active geological features and determine the relative fluxes of endogenous particles and gases in any encountered plume material. • Map compositionally diagnostic properties to determine the surface composition and chemistry, including the identification of any hydrated minerals, and organic compounds, and to seek indicators of ocean geochemical processes.
Measurement Principle:	Gas and grains enter the thermalizing chamber. Neutral volatiles are ionized by electron impact dissociation, then pushed into the time-of-flight mass spectrometer. Ion optics control the number of bounces and timing of pushing ions onto the multi-channel plate detector. Number of bounces and timing of detector counting are pre-determined in order to achieve the required resolution over specific mass ranges (regions of interest, ROIs). The cryotrap provides a sensitivity increase of 10^4, enabling the measurement of trace species and isotopes in the tenuous Europa environment.
Performance Requirements	• Mass Spectral Range: 2-500 u • Mass Resolution ($m/\Delta m$): >17,000 (10% valley definition) • Surface Resolution: Equivalent to spacecraft closest approach distance • Spectral sampling interval: < 5 s for ambient analysis at closest approach
Instrument Characteristics	• Inlet coaligned with spacecraft +Z axis • Inlet FOV: 90° half-angle cone (2 pi steradians) • Mass: 61.75 kg (CBE) • Peak Power: 97 W (ambient analysis + sample cryotrapping, CBE) • Pointing: Ram at closest approach (CA) during flybys



Subsystem Name	Subsystem purpose
Ion Gauge	Determines the pressure inside the vacuum chamber of the instrument; critical health and safety for SI&T and cruise operations
Calibration Gas Assembly	Provides FC43 calibrant for mass scale determination and in-flight calibration
Faraday Cup	Provides absolute calibration and gain determination of the detector
Cryotrap	Provides a greater than 10,000 increase in sensitivity of the instrument in gas poor environment
High Conductance Valve (HCV) HCV Actuator	Allows cryotrap sample analysis; decreases spacecraft contamination effects

Figure 1: MASPEX CAD model and description of main subsystems



(1) Ions are produced by electron impact ionization inside the closed source and pushed into the multi-bounce time of flight mass spectrometer.

(2) Ions travel in the MB-TOF at a velocity that is a function of their mass; selectable number of bounces between reflectrons determines the mass resolution.

(3) Ions are collected and counted by the detector, sorting them as function of their arrival time (hence, their mass), resulting in mass spectra.

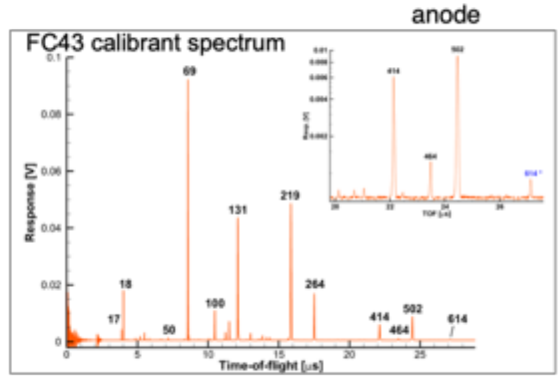


Figure 2. MASPEX's Multi-Bounce (MB) Time Of Flight (TOF) Mass Spectrometer functional principle

