NAI Icy Satellites Environments Focus Group:

Astrobiology Science for the Europa Jupiter System Mission

June 10, 2010

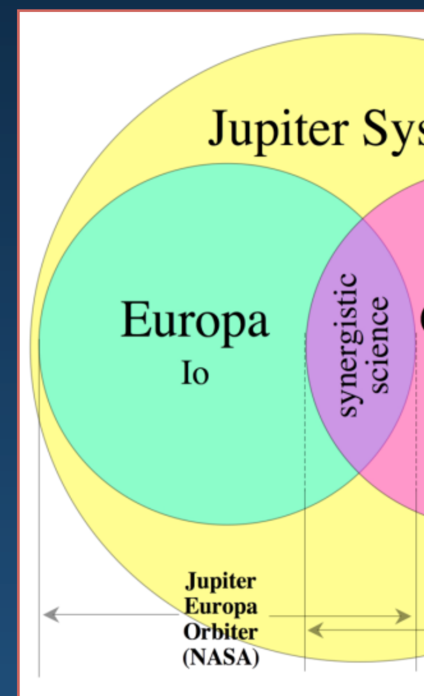
Kevin Hand
Jet Propulsion Laboratory, California Inst. Technology

Key Websites:

- Outer Planets Flagship Mission
  - opfm.jpl.nasa.gov
- Outer Planets Assesment Group
  - www.lpi.usra.edu/opag/
- Lander Workshop, Moscow, Russia
  - http://www.iki.rssi.ru/conf/2009elw/

Europa Jupiter Science Mission (EJSM)

- NASA and ESA: Shared mission leadersh
- Independently launched and operated or
  - NASA-led Jupiter Europa Orbiter (JEO)
  - ESA-led Jupiter Ganymede Orbiter (JGO)
- Complementary science and payloads
  - JEO concentrates on Europa and Io
  - JGO concentrates on Ganymede and Callisto
  - Synergistic overlap
  - 11-12 instruments each
- Science goals:
  - Icy world habitability
  - Jupiter system processes



Bob Pappalardo — Study Scientist	Jet Propulsion Laboratory	Europa and Jupiter System
Ariel Anbar	Arizona State University	Astrobiology
Bruce Bills	Goddard Space Flight Center	Geophysics
Diana Blaney	Jet Propulsion Laboratory	Composition
Don Blankenship	University of Texas	Radar/Geophysics
Phil Christensen	Arizona State University	Composition
Brad Dalton	Jet Propulsion Laboratory	Composition
Jody Deming	University of Washington	Astrobiology
Leigh Fletcher	Jet Propulsion Laboratory	Jupiter Atmosphere
Rick Greenberg	University of Arizona	Geophysics
Kevin Hand	Jet Propulsion Laboratory	Astrobiology
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Tom McCord	Bear Fight Center	Composition
Melissa McGrath	Marshall Space Flight Center	Satellites
Bill Moore	University of California Los Angeles	Geophysics
Jeff Moore	Ames Research Center	Geology
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Chris Paranicas	John Hopkins University — Applied Physics Lab	Fields & Particles
Louise Prockter	John Hopkins University — Applied Physics Lab	Geology
Jerry Schubert	University of California Los Angeles	Jupiter
David Senske	Jet Propulsion Laboratory	Satellites
Adam Showman	University of Arizona	Jupiter
Mark Showalter	SETI Institute	Rings
Mitch Sogin	Marine Biological Laboratory	Astrobiology
John Spencer	South West Research Institute	Satellites
Hunter Waite	South West Research Institute	Fields & Particles
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Frank Sohl	German Aerospace Centre (DLR)	Geophysics
Paolo Tortora	University of Bologna	Radio Science
Federico Tosi	Institute of Physics of Interplanetary Space	Origins
Ingo Mueller-Wodarg	Imperial College	Fields & Particles
Peter Wurz	University of Bern	Origins
Japan JJSDT Membership		

Space Administration

Ames Research Center
Moffett Field, California 94035-1000

October 9, 2008

Regents' Professor Ron Greeley
Co-Chair Europa-Jupiter System Mission Study
School of Earth and Space Exploration
Arizona State University
Box 871404
Tempe, AZ 85287-1404

Dear Ron:

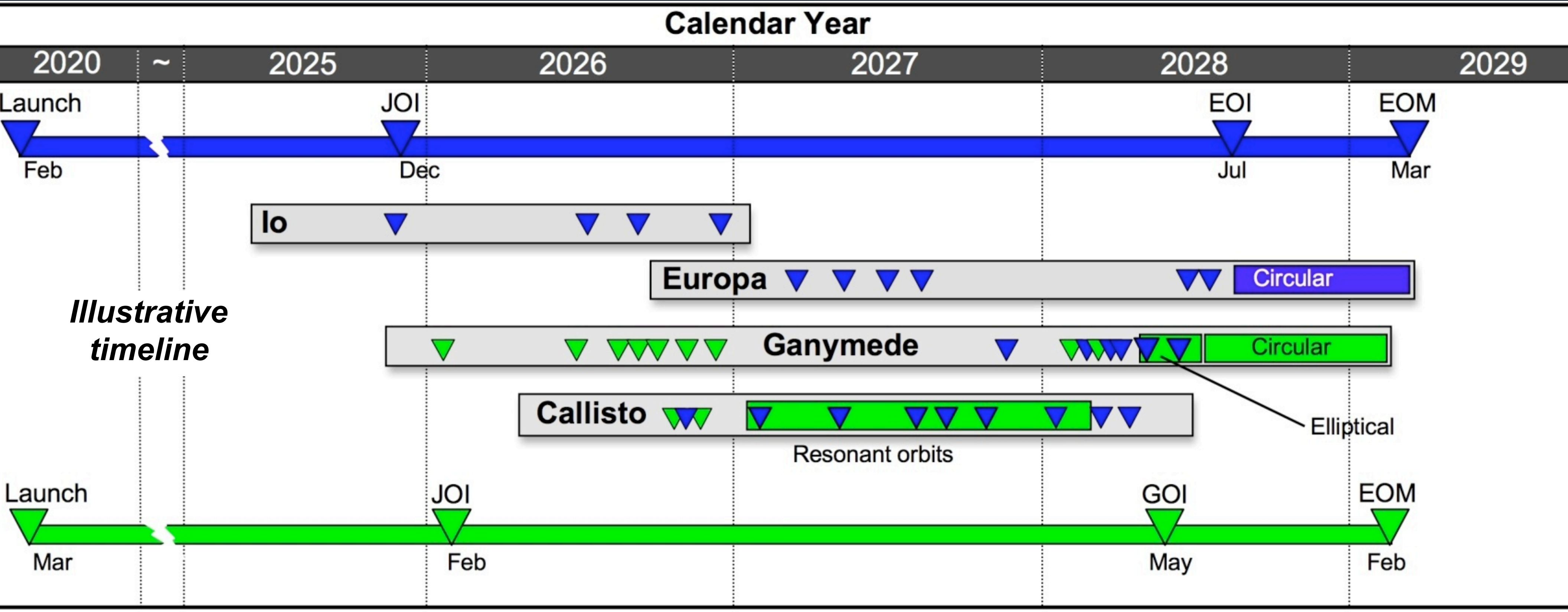
On May 17, 2007, I sent the following e-mail message to you, Karla Clark, Bob Pappalardo, and Mitch Sogin:

> *In a Dec. 12, 2001 letter to Dr. Michael Belton (Chair of the NRC Steering Committee developing the decadal strategy for Solar System Exploration), the NASA Astrobiology Institute placed a Europa orbiter in its highest priority mission category. The envisioned orbiter featured a payload capable of confirming the presence of a subsurface ocean, characterizing the subsurface, and obtaining remote sensing observations pertinent to Europa's surface composition, geological history, and biological potential.*
>
> *The current concept for the Europa Explorer mission, as presented on May 8, 2007 to the NAI Executive Council by Mitch Sogin for the mission Science Definition Team, appears to meet these measurement objectives.*
>
> *The NAI Executive Council reaffirms that such a mission is in its highest priority mission category for advancing the astrobiological goals of Solar system exploration.*
>
> *Sincerely,*
>
> *Carl Pilcher, Director of the NAI*
> *for the NAI Executive Council*

I can confirm that this continues to be the position of the NAI Executive Council.

With best wishes,

Nominal EJSM Timeline



- Launches: 2020
- Jovian system tour phases: 2–3 years
- Moon orbital phases: 6–12 months
- End of Prime Missions: 2029
- Flexibility if either flight element is delayed or advanced

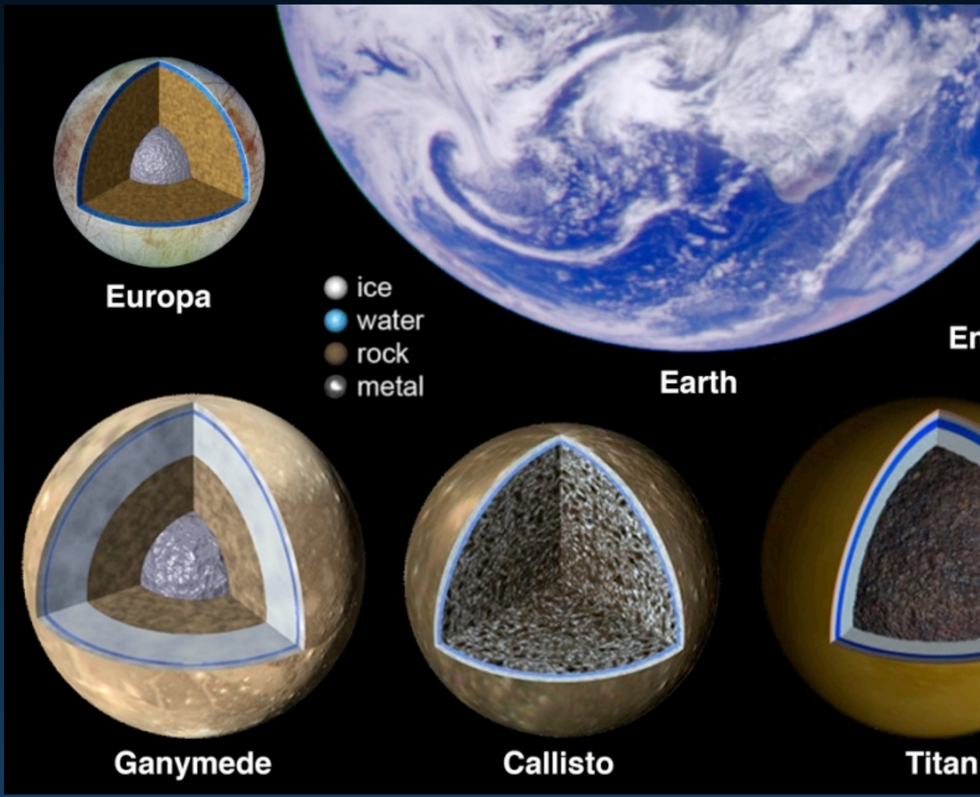
EJSM Theme:
Emergence of Habitable Worlds Around Gas G