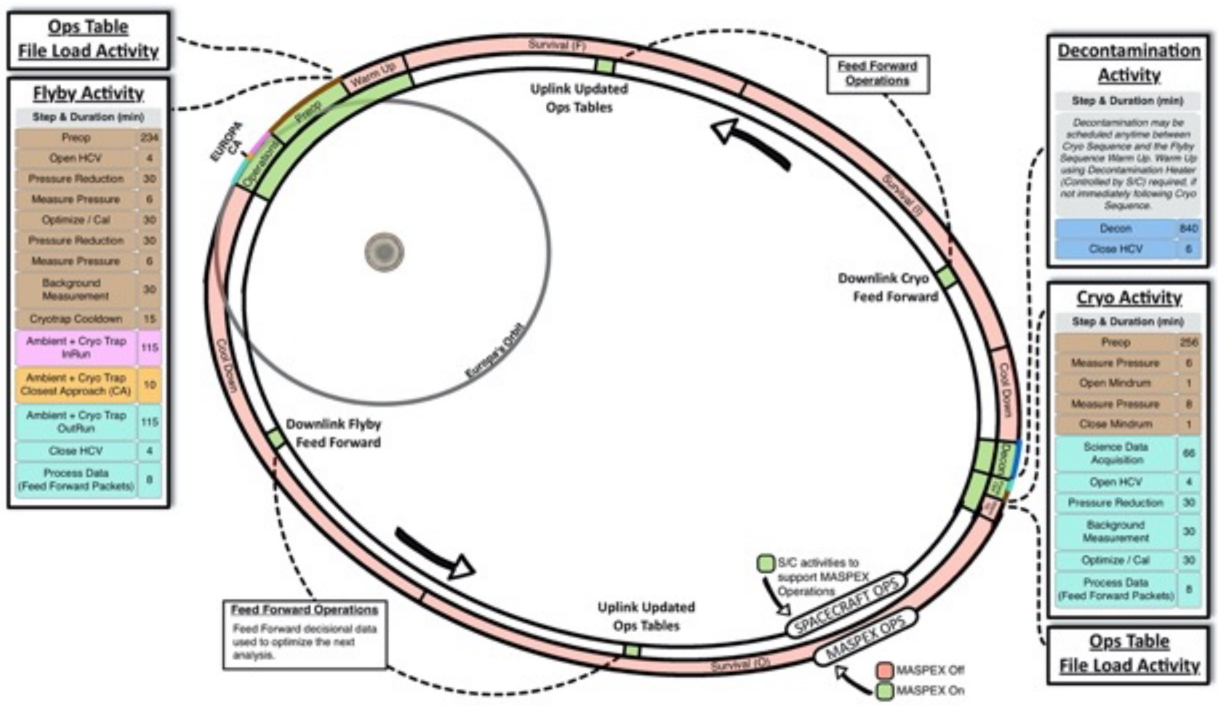


Figure 3. MASPEX "Orbit in the Life" typical suite of activities during nominal Europa operations

MISE Instrument Summary

PI: Diana Blaney[1] **DPI**: Karl Hibbits[2] **IS:** Serina Diniega[1] **IE:** Alessandro Rettura[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, [2]Johns Hopkins University Applied Physics Laboratory

Instrument	MISE = Mapping Imaging Spectrometer for Europa
Primary Science Objectives	• Measure absorption features, due to hydrated salts, and organics, and map compositionally diagnostic properties to determine the global-scale composition and chemistry. • Measure absorption features, due to hydrated salts, and organic compounds, and map compositionally diagnostic properties to determine the regional-scale surface composition and chemistry. • Sample compositionally diagnostic properties to determine composition of individual landforms.
Acquisition Modes	Line scanner or "pushbroom" using a scan mirror for along-track control **Global-scale** = dayside observations from 40 000 km-1200 km altitude **Regional-sale** = dayside observations from 1200-125 km altitude **Local-scale** = dayside observations when below 125 km altitude **Thermal anomaly** = nightside observations **Imaging a known plume** = high-phase observations
Spatial Resolution	250 μrad. 10 km @ 40 000 km altitude, to 25 m @ 100 km altitude
Spectral Range	0.8-4.8 μm required; 0.8-5.0 μm capability
Spectral Sampling	10 nm
Field of View	4.3° cross-track; along-track is variable, nominally 4.3° with 60° capability
Detector Type	CaF2 Dyson spectrometer Actively cooled via LMPT cryocooler and radiator
Spectral Cube Size	Nominal global/regional-scale cube will be 300 lines along-track x 300 elements cross-track x 421 spectral channels