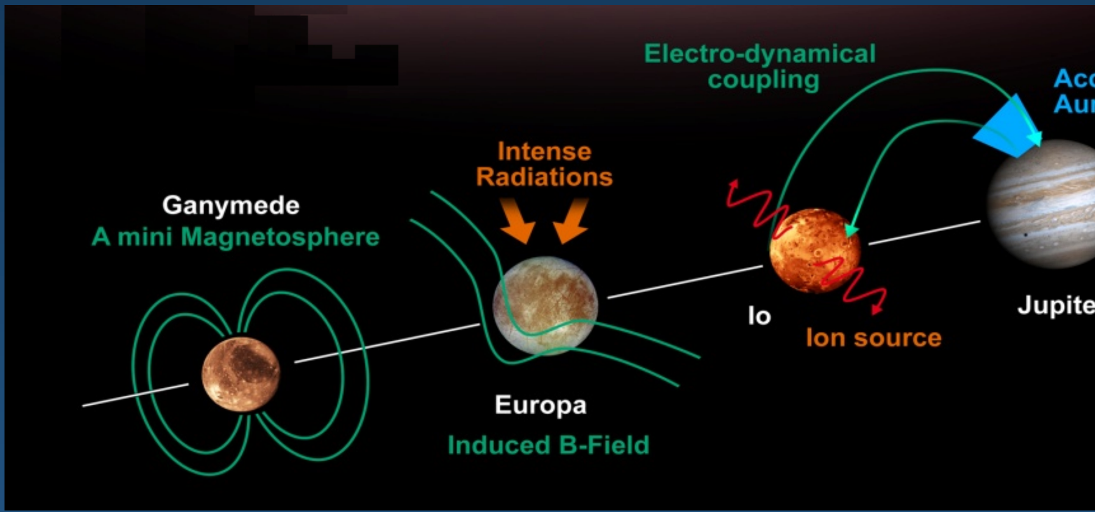
1: Determine if the Jupiter m harbors habitable worlds

- characteristics
- lls and subsurface water
- ternal structure, and (for Ganymede) magnetic field
- l environments
- surface compositions
- e features and future landing sites

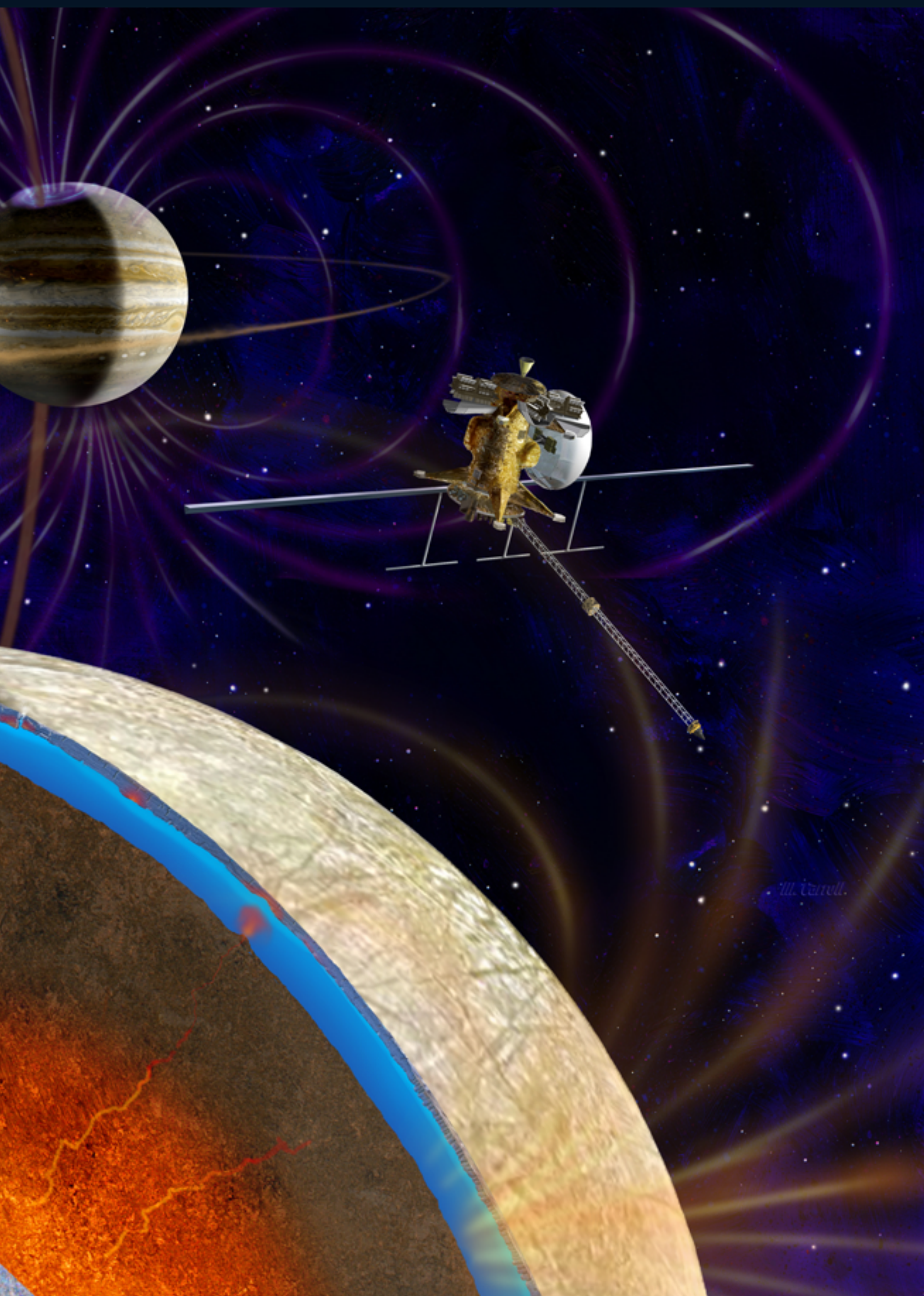
2: Characterize Jupiter m processes

- e system
- atmosphere
- odisk/magnetosphere
- system Interactions
- system origin





JEO Goal:
plore Europa to Investigate Its Habitabil

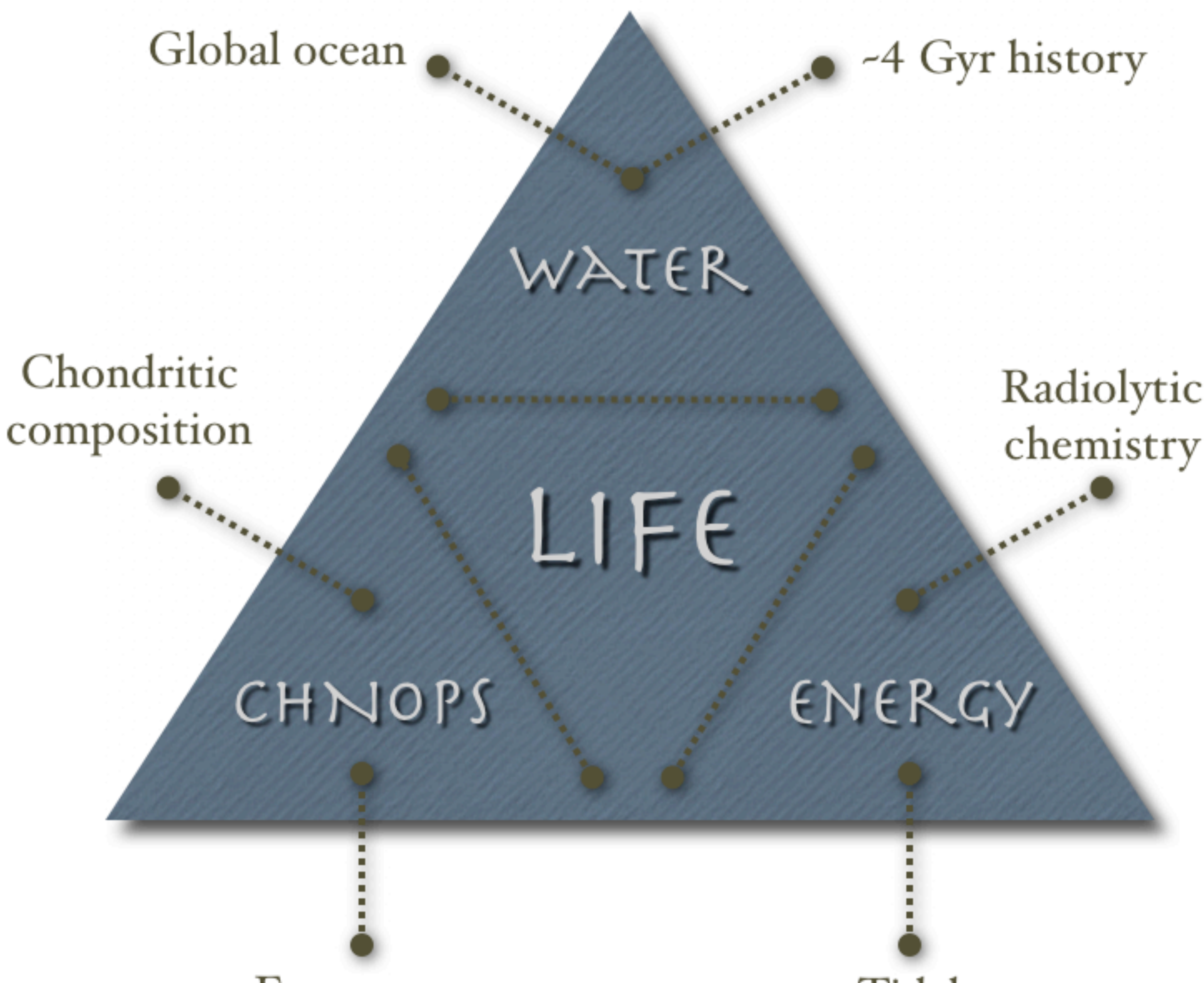


Habitability

- *Objectives (prioritized):*
- Ocean and Interior
- Ice Shell
- Chemistry and Compositio
- Geology and Landing Sites
- Jupiter System
  - Satellite surfaces and interior
  - Satellite atmospheres
  - Plasma and magnetospheres
  - Jupiter atmosphere
  - Rings

“‘Investigate its habitability” recognizes the
significance of Europa’s astrobiological potential
Habitability” includes confirming the existence a
determining the characteristics of water below
Europa’s icy surface, understanding the possible
urces and cycling of chemical and thermal ener
estigating the evolution and chemical composit
of the surface and ocean, and evaluating the
rocesses that have affected Europa through time

- EJSM Public Report


Global ocean
~4 Gyr history
WATER
Chondritic composition
Radiolytic chemistry
LIFE
CHNOPS
ENERGY


EUROPA
ROBERT T. PAPPALARDO, WILLIAM B. MCKINNON,
AND KRISHAN KHURANA, EDITORS

Old Goldilocks

New Goldilocks

Goal	Objective	Description	Sub-area	ID	Investigation
Explore Europa to investigate its habitability	A. Ocea[n]	...to the deeper interior.			...from the ocean over multiple frequencies.
				A3.	Characterize surface motion over the tidal cycle.
				A4.	Determine the satellite's dynamical rotation state.
				A5.	Investigate the core, rocky mantle, and rock-ocean interface.
	B. Ice	**Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange.**		B1.	Characterize the distribution of any shallow subsurface water.
				B2.	Search for an ice-ocean interface.
				B3.	Correlate surface features and subsurface structure to investigate processes governing material exchange among the surface, ice shell, and ocean.
				B4.	Characterize regional and global heat flow variations.
	C. Chemistry	**Determine global surface compositions and chemistry, especially as related to habitability.**		C1.	Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability and potential biosignatures.
				C2.	Relate compositions to geological processes, especially material exchange with the interior.
				C3.	Characterize the global radiation environment and the effects of radiation on surface composition, atmospheric composition, albedo, sputtering, sublimation, and redox chemistry.
				C4.	Characterize the nature of exogenic materials.
	D. Geology	**Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.**		D1.	Determine the formation history and three-dimensional characteristics of magmatic, tectonic, and impact landforms.
				D2.	Determine sites of most recent geological activity, and evaluate future landing sites.
				D3.	Investigate processes of erosion and deposition and their effects on the physical properties of the surface debris.
	E. Jupiter system science	**Understand Europa in the context of the Jupiter system.**	Satellite surfaces and interiors	E1.	Investigate the nature and magnitude of tidal dissipation and heat loss on the Galilean satellites, particularly Io
				E2.	Investigate Io's active volcanism for insight into its geological history and evolution (particularly of its silicate crust)
				E3.	Investigate the presence and location of water within Ganymede and Callisto.
				E4.	Determine the composition, physical characteristics, distribution and evolution of surface materials on Ganymede.
				E5.	Determine the composition, physical characteristics, distribution and evolution of surface materials on Callisto.
				E6.	Identify the dynamical processes that cause internal evolution and near-surface tectonics of Ganymede and Callisto.
			Satellite Atms.	E7.	Characterize the composition, variability and dynamics of Europa's atmosphere and ionosphere
				E8.	Understand the sources and sinks of Io's crustal volatiles and atmosphere.
				E9.	Determine the sources and sinks of the Ganymede and Callisto atmospheres.
			Plasma and magnetospheres	E10.	Determine how plasma and magnetic flux are transported in Jupiter's magnetosphere.
				E11.	Characterize the composition of and transport in Io's plasma torus.
				E12.	Study the pickup and charge exchange processes in the Jupiter system plasma and neutral tori.
				E13.	Study the interactions between Jupiter's magnetosphere and Io, Ganymede and Callisto (incl. characterize Ganymede's magnetic field)
				E14.	Understand the structure, composition and stress balance of Jupiter's magnetosphere.
				E15.	Determine how plasma and magnetic flux are transported in Jupiter's magnetosphere.
			Jupiter atm.	E16.	Characterize the abundance of minor species (especially water and ammonia) in Jupiter's atmosphere to understand the evolution of the Jovian system, including Europa.
				E17.	Characterize Jovian atmospheric dynamics and structure.

...TER EUROPA ORBITER: TRACEABILITY MATRIX

...ce Objective	Science Investigation		Measurement	Instrument	SCIENCE VALU... Jupiter System Science	EUROPA CAMPAIG... 1 Global Framewrk 1A	1B	2 Region... 2A
...rize the extent of the ...d its relation to the ...terior.	A1.	Determine the amplitude and phase of the gravitational tides.	A1a. Doppler shift from spacecraft tracking via two-way Doppler, to resolve 2nd degree gravity field time dependence. Doppler velocity of 0.1 mm/s over 60 s accuracy to recover k_2 to 0.0005 (at the orbital frequency). Multi-frequency communication (e.g., Ka & X) is best, but X is sufficient.	A1a. Telecom system		3	4	4
			A1b. Topographic differences at cross-over points from globally distributed topographic profiles, with better than or equal to 1-m vertical accuracy, to recover h_2 to 0.01 (at the orbital frequency).	A1b. Laser altimeter		3	4	5
	A2.	Characterize the magnetic environment (including plasma), to determine the induction response from the ocean, over multiple frequencies.	A2a. Magnetic field measurements at 8 vectors/s and a sensitivity of 0.1 nT, near-continuously for at least one month.	A2a. Magnetometer		2	3	4
			A2b. Determine the plasma distribution function with 1 min resolution continuously for several months; detect electrons in the few keV to hundreds of keV with angular and time resolution	A2b. Particle and plasma instrument		1	1	2
	A3.	Characterize surface motion over the tidal cycle.	A3a. Topographic differences at cross-over points from globally distributed topographic profiles, with better than or equal to 1 m vertical accuracy, to recover h_2 to 0.01 (at the orbital frequency).	A3a. Laser altimeter		4	5	5
			A3b. Doppler shift from spacecraft tracking via two-way Doppler, to resolve 2nd degree gravity field time dependence. Doppler velocity of 0.1 mm/s over 60 s accuracy to recover k_2 to 0.0005 (at the orbital frequency). Multi-frequency communication (e.g., Ka & X) is best, but X is sufficient.	A3b. Telecom system		3	4	4
	A4.	Determine the satellite's dynamical rotation state.	A4a. Doppler shift from spacecraft tracking via two-way Doppler, to determine mean spin pole direction. Doppler velocity of 0.1 mm/s over 60 s accuracy. Multi-frequency communication (e.g., Ka & X) is best, but X is sufficient.	A4a. Telecom system		2	2	3
			A4b. Topographic differences at cross-over points from globally distributed topographic profiles to determine spin pole direction and libration amplitudes, with better than or equal to 1 m vertical accuracy.	A4b. Laser altimeter		2	2	3
	A5.	Investigate the core, rocky mantle, and rock-ocean interface.	A5a. Doppler shift from spacecraft tracking via two-way Doppler, to resolve high degree gravity field. Doppler velocity of 0.1 mm/s over 60s accuracy. Multi-frequency communication (e.g., Ka & X) is best, but X is sufficient.	A5a. Telecom system		2	2	3
			A5b. Topographic profiles to resolve coherence with gravity, with better than or equal to 1 m vertical accuracy.	A5b. Laser altimeter		2	2	3
			A5c. Magnetic field measurements at 8 vectors/s and a sensitivity of 0.1 nT, near-continuously for several months.	A5c. Magnetometer		1	1	2
			A5d. Determine the distribution function of the plasma ions and electrons with continuous observations over several months	A5d. Particle and plasma instrument		1	1	1
...rize the ice shell and ...urface water, including ...rogeneity, and the ... surface-ice-ocean ...e.	B1.	Characterize the distribution of any shallow subsurface water.	B1a. Identify and locally characterize subsurface thermal or compositional horizons and structures related to the current or recent presence of water or brine, by obtaining sounding profiles of subsurface dielectric horizons and structures, with better than 50 km profile spacing over more than 80% of the surface, at depths of 100 m to 3 km at 10 m vertical resolution, and performing targeted subsurface characterization of selected sites at least 30 km in length.	B1a. Radar sounder (nominally ~50 MHz, with ~10 MHz bandwidth)		3	3	4
			B1b. Topography at better than or equal to 100 m/pixel spatial scale and better than or equal to 10 m vertical resolution and accuracy, over more than 80% of the surface, co-located with sounding profiles.	B1b. Wide-angle camera (stereo) and laser altimeter		1	2	3
	B2.	Search for an ice-ocean interface.	B2a. Identify deep thermal, compositional, or structural horizons by obtaining sounding profiles of subsurface dielectric horizons, with better than 50 km profile spacing over more than 80% of the surface, at depths of 1 to 30 km at 100 m vertical resolution.	B2a. Radar sounder (nominally ~5 or 50 MHz, with ~1 MHz bandwidth)		1	2	2
			B2b. Topography at better than or equal to 100 m/pixel spatial scale and better than or equal to 10 m vertical resolution, over more than 80% of the surface, co-located with sounding data.	B2b. Wide-angle camera (stereo) and laser altimeter		1	2	3
	B3.	Correlate surface features and subsurface structure to investigate processes governing material exchange among the surface, ice shell, and ocean.	B3a. Global identification and local characterization of subsurface dielectric horizons and structures, at depths 1 to 30 km at 100 m vertical resolution and depths of 100 m to 3 km at 10 m vertical resolution, by obtaining sounding profiles with better than 50 km spacing over more than 80% of the surface, plus targeted characterization of selected sites at least 30 km in length.	B3a. Radar sounder (dual-frequency, nominally ~5 & ~50 MHz, with ~1 and ~10 MHz bandwidth)		3	3	4

Origins	Evolution	Processes	Habitability	Life

SI = Science Investigation

0	1	2	3	...
Does not address SI	Touches on SI	May address Partial SI	Definitely addresses Partial SI	May...