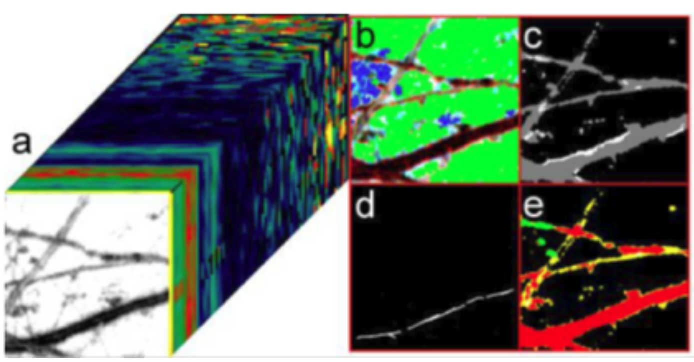
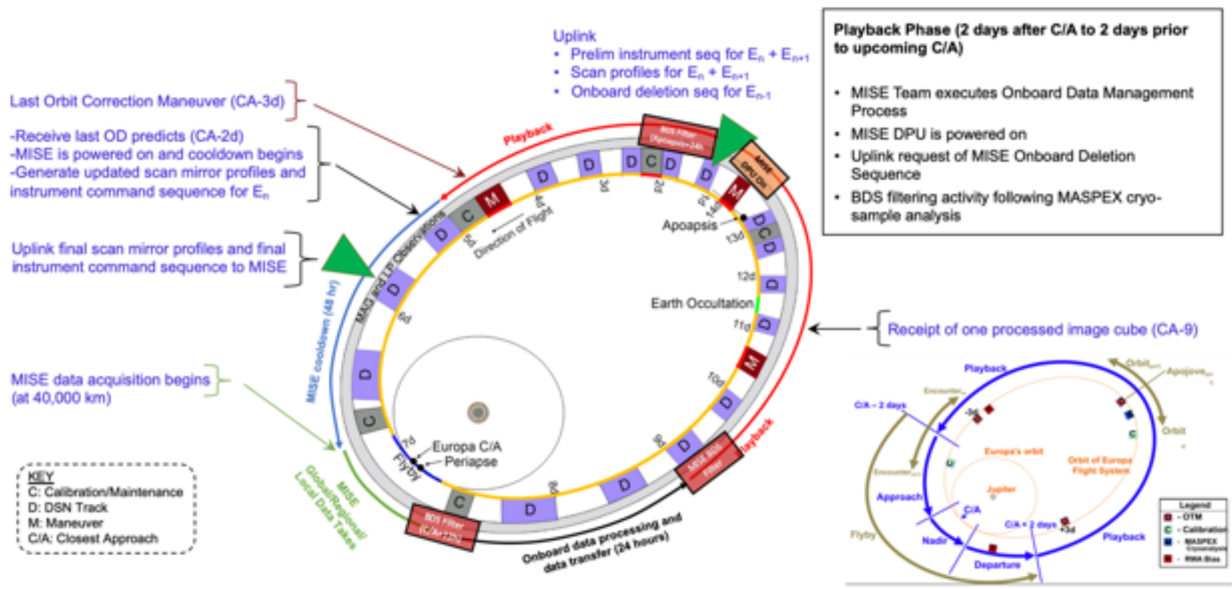
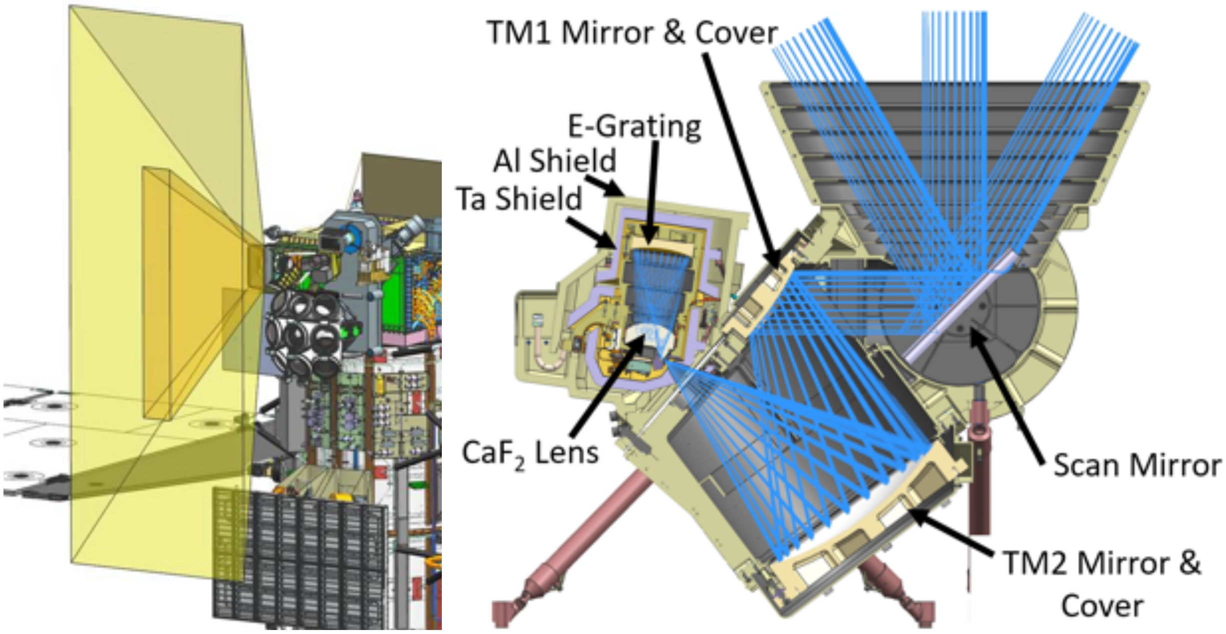