ITER EUROPA ORBITER: TRACEABILITY MATRIX

cience Objective		Science Investigation	Measurement	Instrument	Jupiter System Science	SCIENCE VALUE — EUROPA CAMPAIGNS — 1 Global Framewrk 1A	1B	2 Regional P 2A
cterize the ice shell and bsurface water, including eterogeneity, and the of surface-ice-ocean nge.	B3.	Correlate surface features and subsurface structure to investigate processes governing material exchange among the surface, ice shell, and ocean.	B3b. Map thermal emission from the surface by measuring the albedo over more than 80% of the surface at spatial resolution of better than or equal to 250 m/pixel to 10% radiometric accuracy, and make targeted thermal observations at better than 250 m/pixel spatial resolution and temperature accuracy better than 2 K.	B3b. Thermal imager		2	2	3
			B3c. Surface reflectance measurements by visible to short wavelength infrared spectroscopy of targeted features at better than or equal to 25 m/pixel spatial resolution, with better than 6 nm spectral resolution through a spectral range of at least 0.9–2.5 microns (0.4–2.5 microns desirable), and better than 12 nm through a spectral range of at least 2.5–5 microns. SNR better than 128 for 0.9–2.6 microns and better than 32 for 2.6–5 microns.	B3c. Vis-IR imaging spectrometer		1	2	3
			B3d. Topography at better than or equal to 100 m/pixel spatial scale and better than or equal to 10 m vertical resolution and accuracy, over more than 80% of the surface, co-located with sounding data.	B3d. Wide-angle camera (stereo) and laser altimeter		1	2	3
			B3e. Detailed morphological characterization of targeted features through imaging at better than or equal 1 m/pixel, and topographic sampling of targeted sites with better than 1 m vertical accuracy.	B3e. Narrow-angle camera and laser altimeter		1	1	1
			B3f. Determine surface color characteristics at ~100 m/pixel scale in at least 3 colors, over more than 80% of the surface.	B3f. Wide-angle camera, color		3	4	4
			B3g. Surface reflectance measurements by ultraviolet spectroscopy at better than or equal to 100 m/pixel spatial resolution, and better than or equal 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns, using profiles at better than or equal to 25 km spacing over more than 80% of the surface, plus targeted characterization of selected sites.	B3g. UV imaging spectrometer		1	1	1
			B3h. High-resolution visible stereo imaging of targeted features, at better than or equal 10 m/pixel.	B3h. Medium-angle camera		2	2	3
			B3i. Doppler velocity of 0.1 mm/s over 60 s accuracy, to identify regions of density contrast within the ice crust. Multi-frequency communication (e.g., Ka & X) is best, but X is sufficient.	B3i. Telecom system		1	2	3
	B4.	Characterize regional and global heat flow variations.	B4a. Identify and map subsurface thermal horizons, by obtaining sounding profiles of subsurface dielectric horizons, with better than 50 km profile spacing over more than 80% of the surface, at depths of 1 to 30 km at 100 m vertical resolution.	B4a. Radar sounder		1	2	2
			B4b. Map thermal emission from the surface by measuring the albedo over more than 80% of the surface at spatial resolution of better than or equal to 250 m/pixel to 10% radiometric accuracy.	B4b. Thermal imager		2	2	3
nine global surface ositions and chemistry, ially as related itability.	C1.	Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability and potential biosignatures.	C1a. Surface reflectance measurements by visible to short wavelength infrared spectroscopy at better than or equal to 25 m/pixel spatial resolution, with better than 5 nm (10 nm floor) spectral resolution through a spectral range of 0.4–2.5 microns (1–2.5 microns floor), and better than 10 nm spectral resolution (20 nm floor) through a spectral range of at least 2.5–5 microns, along profiles with less than or equal to 25 km spacing over more than 80% of the surface, plus targeted characterization of selected sites. SNR better than 128 for 0.9–2.6 microns and better than 32 for 2.6–5 microns.	C1a. Vis-IR imaging spectrometer		2	2	3
			C1b. Characterize the composition of sputtered products from energetic particle bombardment of the surface, using ion and neutral mass spectrometry over a mass range of 300 Daltons, mass resolution of ≥500, and pressure range of 10^{-6} to 10^{-17} mbar, and energy resolution of 10%.	C1b. Ion and neutral mass spectrometer		1	1	3
			C1c. Surface reflectance measurements by ultraviolet spectroscopy at better than or equal to 100 m/pixel spatial resolution, and better than or equal 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns, using profiles at less than or equal to 25 km spacing over more than 80% of the surface, plus targeted characterization of selected sites.	C1c. UV imaging spectrometer		1	1	1
	C2.	Relate compositions to geological processes, especially material exchange with the interior.	C2a. Surface reflectance measurements by visible to short wavelength infrared spectroscopy of targeted features at better than or equal to 25 m/pixel spatial resolution, with better than 5 nm (10 nm floor) spectral resolution through a spectral range of at least 0.4–2.5 microns (1–2.5 microns floor), and better than 10 nm (20 nm floor) through a spectral range of at least 2.5–5 microns. SNR better than 128 for 0.9–2.6 microns and better than 32 for 2.6–5 microns.	C2a. Vis-IR imaging spectrometer		2	3	3
			C2b. Global identification and local characterization of physical and dielectric subsurface horizons, at depths 1 to 30 km at 100 m vertical resolution and depths of 100 m to 3 km at 10 m vertical resolution, by obtaining sounding profiles with better than 50 km spacing, plus targeted characterization of selected sites.	C2b. Radar sounder		2	2	3

:				
Origins	Evolution	Processes	Habitability	Life

SI = Science Investigation

0	1	2	3	4
Does not address SI	Touches on SI	May address Partial SI	Definitely addresses Partial SI	May add Full S

TER EUROPA ORBITER: TRACEABILITY MATRIX

ience Objective	Science Investigation	Measurement	Instrument	Jupiter System Science	SCIENCE VALU / EUROPA CAMPAIGN / 1 Global Framewrk / 1A	1B	2 Regiona / 2A
ine global surface sitions and chemistry, ally as related tability.	C2. Relate compositions to geological processes, especially material exchange with the interior.	C2c. Surface reflectance measurements by ultraviolet spectroscopy of targeted features at better than or equal to 100 m/pixel spatial resolution, and better than or equal 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns.	C2c. UV imaging spectrometer		1	1	1
		C2d. High-resolution visible stereo imaging of targeted features, at better than or equal 10 m/pixel.	C2d. Medium-angle camera (stereo)		2	2	2
		C2e. Map thermal emission from the surface by measuring albedo to 10% radiometric accuracy at better than or equal to 250 m/pixel spatial resolution, and by making thermal observations at spatial resolution better than or equal to 250 m/pixel spatial resolution and temperature accuracy better than 2 K, over more than 80% of the surface.	C2e. Thermal imager		3	4	4
		C2f. Detailed morphological characterization of targeted features through imaging at better than or equal to 1 m/pixel.	C2f. Narrow-angle camera		3	3	4
		C2g. Topography at better than or equal to 100 m/pixel spatial scale and better than or equal to 10 m vertical resolution over >80% of the surface, and topographic characterization at better than 10 m/pixel spatial scale and better than or equal to 1 m vertical resolution and accuracy for targeted features, co-located with sounding data.	C2g. Wide-angle camera (stereo), medium-angle camera (stereo), and laser altimeter		2	2	2
	C3. Characterize the global radiation environment and the effects of radiation on surface composition, atmospheric composition, albedo, sputtering, sublimation, and redox chemistry.	C3a. Surface reflectance measurements by visible to short wavelength infrared spectroscopy of targeted features at better than or equal to 25 m/pixel spatial resolution, with better than 5 nm (10 nm floor) spectral resolution through a spectral range of 0.4–2.5 microns (1–2.5 microns floor), and better than 10 nm spectral resolution (20 nm floor) through a spectral range of at least 2.5–5 microns. SNR better than 128 for 0.9–2.6 microns and better than 32 for 2.6–5 microns.	C3a. Vis-IR imaging spectrometer		1	2	3
		C3b. Surface reflectance measurements by ultraviolet spectroscopy at better than or equal to 100 m/pixel spatial resolution, and better than or equal to 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns, using profiles at less than or equal to 25 km spacing over more than 80% of the surface, plus targeted characterization of selected sites.	C3b. UV imaging spectrometer		1	1	1
		C3c. Identify and map any age-sensitive chemical and physical indicators (e.g., H_2O frost, ice crystallinity, SO_2, H_2O_2) using surface reflectance measurements by visible to short wavelength infrared spectroscopy at better than or equal to 25 m/pixel spatial resolution, with better than 6 nm spectral resolution through a spectral range of at least 0.9–2.5 microns (0.4–2.5 microns desirable) with SNR better than 128, and better than 12 nm through a spectral range of at least 2.5–5 microns with SNR greater than 32, and by ultraviolet spectroscopy at better than or equal to 100 m/pixel spatial resolution, and better than or equal 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns, using profiles at less than or equal to 25 km spacing over more than 80% of the surface, plus targeting of selected sites.	C3c. Vis-IR imaging spectrometer and UV imaging spectrometer		2	2	3
		C3d. Characterize the composition of sputtered products from energetic particle bombardment of the surface, through ion and neutral mass spectrometry over a mass range of 300 Daltons, mass resolution of more than 500, and pressure range of 10^{-4} to 10^{-17} mbar, and energy resolution of 10%.	C3d. Ion and neutral mass spectrometer		1	1	3
		C3e. Characterize the structure of the sputter-produced atmosphere using ultraviolet stellar occultations, and ultraviolet imaging of atmospheric emissions, at equal to or better than 0.5 nm spectral resolution and 100 m/pixel scale through a spectral range of at least 0.1–0.20 microns.	C3e. UV imaging spectrometer		3	3	4
	C3. Characterize the global radiation environment and the effects of radiation on surface composition, atmospheric composition, albedo, sputtering, sublimation, and redox chemistry.	C3f. Determine the flux of trapped and precipitating ions (with composition) and electrons in the energy range 10 eV to 10 MeV at 15° angular resolution and $\Delta E/E = 0.1$ and a time resolution of at least 1 minute.	C3f. Particle and plasma instrument		1	1	2
		C3g. Determine surface color characteristics at ~100 m/pixel scale in at least 3 colors, over more than 80% of the surface.	C3g. Wide-angle camera, color		3	4	4
		C3h. Measure the surface albedo at spatial resolution of better than or equal to 250 m/pixel to 10% radiometric accuracy, over more than 80% of the surface.	C3h. Thermal imager		3	4	4
		C3i. Detailed morphological characterization of targeted features through imaging at better than or equal 1 m/pixel.	C3i. Narrow-angle camera		3	3	4
	C4. Characterize the nature of exogenic materials.	C4a. Determine the ion (with composition) and electron precipitation flux at energies of 10 eV to 10 MeV at 15° angular resolution and $\Delta E/E = 0.1$ and a time resolution of at least 1 minute.	C4a. Particle and plasma instrument		1	1	2

Origins	Evolution	Processes	Habitability	Life

SI = Science Investigation

0	1	2	3	
Does not address SI	Touches on SI	May address Partial SI	Definitely addresses Partial SI	May a… Fu…