Illustration of types of MISE-science results possible. Each MISE observation will consist of (a) 2-dimensional image of the surface (i.e., the footprint) with full spectral information behind each pixel. MISE can assess habitability via different spectral products: (b) Map of ice phases: red=acid hydrate, green=crystalline ice, blue=amorphous ice. (c) Distribution of salts, (d) Map of thermal anomalies, and e) Composite maps of various materials including organics. MISE will assess habitability based upon abundance and distribution of all three indicators of habitability (salts, current activity, and organics).



Notional encounter timeline, as presented at Instrument Critical Design Review (iCDR) (8/26/2019). Items to note: ~Two days before closest approach, MISE is powered on and cooldown begins. Science data acquisition starts below 40,000 km of altitude. After data takes, the global- and regional-scales data are processed on board; the local-scale and calibration data are transferred raw. Flash memory contains enough data storage for one flyby (with redundancy). Flash is erased entirely before the next flyby, after data take is confirmed good.



Schematics showing (*left*) MISE position on spacecraft with instrument field of view (dark yellow box) and baffle keep out zone (light yellow box) **and (*right*) design of instrument, as presented at instrument CDR (8/26/2019).** Items to note: The radiator is next to the instrument and must be kept out of the sun while cooling. MISE's Data Processing and Cryocooler Electronic Units are inside the vault (not shown in the panel above).