TER EUROPA ORBITER: TRACEABILITY MATRIX

cience Objective		Science Investigation	Measurement	Instrument	SCIENCE VALU: Jupiter System Science	EUROPA CAMPAIGN: 1 Global Framewrk 1A	1 Global Framewrk 1B	2 Regional 2A
hine global surface sitions and chemistry, ally as related itability.	C4.	Characterize the nature of exogenic materials.	C4b. Ion and neutral mass spectrometry over a mass range of 300 Daltons, mass resolution of more than 500, and pressure range of 10^{-8} to 10^{-17} mbar, and energy resolution of 10%.	C4b. Ion and neutral mass spectrometer		1	1	2
			C4c. Surface reflectance measurements by visible to short wavelength infrared spectroscopy at better than or equal to 25 m/pixel spatial resolution, with better than 5 nm (10 nm floor) spectral resolution through a spectral range of 0.4–2.5 microns (1–2.5 microns floor) with SNR better than 128, and better than 10 nm resolution (20 nm floor) through a spectral range of at least 2.5–5 microns (SNR better than 32), along profiles with less than or equal to 25 km spacing over more than 80% of the surface, plus targeted characterization of selected sites.	C4c. Vis-IR imaging spectrometer		1	2	3
			C4d. Surface reflectance measurements by ultraviolet spectroscopy at better than or equal to 100 m/pixel spatial resolution, and better than or equal 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns, using profiles at less than or equal to 25 km spacing over more than 80% of the surface, plus targeted characterization of selected sites.	C4d. UV imaging spectrometer		1	1	1
			C4e. Determine surface color characteristics at ~100 m/pixel scale in at least 3 colors, over more than 80% of the surface.	C4e. Wide-angle camera, color		3	4	4
stand the formation of e features, including sites nt or current activity, and y and characterize late sites for future *in situ* ation.	D1.	Determine the formation history and three-dimensional characteristics of magmatic, tectonic, and impact landforms.	D1a. Determine the distributions and morphologies of surface landforms at regional and local scales, and the regional and global stratigraphic relationships among them, by determining surface color characteristics at ~100 m/pixel scale in at least 3 colors with near-uniform lighting conditions and solar phase angles less than or equal to 45 degrees, over more than 80% of the surface.	D1a. Wide-angle camera (color) and medium-angle camera		3	3	4
			D1b. Topography at better than or equal to 100 m/pixel spatial scale and better than or equal to 10 m vertical resolution, over more than 80% of the surface, co-located with sounding profiles.	D1b. Wide-angle camera (stereo)		1	3	3
			D1c. Topographic characterization at better than 10 m/pixel scale and better than or equal to 1 m vertical resolution and accuracy for targeted features, co-located with sounding profiles.	D1c. Medium-angle camera (stereo) and laser altimeter		2	2	2
			D1d. Global identification and local characterization of physical and dielectric subsurface horizons, at depths 1 to 30 km at 100 m vertical resolution and depths of 100 m to 3 km at 10 m vertical resolution, by obtaining sounding profiles with better than 50 km spacing over more than 80% of the surface, plus targeted characterization of selected sites.	D1d. Radar sounder (nominally ~50 MHz, with ~10 MHz bandwidth)		3	3	4
			D1e. Characterize small-scale surface morphology, with stereo imaging at ~1 to 10 m/pixel over targeted high-priority sites, with vertical resolution of better than or equal to 1 m.	D1e. Medium-angle camera or narrow-angle camera		0	0	2
			D1f. Identify and map any age-sensitive chemical and physical indicators (e.g., H_2O frost, ice crystallinity, SO_2, H_2O_2) using surface reflectance measurements by visible to short wavelength infrared spectroscopy at better than or equal to 25 m/pixel spatial resolution, with better than 6 nm spectral resolution through a spectral range of at least 0.9–2.5 microns (0.4–2.5 microns desirable) with SNR better than 128, and better than 12 nm resolution through a spectral range of at least 2.5–5 microns with SNR better than 32, and by ultraviolet spectroscopy at better than or equal to 100 m/pixel spatial resolution, and better than or equal 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns, using profiles at less than or equal to 25 km spacing over more than 80% of the surface, plus targeting of selected sites.	D1f. Vis-IR spectrometer and UV imaging spectrometer		1	2	2
			D1g. Map thermal emission from the surface by measuring albedo to 10% radiometric accuracy at spatial resolution better than or equal to 250 m/pixel, and by making daytime and nighttime thermal observations at spatial resolution better than or equal to 250 m/pixel and temperature accuracy better than 2 K, over more than 80% of the surface.	D1g. Thermal imager		2	3	3
			D1h. Detailed morphological characterization of targeted features through imaging at better than or equal 1 m/pixel.	D1h. Narrow-angle camera		1	2	3
	D2.	Determine sites of most recent geological activity and evaluate future landing sites.	D2a. Thermal mapping better than or equal to 250 m/pixel spatial resolution and temperature accuracy better than 2 K, over more than 80% of the surface, with the same regions observed in both the day and night.	D2a. Thermal imager		2	2	4
			D2b. Search for and identify any regions of outgassing using ultraviolet stellar occultations, and ultraviolet imaging of the surface and atmosphere, at better than or equal to 0.5 nm spectral resolution through a range of at least 0.1–0.2 microns.	D2b. UV imaging spectrometer		2	3	4
			D2c. High-resolution visible stereo imaging of targeted features, at better than or equal 10 m/pixel.	D2c. Medium-angle camera (stereo)		1	1	2

Origins	Evolution	Processes	Habitability	Life

SI = Science Investigation

0	1	2	3	4
Does not address SI	Touches on SI	May address Partial SI	Definitely addresses Partial SI	May ad Full

ITER EUROPA ORBITER: TRACEABILITY MATRIX

Science Objective		Science Investigation	Measurement	Instrument	SCIENCE VALUE: Jupiter System Science	EUROPA CAMPAIGNS: 1 Global Framewrk 1A	1 Global Framewrk 1B	2 Regional P 2A
rstand the formation of ce features, including sites cent or current activity, and ify and characterize idate sites for future *in situ* oration.		D2. Determine sites of most recent geological activity and evaluate future landing sites.	D2d. Detailed morphological characterization of targeted features through imaging at better than or equal 1 m/pixel.	D2d. Narrow-angle camera		1	2	3
			D2e. Identify and map any age-sensitive chemical and physical indicators (e.g., H_2O frost, ice crystallinity, SO_2, H_2O_2) using surface reflectance measurements by visible to short wavelength infrared spectroscopy at better than or equal to 25 m/pixel spatial resolution, with better than 6 nm spectral resolution through a spectral range of at least 0.9–2.5 microns (0.4–2.5 microns desirable) with SNR better than 128, and better than 12 nm through a spectral range of at least 2.5–5 microns with SNR better than 32, and by ultraviolet spectroscopy at better than or equal to 100 m/pixel spatial resolution, and better than or equal 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns, using profiles at less than or equal to 25 km spacing over more than 80% of the surface, plus targeting of selected sites.	D2e. Vis-IR spectrometer and UV imaging spectrometer		1	2	2
			D2f. Characterize the interaction between the surface and plasma to evaluate surface aging processes. Measure depth and temperature of the 1.65 micron water band (deeper for colder temperatures of crystalline (young) ice and nearly absent for pure amorphous (older) ice in addition to measurements at 3.1 and 4.53 microns. Determine the ion and electron precipitation flux with ion composition for energies of 1 eV to 1 MeV.	D2f. Particle and plasma instrument and Vis-IR imaging spectrometer		2	2	2
		D3. Investigate processes of erosion and deposition and their effects on the physical properties of the surface debris.	D3a. Determine thermal inertia of surface materials, by thermal mapping, to better than or equal to 250 m/pixel spatial resolution and better than 2 K absolute temperature over >80% of the surface, with the same regions observed in both the day and night.	D3a. Thermal imager		2	2	3
			D3b. Detailed morphological characterization of targeted features through imaging at better than or equal 1 m/pixel.	D3b. Narrow-angle camera		1	2	3
			D3c. Characterize the interaction between the surface and plasma to evaluate surface aging processes. Measure depth and temperature of the 1.65 micron water band (deeper for colder temperatures of crystalline (young) ice and nearly absent for pure amorphous (older) ice in addition to measurements at 3.1 and 4.53 microns. Determine the precipitation flux of electrons and ions (with composition) in the eV to few MeV energy range.	D3c. Particle and plasma instrument and Vis-IR imaging spectrometer		2	2	2
			D3d. Measure ion-cyclotron waves and relate to plasma-pickup and erosion by magnetic field sampling at 32 vectors/s and a sensitivity of 0.1 nT, to constrain sputtering rates.	D3d. Magnetometer		1	1	2
rstand Europa in the xt of the Jupiter m.	Satellite surfaces and interiors	E1. Investigate the nature and magnitude of tidal dissipation and heat loss on the Galilean satellites, particularly Io.	E1a. Determine regional and global heat flow by 1) measuring global surface thermal emission at spatial resolution of 5 km/pixel to 10% radiometric accuracy at at least two wavelengths; 2) identifying thermally-controlled subsurface horizons within the ice shell by radar sounding at depths of 1 to 30 km at 100 m vertical resolution.	E1a. Thermal imager and radar sounder	3			
			E1b. Thermal Mapping with 2K absolute accuracy, from ~80K to >160K, spatial resolution better than 10 km/pixel, preferably better than 500 m/pixel, within 30 degrees of the noon meridian and at night.	E1b. Thermal imager	2			
			E1c. Determine regional and global time-varying gravity and topography/shape of Io. Topographic differences at cross-over points with better than or equal to 10 m vertical accuracy. Doppler shift from spacecraft tracking via two-way Doppler, to resolve 2nd degree gravity field time dependence. Doppler velocity of 0.1 mm/s over 60 s accuracy.	E1c. Telecom system and laser altimeter	3			
		E2. Investigate Io's active volcanism for insight into its geological history and evolution (particularly of its silicate crust).	E2a. Repeated (daily to monthly) monochromatic imaging of selected active volcanic features at ~1 km/pixel spatial resolution.	E2a. Narrow angle camera	1			
			E2b. IR imaging of volcanic thermal emission at better than 100 km/pixel spatial scale, absolute accuracy 2K, at silicate melt temperatures, over a range of temporal scales (e.g., hourly, daily, weekly, monthly). Desire better than 20 km/pixel spatial resolution.	E2b. IR imaging spectrometer	4			
			E2c. Frequent multispectral global mapping (minimum 3 colors) at better than or equal to 10 km/pix. Violet, green, NIR over a range of temporal scales (e.g., hourly, daily, weekly, monthly).	E2c. Narrow-angle camera	4			
			E2d. High-resolution visible imaging (better than 100 m spatial resolution) of selected volcanic features for change detection (e.g., with Galileo and Voyager data).	E2d. Narrow-angle camera	2			
			E2e. Global (>80%) monochromatic imaging at ~1 km/pixel spatial resolution at available opportunities.	E2e. Narrow-angle camera	1			
			E2f. IR imaging of volcanic thermal emission at better than 100 km/pixel spatial scale, absolute accuracy 2K, at silicate melt temperatures, over a range of temporal scales (e.g., hourly, daily, weekly, monthly). Desire better than 20 km/pixel spatial resolution.	E2f. IR imaging spectrometer	1			

s: Origins | Evolution | Processes | Habitability | Life

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…TER EUROPA ORBITER: TRACEABILITY MATRIX