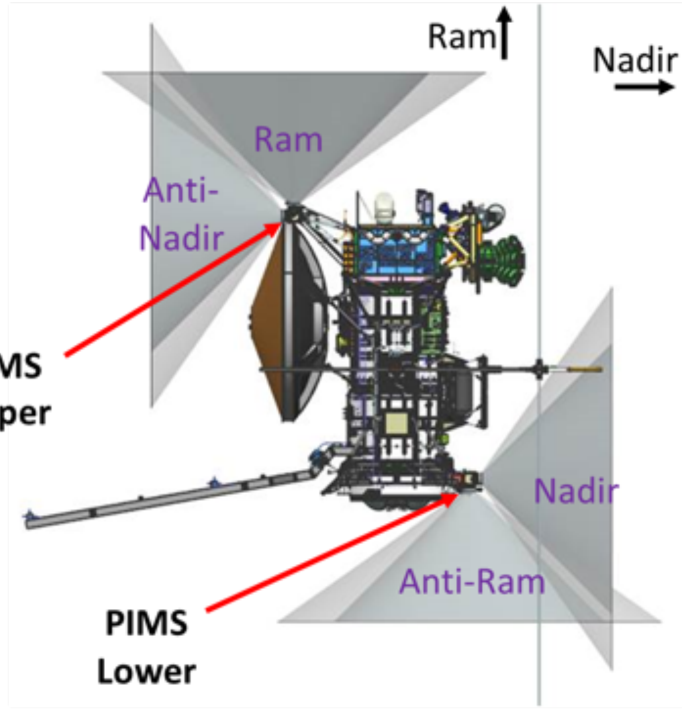
PIMS Instrument Summary

PI: Joe Westlake[1]. **DPI**: Ralph NcNutt[1], **IS:** Adrienn Luspay-Kuti[1] and Corey Cochrane[2]. **IE:** David Coren[1].

[1]Johns Hopkins University Applied Physics Laboratory, [2]Jet Propulsion Laboratory, California Institute of Technology.

Instrument:	PIMS: Plasma Instrument for Magnetic Sounding.
Primary Science Objectives:	• Measure Jovian magnetospheric plasma and the Europa ionospheric plasma to characterize the influence of the plasma on the observed magnetic fields. • Measure the characteristics of the Europa ionosphere, possible plume ionosphere, and the magnetosphere to characterize their compositions and plasma sources.
Measurement Type:	In-situ charged particle (plasma) detector.
Species:	Positive ions. Negative ions. Electrons.
Measurement Technique:	Measures the AC and DC plasma current as function of 1) energy, by stepping an amplitude-modulated high-voltage applied across a set of grids mounted within the detector and 2) direction, by virtue of multiple fields-of-view and segmented detectors.
Energy Range:	0.1 – 50 eV/q 0.02 – 6 keV/q
Energy Resolution, ΔE/E	< 15%
Field of View	Four ~90° cones. Three detector sectors per cone.

Figure: PIMS Accommodation on Clipper and the Instrument Fields of View (grey cones)



REASON Instrument Summary

PI: Don Blankenship[1]. **DPI**: Alina Moussessian[2], **Associate DPI**: Wes Patterson[3] and Jeff Plaut[2], **IS:** Trina Ray[2] and Gregor Steinbrügge[2]. **IE:** Vishnu Sridhar[2] and Amruta Mehta[2]

[1]University of Texas Institute for Geophysics, [2]Jet Propulsion Laboratory, California Institute of Technology. [3]Johns Hopkins University Applied Physics Laboratory, [2]Jet Propulsion Laboratory, California Institute of Technology.

Instrument	REASON: Radar for Europa Assessment and Sounding: Ocean to Near-surface
Primary Science Objectives	• Map the distribution of subsurface water, near-surface brines, ice shell structure, and exchange processes in the shallow subsurface. • Map the distribution of subsurface water, near-surface brines, ice shell structure, and exchange processes to address deep subsurface exchange. • Search for an ice-ocean interface by characterizing the surface elevation and ice shell thermophysical properties, as well as searching directly for any ice-ocean interfaces. • Determine regolith cohesiveness, thickness, and subsurface layering; surface roughness and slopes; and the distribution of blocks.
Measurement type	Dual-frequency pulsed radar sounder
Antenna Assemblies	2 HF Antenna Assemblies: total of 4 deployable monopoles 8 m length each 4 VHF Antenna Assemblies: total of 4 deployable folded dipoles 3 m length each
Operational Parameters	Measurement altitude range: < 1,000 km; Performance degraded below 35 km Measurement duration: ~8 minutes inbound and outbound, each
Center Frequency	HF: 9 MHz / VHF: 60 MHz; Pulse Repetition Frequency (PRF) 50 Hz – 3 kHz
Wavelength (in vacuum)	HF: 33.31 m / VHF: 5.00 m
Resolution	HF: vertical ≤ 300 m; along-track ≤ 5.5 km / VHF: vertical ≤ 30 m; along-track ≤ 2km
Vertical Precision	HF: 150 m / VHF: 15 m
Sounding Depth	HF: ≥30 km or better / VHF: Shallow-depth ≥3 km; Full-depth ≥30 km (depends on ice conditions at Europa along with surface and subsurface structure)
Mass, Power	105 kg (allocated) 111 W (allocated), <30 W radiated per frequency
Energy per orbit/fly-by	47 W*hr (allocated)
Peak Transmit Power	12 to 30 W for both frequencies