…ence Objective		Science Investigation	Measurement	Instrument	SCIENCE VALU…: Jupiter System Science	EUROPA CAMPAIG…: 1 Global Framewrk 1A	1B	2 Region… 2A
…tand the formation of … features, including sites …t or current activity, and … and characterize …te sites for future *in situ* …tion.		D2. Determine sites of most recent geological activity and evaluate future landing sites.	D2d. Detailed morphological characterization of targeted features through imaging at better than or equal 1 m/pixel.	D2d. Narrow-angle camera		1	2	3
			D2e. Identify and map any age-sensitive chemical and physical indicators (e.g., H_2O frost, ice crystalinity, SO_2, H_2O_2) using surface reflectance measurements by visible to short wavelength infrared spectroscopy at better than or equal to 25 m/pixel spatial resolution, with better than 6 nm spectral resolution through a spectral range of at least 0.9–2.5 microns (0.4–2.5 microns desirable) with SNR better than 128, and better than 12 nm through a spectral range of at least 2.5–5 microns with SNR better than 32, and by ultraviolet spectroscopy at better than or equal to 100 m/pixel spatial resolution, and better than or equal 3 nm spectral resolution, through a spectral range of at least 0.1–0.35 microns, using profiles at less than or equal to 25 km spacing over more than 80% of the surface, plus targeting of selected sites.	D2e. Vis-IR spectrometer and UV imaging spectrometer		1	2	2
			D2f. Characterize the interaction between the surface and plasma to evaluate surface aging processes. Measure depth and temperature of the 1.65 micron water band (deeper for colder temperatures of crystalline (young) ice and nearly absent for pure amorphous (older) ice in addition to measurements at 3.1 and 4.53 microns. Determine the ion and electron precipitation flux with ion composition for energies of 1 eV to 1 MeV.	D2f. Particle and plasma instrument and Vis-IR imaging spectrometer		2	2	2
		D3. Investigate processes of erosion and deposition and their effects on the physical properties of the surface debris.	D3a. Determine thermal inertia of surface materials, by thermal mapping, to better than or equal to 250 m/pixel spatial resolution and better than 2 K absolute temperature over >80% of the surface, with the same regions observed in both the day and night.	D3a. Thermal imager		2	2	3
			D3b. Detailed morphological characterization of targeted features through imaging at better than or equal 1 m/pixel.	D3b. Narrow-angle camera		1	2	3
			D3c. Characterize the interaction between the surface and plasma to evaluate surface aging processes. Measure depth and temperature of the 1.65 micron water band (deeper for colder temperatures of crystalline (young) ice and nearly absent for pure amorphous (older) ice in addition to measurements at 3.1 and 4.53 microns. Determine the precipitation flux of electrons and ions (with composition) in the eV to few MeV energy range.	D3c. Particle and plasma instrument and Vis-IR imaging spectrometer		2	2	2
			D3d. Measure ion-cyclotron waves and relate to plasma-pickup and erosion by magnetic field sampling at 32 vectors/s and a sensitivity of 0.1 nT, to constrain sputtering rates.	D3d. Magnetometer		1	1	2
…tand Europa in the … of the Jupiter …	Satellite surfaces and interiors	E1. Investigate the nature and magnitude of tidal dissipation and heat loss on the Galilean satellites, particularly Io.	E1a. Determine regional and global heat flow by 1) measuring global surface thermal emission at spatial resolution of 5 km/pixel to 10% radiometric accuracy at at least two wavelengths; 2) identifying thermally-controlled subsurface horizons within the ice shell by radar sounding at depths of 1 to 30 km at 100 m vertical resolution.	E1a. Thermal imager and radar sounder	3			
			E1b. Thermal Mapping with 2K absolute accuracy, from ~80K to >160K, spatial resolution better than 10 km/pixel, preferably better than 500 m/pixel, within 30 degrees of the noon meridian and at night.	E1b. Thermal imager	2			
			E1c. Determine regional and global time-varying gravity and topography/shape of Io. Topographic differences at cross-over points with better than or equal to 10 m vertical accuracy. Doppler shift from spacecraft tracking via two-way Doppler, to resolve 2nd degree gravity field time dependence. Doppler velocity of 0.1 mm/s over 60 s accuracy.	E1c. Telecom system and laser altimeter	3			
		E2. Investigate Io's active volcanism for insight into its geological history and evolution (particularly of its silicate crust).	E2a. Repeated (daily to monthly) monochromatic imaging of selected active volcanic features at ~1 km/pixel spatial resolution.	E2a. Narrow angle camera	1			
			E2b. IR imaging of volcanic thermal emission at better than 100 km/pixel spatial scale, absolute accuracy 2K, at silicate melt temperatures, over a range of temporal scales (e.g., hourly, daily, weekly, monthly). Desire better than 20 km/pixel spatial resolution.	E2b. IR imaging spectrometer	4			
			E2c. Frequent multispectral global mapping (minimum 3 colors) at better than or equal to 10 km/pix. Violet, green, NIR over a range of temporal scales (e.g., hourly, daily, weekly, monthly).	E2c. Narrow-angle camera	4			
			E2d. High-resolution visible imaging (better than 100 m spatial resolution) of selected volcanic features for change detection (e.g., with Galileo and Voyager data).	E2d. Narrow-angle camera	2			
			E2e. Global (>80%) monochromatic imaging at ~1 km/pixel spatial resolution at available opportunities.	E2e. Narrow-angle camera	1			
			E2f. IR imaging of volcanic thermal emission at better than 100 km/pixel spatial scale, absolute accuracy 2K, at silicate melt temperatures, over a range of temporal scales (e.g., hourly, daily, weekly, monthly). Desire better than 20 km/pixel spatial resolution.	E2f. IR imaging spectrometer	1			

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cience Objective		Science Investigation	Measurement	Instrument	SCIENCE VALU: Jupiter System Science	EUROPA CAMPAIGN: 1 Global Framewrk 1A	1B	2 Regiona 2A
stand Europa in the xt of the Jupiter n.	Satellite surfaces and interiors	**E2.** Investigate Io's active volcarism for insight into its geological history and evolution (particularly of its silicate crust).	E2g. UV - VIS plume imaging: high phase angle plume monitoring (for dust and gas emissions) and low phase angle observations (for gas absorptions) over a range of temporal scales. Visible spatial resolution better than 20 km/pixel; UV spatial resolution better than 50 km/pixel.	E2g. UV imaging spectrometer and narrow-angle camera	1			
			E2h. Long-distance visible and thermal characterization (e.g., from Ganymede or Jupiter orbit) over a period of years. Desire close flybys of Io to characterize terrains/active features/change at high resolution.	E2h. Narrow-angle camera and thermal imager	1			
		E3. Investigate the presence and location of water within Ganymede and Callisto.	E3a. Determine Degree-2 dynamic gravity field and spin pole orientation. Doppler velocity of 0.1 mm/s over 60 s accuracy. Multi-frequency preferred. Many flybys.	E3a. Telecom system	2			
			E3b. Magnetic field measurements at 8 vectors/s and a sensitivity of 0.1 nT with multiple flybys at different orbital phases and closest approach of < 0.5 moon radii.	E3b. Magnetometer	3			
			E3c. Characterize the extent and location of water (including brines) in 3D by obtaining profiles at depths of 1 to 30 km at 100 m vertical resolution, and obtain simultaneous topography at better than or equal to 1 km/pixel spatial scale and better than or equal to 10 m range accuracy.	E3c. Radar sounder and laser altimeter	3			
		E4. Determine the composition, physical characteristics, distribution, and evolution of surface materials on Ganymede.	E4a. Identify globally distributed bulk material compositions, grain size, porosity, crystallinity, and physical state from the IR (0.8–2.5 microns) with a spectral resolution of 4 nm and an IFOV smaller than 100 m, to the thermal with 2K absolute accuracy, from ~80K to >160K and spatial resolution better than 10 km/pixel.	E4a. Vis-IR imaging spectrometer and thermal imager	2			
			E4b. Map global distribution of different materials, including radiolytic materials (e.g., SO_4, O_3, H_2O_2, CH, O_2), and document variability over a range of timescales in the IR (0.8–5 microns) with a spectral resolution better than 10 nm (4 nm in the 1–2.5 micron range) and IFOV less than 1 km, along with UV observations (0.1 to 0.4 microns) with spectral resolution of better than 2 nm and spatial resolution better than 1 km/pixel.	E4b. Vis-IR imaging spectrometer and UV imaging spectrometer	2			
			E4c. Determine origin and evolution of non-ice materials, including the role of geologic processes in the IR (0.8–5 microns; spectral resolution of better than 10 nm and IFOV smaller than 1 km) of representative features. Co-registered with higher-resolution panchromatic images.	E4c. Vis-IR imaging spectrometer and narrow-angle camera	2			
			E4d. Document composition, physical state, distribution, and transport of surface volatiles, e.g., sublimation, over the UV wavelength range of 0.1 to 0.4 microns with spectral resolution of 2 nm and spatial resolution better than 1 km/pixel. Spatial coverage of 50% to search for short-lived or mobile species and repeated coverage to look for changes. Visible wavelength mapping at 0.55–0.75 microns, spectral resolution of 1 nm. 50% global coverage with spatial resolution better than 1 km/pixel; repeated coverage to look for changes. IR coverage from 0.8–5 microns with spectral resolution better than 10 nm, IFOV smaller than 1 km. 50% global coverage with spatial resolution better than 1 km/pixel; repeated coverage to look for changes.	E4d. UV imaging spectrometer and Vis-IR imaging spectrometer	2			
		E5. Determine the composition, physical characteristics, distribution, and evolution of surface materials on Callisto.	E5a. Identify bulk material compositions, grain size, porosity, crystallinity, and physical state using globally-distributed hyperspectral IR imaging (0.8–2.5 microns). Spectral resolution of 4 nm, IFOV smaller than 100 m.	E5a. Vis-IR imaging spectrometer	2			
			E5b. Identify globally distributed bulk material compositions, grain size, porosity, crystallinity, and physical state from the IR (0.8–2.5 microns) with spectral resolution of 4 nm and IFOV smaller than 100 m, to the thermal with 2K absolute accuracy, from ~80K to >160K and spatial resolution better than 10 km/pixel.	E5b. Vis-IR imaging spectrometer and thermal imager	2			
			E5c. Map global distributions of different materials, including radiolytic materials (e.g., SO_4, O_3, H_2O_2, CH, O_2), and document variability over a range of timescales using global IR imaging (0.8–5 microns). Spectral resolution better than 10nm (4 nm in the 1–2.5 micron range), IFOV smaller than 1 km, along with UV observations (0.1 to 0.4 microns) with spectral resolution of better than 2 nm and spatial resolution better than 1 km/pixel.	E5c. Vis-IR imaging spectrometer and UV imaging spectrometer	2			
			E5d. Determine origin and evolution of non-ice materials, including the role of geologic processes in the IR (0.8–5 microns; spectral resolution of better than 10 nm and IFOV smaller than 1 km) of representative features. Co-registered with higher-resolution panchromatic images.	E5d. Vis-IR imaging spectrometer and narrow-angle camera	2			

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[...]ence Objective			Science Investigation	Measurement	Instrument	SCIENCE VALU[...] Jupiter System Science	EUROPA CAMPAIG[...] 1 Global Framewrk 1A	1B	2 Regiona[...] 2A
[...]tand Europa in the [...] of the Jupiter [...]	Satellite surfaces and interiors	E6.	Identify the dynamical processes that cause internal evolution and near-surface tectonics of Ganymede and Callisto.	E6a. Measure the low order static gravity (J_2 and C_{22}) at 10^{-7} accuracy for the non-dimensional gravitational harmonics of both moons, via Doppler tracking.	E6a. Telecom system	5			
				E6b. Measure higher-order gravity to evaluate non-hydrostatic effects, via Doppler tracking.	E6b. Telecom system	4			
				E6c. Measure the dynamic degree-2 gravity signal to determine tidal k_2 to within 0.1, via Doppler tracking.	E6c. Telecom system	2			
				E6d. Measure the pole position to 0.1 deg accuracy to determine the obliquity of the spin axis.	E6d. Medium-angle camera	2			
				E6e. Globally distributed altimetry to 1 m vertical resolution and better than 1 km horizontal resolution (100 m horizontal resolution preferable, at least along specific spacecraft tracks if not globally)	E6e. Laser altimeter	1			
				E6f. Global (more than 80% coverage) visible imaging at 100 m/pixel spatial resolution. Additionally, desire ~10–20% coverage at 10 m/pixel.	E6f. Narrow-angle camera	1			
				E6g. Globally distributed profiling of thermal, compositional and structural horizons for Ganymede and Callisto's icy shells to depths from 1 up to 30 km at 100 m vertical resolution.	E6g. Radar sounder	3			
				E6h. Measurement of, or upper limit on, heat flow using thermal measurements in the 8 to 100 micron range with a spectral resolution of 2K and spatial resolution better than 30 km/pixel; observation collected several times of day and at night.	E6h. Thermal imager	4			
				E6i. Magnetic field. Determination of induction response at orbital (as well as Jupiter rotation) time scales to an accuracy of 0.1 nT but with the emphasis on looking for secular variation of the "steady" field or variation in the induction signal since Galileo.	E6i. Magnetometer	3			
	Satellite atmospheres	E7.	Characterize the composition, variability, and dynamics of Europa's atmosphere and ionosphere.	E7a. Perform UV imaging of Europa over the spectral range 100–200 nm at better than 0.5 nm resolution, better than 1 km spatial resolution, and better than 48 hr temporal resolution, including through the synodic cycle.	E7a. UV imaging spectrometer	4			
				E7b. Perform stellar occultations of Europa at UV wavelengths to search for water absorption and oxygen emission signatures. Cover 100–200 nm at better than 0.5 nm resolution, and latitude/longitude resolution of less than 30 deg.	E7b. UV imaging spectrometer	3	3	4	4
				E7c. Scan perpendicular to the limb from ~5 km above the surface to the surface of the satellite at IR wavelengths to measure or search for emission from O_2 (1.27 microns), H_2O, CO_2 (4.26 microns) and other species in the Europa atmosphere.	E7c. IR imaging spectrometer	3			
				E7d. Perform radio occultations of Europa to measure its ionosphere.	E7d. Two-band radio communication system with USO	3			
				E7e. Determine the fluxes of positive ions and neutral particles, by ion mass spectrometry over a mass range of 300 Daltons, mass resolution of better than 500, and pressure range of 10^{-6} to 10^{-17} mbar, and energy resolution of 10%.	E7e. Ion and neutral mass spectrometer	4			
				E7f. Understand how sputtering generates an exosphere. Determine the flux and composition of the impacting charged particles (ions and electrons) between energies of 10 eV to 10 MeV at 15° angular resolution and $\Delta E/E$ = 0.1 and a time resolution of at least 1 minute.	E7f. Particle and plasma instrument	3	1	1	2
		E8.	Understand the sources and sinks of Io's crustal volatiles and atmosphere.	E8a. Characterize volatile cycle, including composition, physical state, distribution, and transport of surface volatiles by global mapping of the surface at UV-IR wavelengths (e.g., for SO_2 frost variations) on a range of temporal scales (~days). IR (1–5 microns) at 20 nm spectral resolution and ~10–500 km/pixel; VNIR (0.35–1 microns) at 2 nm resolution; NUV (0.2–0.35 microns) with better than 20 nm spectral resolution and better than 100 km spatial resolution.	E8a. UV imaging spectrometer and Vis-IR imaging spectrometer	3			
				E8b. Dayside, nightside and eclipse coverage at UV wavelengths, 0.1–0.35 microns (for SO_2 and other gas density) at 0.5 nm spectral resolution, better than 500 km/pixel spatial resolution	E8b. UV imaging spectrometer	2			
				E8c. Determine roles and rates of sublimation, sputtering, and radiation darkening by global mapping of surface at UV-IR wavelengths at ~10–500 km/pix at better than 10 nm spectral resolution for 1–5 microns, and at ~2 nm for 0.1–1 microns, over a wide range of longitudes (i.e. to facilitate comparisons between leading and trailing hemispheres, especially in non-plume regions) and with thermal IR mapping with regional spatial resolution better than 10 km, including polar coverage.	E8c. Thermal instrument	1			

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ience Objective			Science Investigation	Measurement	Instrument	SCIENCE VALU			
						Jupiter System Science	EUROPA CAMPAIG		
							1 Global Framewrk		2 Region
							1A	1B	2A
tand Europa in the t of the Jupiter .	Satellite atmospheres	E8.	Understand the sources and sinks of Io's crustal volatiles and atmosphere.	E8d. Determine column densities of atmospheric/plume species across the globe and document correlations with plumes, geologic features and local albedo variations by global EUV - NIR (0.06–5 microns) surface and limb spectroscopy at better than 50 km resolution. UV spectral resolution of 0.3 nm. UV spatial resolution of better than 500 km/pixel. Visible imaging in eclipse.	E8d. UV imaging spectrometer, Vis-IR imaging spectrometer, and narrow-angle camera	2			
				E8e. UV stellar occultations (FUV-NUV) over a range of latitude/longitude space and a range of temporal scales/periodically throughout the mission. UV spectral resolution of 0.5 nm, 0.1–0.25 microns.	E8e. UV imaging spectrometer	3			
				E8f. Perform long-term and high-temporal-resolution monitoring of atmosphere, plumes, limb-glow, and equatorial spots via EUV - VNIR (0.06–1 microns) imaging limb observations of plumes, atmosphere, neutral clouds over a range of temporal scales (e.g., hourly, daily, weekly, monthly). UV spectral resolution of 0.5 nm, spatial resolution of <500 km/pixel. VNIR spatial resolution better than 10 km/pixel.	E8f. UV imaging spectrometer and Vis-IR imaging spectrometer	3			
				E8g. Determine the composition, distribution and physical characteristics (grain-size, crystallinity) of volatile materials on the surface, including SO_2 frost by vis-IR (0.4–5 micron) imaging on a global scale (better than 10 km/pixel for yellow and white-gray units), and at higher resolution for green and red units (~1 km/pixel).	E8g. Vis-IR imaging spectrometer	3			
				E8h. In situ neutral mass spectroscopy measurements of Io's atmosphere.	E8h. Ion and neutral mass spectrometer	3			
		E9.	Determine the sources and sinks of the Ganymede and Callisto atmospheres.	E9a. Determine column densities of atmospheric species across the globe at better than 1 km spatial resolution using IR limb scans, UV spectroscopy, and UV and visible-IR stellar occultations. UV spectral coverage 100–320 nm at 0.5 nm resolution. Perform long-term and high-temporal-resolution monitoring in context of magnetospheric variations.	E9a. UV imaging spectrometer and Vis-IR imaging spectrometer	3			
				E9b. Determine the composition, distribution and physical characteristics (grain-size, crystallinity, physical state) of volatile materials on the surface, including UV measurements of O_3, H_2O_2 and other species (100–320 nm at 2 nm resolution).	E9b. UV imaging spectrometer and Vis-IR imaging spectrometer	3			
				E9c. Investigate sputtering processes at high latitudes as compared with lower latitudes by measuring water ice grain sizes and products such as O_3, H_2O_2 and other species (UV observations over 100–320 nm at 2 nm resolution); measure flux of precipitating ions to representative satellite regions.	E9c. UV imaging spectrometer and particle and plasma instrument	2			
				E9d. Global FUV - IR (0.1–5 microns) spectroscopy at better than 50 km spatial resolution to measure SO_2, SO, S, O, Cl and other species in absorption and/or emission. UV spectral resolution of 0.5 nm; IR spectral resolution better than 10 nm.	E9d. UV imaging spectrometer and Vis-IR imaging spectrometer	3			
				E9e. Perform stellar occultations at IR and UV wavelengths to search for water absorption and oxygen emission signatures. For UV, cover 100–200 nm at better than or equal to 0.5 nm resolution, and latitude/longitude resolution of better than 30 deg.	E9e. UV imaging spectrometer and Vis-IR imaging spectrometer	3			
				E9f. Scan perpendicular to the limb from ~5 km above the surface to the surface of the satellite at IR wavelengths to measure or search for emission from O_2 (1.27 microns), H_2O, CO_2 (4.26 microns) and other species in the Ganymede and Callisto atmospheres.	E9f. Vis-IR imaging spectrometer	4			
				E9g. Perform radio occultations of Ganymede and Callisto to measure the ionospheres.	E9g. Two-band radio communication system with USO	3			
	Plasma and magnetospheres	E10.	Characterize the neutral atoms and molecules escaping Europa's gravity.	E10a. Detect neutrals coming off Europa with a mass range up to 300 Daltons and a mass resolution of up to 500.	E10a. Ion and neutral mass spectrometer	2	2	3	3
				E10b. Measure the flux of pickup ions in the tens to hundreds of eV energy range.	E10b. Plasma instrument	2	2	3	3
				E10c. Determine the cold plasma temperature of the electrons to estimate ionization rates near Europa.	E10c. Plasma instrument	2	2	3	3