Figure 1. Schematic of Europa Clipper showing the positions of REASON antennas on the Europa Clipper Solar Array (left; date of figure is April 2020) and REASON Antenna Assemblies stowed and deployed (right, date of figures Oct 2020).

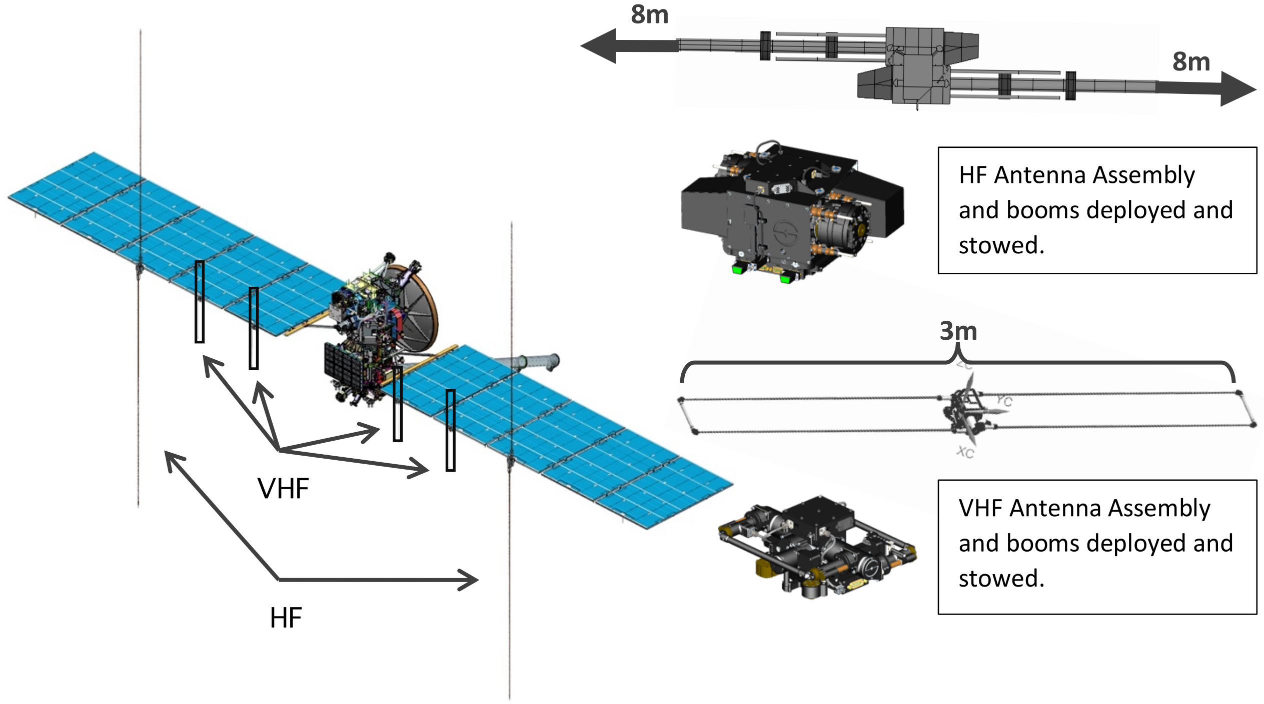


Figure 2. REASON Conops depiction showing REASON transmitting radar pulses that penetrate the surface of Europa. Representative radar wave transmission from one HF antenna is shown in orange, from one VHF antenna shown in green. Date of figure is April 2020.

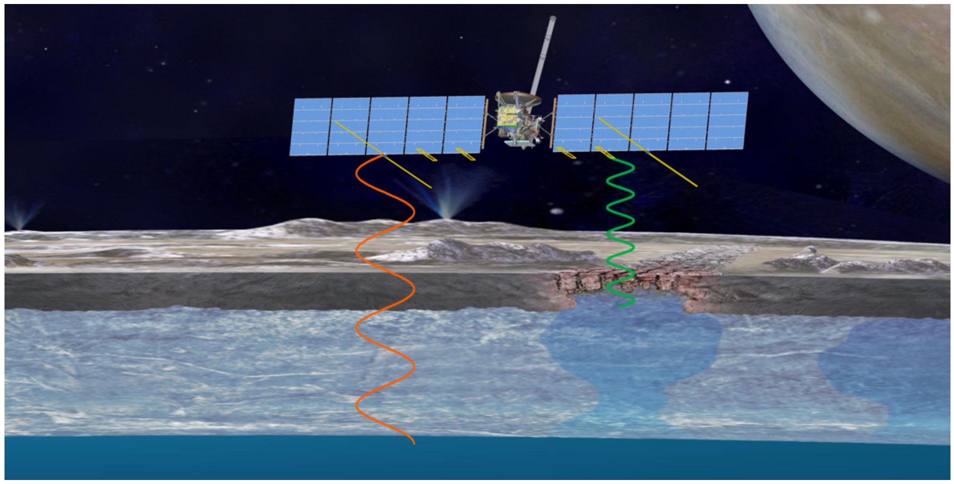
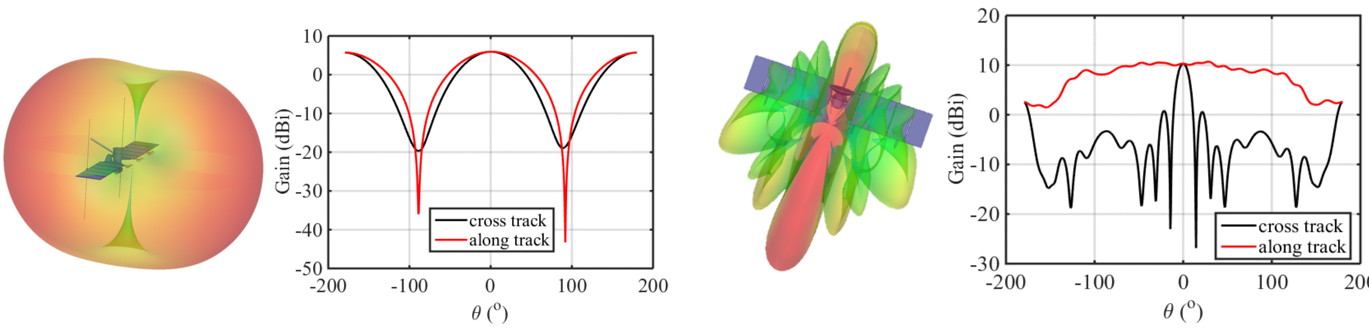


Figure 3. Idealized antenna beam patterns from REASON HF (left) and VHF (right) antennas. The graphs show antenna gain as a function of look angle in the along-track (red) and cross-track (black) directions. Interactions with the solar panels, other instruments, and the spacecraft bus can greatly affect the beam patterns. It is not possible to characterize the beam pattern on Earth prior to launch. The final beam pattern must be measured after deployment, in space. Date of figure is Jan 2019.



SUDA Instrument Summary

PI: Sascha Kempf[1]. **IS:** Murthy S. Gudipati[2]. **IE:** Adrian Arteaga Garcia[2].

[1] Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder,
[2]Jet Propulsion Laboratory, California Institute of Technology.

Instrument:	SUDA: SUrface Dust Analyzer
Instrument Provider:	Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder
Measurement type:	In-situ dust (ice/non-ice) mass, charge, and composition analyzer
Primary Science Objectives:	• Map compositionally diagnostic properties to determine the surface composition and chemistry, including the identification of any hydrated minerals, and organic compounds, and to seek indicators of ocean geochemical processes. • Characterize the composition of near surface exospheric particles, including any organic compounds if present, and distinguish between exogenic and endogenic sources of material. • Identify and characterize potential activity in any encountered plumes, and determine the composition, including any organic compounds if present.
Measurement Techniques:	• <u>Time-of-flight (ToF) impact ionization mass spectrometer</u> – A hypervelocity particle impact on the SUDA target ionizes a fraction of the particle's atoms and molecules. Ions are extracted with an electric field and focused onto an ion detector, which generates a ToF mass spectrum. A unique mass spectrum (i.e., chemical composition) is obtained for each detected impact event. • <u>Velocity measurement</u> – Dust particle charge is sensed by a grid electrode at the front of the instrument. The flight time between velocity sense grid and the target provides the boresight component the particle's velocity. • <u>Impact Charge</u> – Particle impact charge is measured via a charge sensitive amplifier attached to the impact target. Impact charge is used to determine the particle size. <u>Individual Ion Count</u> – The ion grid counts each atomic or molecular ion passing through the ion grid before reaching the detector.
Dust/Ice Grain Properties	• Velocity (1D): Range: 3.5 – 7.5 km/s | Uncertainty ≤ 1% • Charge : Range ≥ 0.25 fC | Base Noise ~ 0.12 fC • Grain Size: Range = 100 to 1000 nm | Uncertainty ≤ 20%
Grain Composition	• Mass Spectral Range: Up to 500 u • Mass Resolution (Δm): 1 u at 200 u • Surface Resolution: Better than spacecraft altitude

Instrument Characteristics	• FOV: ±23° • Mass: 14.8 kg • Power: 20.4 W (flyby mode) • Impact Target: 24 cm diameter, Iridium, <5 nm-RMS • Dual polarity / cation & anion modes (one mode per flyby) • Pointing: Ram pointed at closest approach (CA) to Europa

Figure 1: SUDA Accommodation on the Europa Clipper avionics module and spacecraft

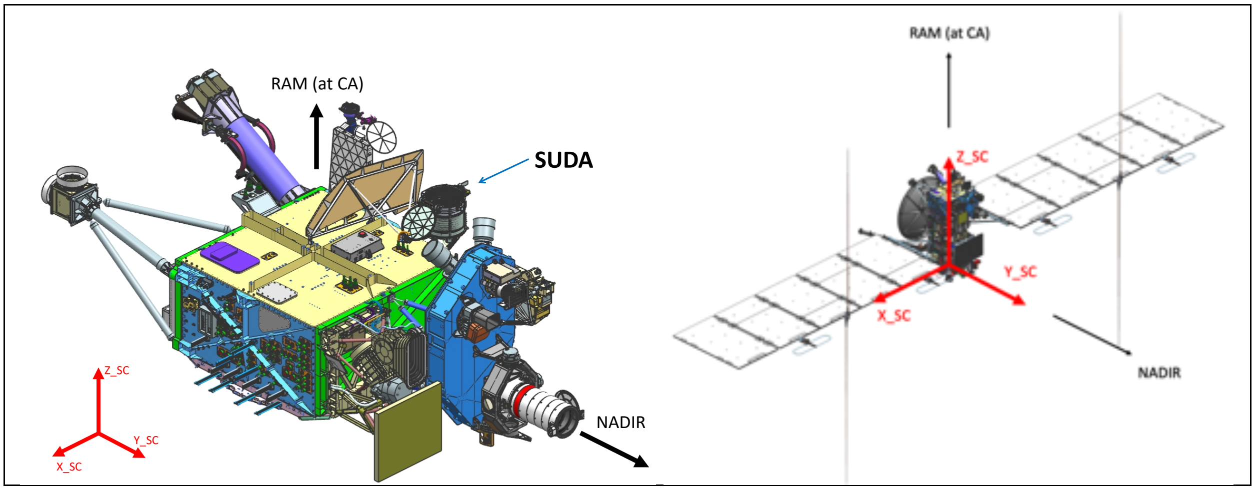


Figure 2: SUDA Functional Principle