Origins	Evolution	Processes	Habitability	Life

SI = Science Investigation

0	1	2	3	
Does not address SI	Touches on SI	May address Partial SI	Definitely addresses Partial SI	May a F

TER EUROPA ORBITER: TRACEABILITY MATRIX

ience Objective		Science Investigation		Measurement	Instrument	Jupiter System Science	SCIENCE VALU EUROPA CAMPAIGN 1 Global Framework 1A	1B	2 Regiona 2A
stand Europa in the t of the Jupiter n.	Plasma and magnetospheres	E11.	Characterize the composition of and transport in Io's plasma torus.	E11a. Perform EUV imaging spectroscopy (30–110 nm) of the Io plasma torus at 0.1 Rj/px and <0.5 nm spectral resolution over a range of timescales (e.g., hourly, daily, weekly, monthly) with emphasis on daily monitoring for > 30 days.	E11a. UV imaging spectrometer	3			
				E11b. Measure the flux and composition of charged particles (ions and electrons) between energies of 10 eV to 10 MeV at 15° angular resolution and ΔE/E = 0.1 and a time resolution of at least 1 minute during passes of Io's torus. Magnetometer provides pitch angle distribution information. 8 vectors/s cadence is adequate. 0.1 nT resolution and 0.1 degree orientation knowledge.	E11b. Particle and plasma instrument and magnetometer	3			
		E12.	Study the pickup and charge exchange processes in the Jupiter system plasma and neutral tori.	E12a. Measure pickup ions in the tens to hundreds of eV energy range and energetic ions in the tens to few hundred keV/nuc energy range.	E12a. Ion and neutral mass spectrometer and particle and plasma instrument	3			
				E12b. Image neutral tori (e.g., H, O, S) at the orbits of Io, Europa, Ganymede, and Callisto.	E12b. UV imaging spectrometer	4			
		E13.	Study the interactions between Jupiter's magnetosphere and Io, Ganymede, and Callisto (including characterize Ganymede's magnetic field).	E13a. Determine the trapped and precipitating fluxes of ions and electrons with energies between 10 eV and 10 MeV, 15° angular resolution or higher, ΔE/E=0.1, and time resolution of 1 minute or higher.	E13a. Magnetometer and particle and plasma instrument	3			
				E13b. Investigate the generation of Ganymede's aurora with UV imaging (0.1–0.35 microns) of Ganymede (at 0.3 nm spectral resolution) at 1 km spatial resolution and at cadences of a minute or longer.	E13b. UV imaging spectrometer	3			
				E13c. Investigate the modification of surface composition and structure on open vs. closed field line regions by imaging of Ganymede at FUV-NIR wavelengths (100–350 nm and 0.8–2.5 microns) at 1 km spatial resolution.	E13c. UV imaging spectrometer and Vis-IR imaging spectrometer	4			
				E13d. Determine the flux and composition of precipitating ions and electrons between energies of 10 eV and 10 MeV and 15° angular resolution, ΔE/E=0.1, and time resolution of at least 1 minute.	E13d. Magnetometer and particle and plasma instrument	3			
				E13e. UV and visible measurements at 1 min resolution of emission from moon magnetic footpoints in the Jovian auroral region.	E13e. UV imaging spectrometer and narrow-angle camera	2			
				E13f. Investigate effects of direct magnetospheric plasma, energetic particle, solar UV, and interplanetary dust interactions with the moon surfaces & atmospheres, search for hemispherical differences, and associated temporal variations with global UV-NIR measurements (0.1–3 microns) of hemispherical distributions of radiation products (sulfates, H_2O_2, O_2, CO_2) at 10 km resolution, and via repeated observations (timescale of months).	E13f. Particle and plasma instrument, UV imaging spectrometer, and Vis-IR imaging spectrometer	2			
		E14	Understand the structure, composition, and stress balance of Jupiter's magnetosphere.	E14a. Make continuous measurements of vector magnetic field (1 s resolution)	E14a. Magnetometer	3			
				E14b. Make continuous measurements of plasma and energetic charged particles (10 eV to 10 MeV), with full sky coverage and an angular resolution of 15°, ΔE/E=0.1, and 10 s time resolution or higher.	E14b. Particle and plasma instrument	3			

Origins	Evolution	Processes	Habitability	Life

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Does not address SI	Touches on SI	May address Partial SI	Definitely addresses Partial SI	May a Fu

…TER EUROPA ORBITER: TRACEABILITY MATRIX

…e Objective			Science Investigation	Measurement	Instrument	Jupiter System Science	EUROPA CAMPA… 1 Global Framewrk 1A	1B	2 Reg… 2A
…nd Europa in the …f the Jupiter	Plasma and magnetospheres	E15.	Determine how plasma and magnetic flux are transported in Jupiter's magnetosphere.	E15a. Make continuous measurements of vector magnetic field (1 s resolution).	E15a. Magnetometer	2			
				E15b. Make continuous measurements of plasma and energetic charged particles (10 eV to 10 MeV), with full sky coverage and an angular resolution of 15°, ΔE/E=0.1, and 10 s time resolution or higher.	E15b. Particle and plasma instrument	2			
	Jupiter atmosphere		Characterize the abundance of minor species (especially water and ammonia) in Jupiter's atmosphere to understand the evolution of the Jovian system, including Europa.	E16a. Measure the global distribution of water vapor humidity in the 2–8 bar region with 100 km spatial resolution. Use 5-micron imaging spectroscopy with spectral resolution R > 400.	E16a. Vis-IR imaging spectrometer	4			
				E16b. Measure the global distribution of gaseous ammonia with 100 km horizontal spatial resolution at 2–6 bars (5 micron spectroscopy, R>400) and 200 km resolution at 0.1–0.4 bars (10 micron spectroscopy, R>400).	E16b. Vis-IR imaging spectrometer	4			
				E16c. Measure the vertical distribution of stratospheric water, 1–300 mbar (sub-mm sounding from 100–3000 GHz), 1–20 mbar with far-IR (R>400) spectroscopy.	E16c. Sub-mm wave sounder	0			
				E16d. Measure the global distribution of gaseous water and ammonia in the 10–100 bar region using passive microwave radiometry at 1–6 cm wavelength, possibly using the telecom antenna as a receiver for 1–5-bar region.	E16d. Microwave radiometer	0			
				E16e. Measure the 3-D distribution of disequilibrium species in the 0.1–4.0 bar region: measure PH_3, CO, AsH_3, GeH_4 at 100 km resolution using 5 micron spectroscopy at R>400. Measure PH_3, NH_3 in 100–600 mbar region at 200 km resolution at 10 microns with R>400 or at 1.0–4.0 microns with R>400. Measure at p<250 mbar in UV spectra.	E16e. Vis-IR imaging spectrometer, thermal imager, and UV imaging spectrometer	3			
				E16f. Determine the distribution of aerosols with altitude, latitude and longitude; investigate single scattering albedos, column abundances, topography of upper cloud layers, particles size distributions, IR opacities. Monitor changes in aerosol distribution associated with variations in atmospheric state (temperature, composition). Perform observations at multiple phase angles.	E16f. Vis-IR imaging spectrometer, wide- and medium-angle camera, and UV imaging spectrometer	4			
		E17.	Characterize Jovian atmospheric dynamics and structure.	E17a. Global visible/near-IR dayside imaging at 30 km/pixel to characterize dynamics. Imaging should include repeated coverage of the same regions at ~2 hour intervals for cloud tracking (necessary to obtain winds). Wavelengths should include visible and/or near-IR continuum as well as one or more methane absorption band (e.g., 889 nm and other) to obtain vertical structure of winds and clouds. Imaging strategy must characterize behavior over a range of timescales, including short (1–3 days), medium (~1 month), and long (~1 year) timescale variability. Strategy ideally should involve global or near-global daily coverage for periods of weeks-to-months.	E17a. Wide/medium-angle camera and Vis-IR imaging spectrometer	4			
				E17b. Obtain global temperature maps (100 km resolution) for vertical temperature structure and horizontal gradients (for deriving thermal wind shears). Pressure ranges 1–10 mbar and 100–500 mbar for 7–250 micron spectroscopy, 5–300 mbar for sub-mm spectroscopy. Limb spectroscopy with 20–40 km vertical spatial resolution for vertical distribution.	E17b. Thermal imager and sub-mm spectrometer	1			
				E17c. Make repeated radio occultations to obtain vertical temperature profiles closely spaced in space and time (e.g., at the same latitude ±10 degrees, once every 2 weeks) to investigate wave propagation in the stratosphere and upper troposphere, in addition to investigating the temporal behavior of the Jovian ionosphere.	E17c. Two-band radio communication system with USO	4			
				E17d. Perform stellar and solar occultations over a wide range of latitudes to obtain high vertical resolution temperature structure and composition in the upper stratosphere (1 km at 20 K per measurement).	E17d. Vis-IR imaging spectrometer, thermal imager, and UV imaging spectrometer	2			
				E17e. Measure the 3-D distribution of stratospheric hydrocarbons and other molecules in the stratosphere, at 100 km spatial resolution with global coverage and spectral resolution R > 2000 in the mid-IR (8–16 microns) and FUV (110–200 nm). Limb spectroscopy with 20–40 km vertical spatial resolution for vertical distribution.	E17e. Mid-IR spectrometer and UV imaging spectrometer	3			
				E17f. Measure Jovian aurora on timescales of minutes, hours, and days at IR (0.8–2.5 microns) and UV (0.1–0.2 microns) wavelengths.	E17f. Vis-IR imaging spectrometer and UV imaging spectrometer	2			

0	1	2	3

…TER EUROPA ORBITER: TRACEABILITY MATRIX

…ence Objective		Science Investigation	Measurement	Instrument	SCIENCE VALU… Jupiter System Science	EUROPA CAMPAIGN… 1 Global Framewrk 1A	1B	2 Regional… 2A
…tand Europa in the …t of the Jupiter …	Rings	E18. Characterize the properties of the small moons, ring source bodies, and dust.	E18a. Conduct a comprehensive search for embedded moons within the ring system, down to a limiting size of ~100 m (~14th magnitude). Conduct multiple surveys of the ring region at low phase angles to ensure completeness of coverage. Each object should be detected at least ~20 times over a time frame of ~1 year to enable a precise determination of its orbit; astrometric precision of better than 30 km is required.	E18a. Narrow-angle camera with a clear or very broad-band filter	3			
			E18b. Search for km-sized moons throughout the Jovian system (from the rings to beyond the orbit of Callisto) with a detection threshold of ~1 km (~10th magnitude). This requires repeated, complete mosaics of the system taken at low phase angles and using a medium- or a wide-angle camera. After discovery, each previously unknown object should be targeted with a narrow-angle camera ~ 20 times over a time frame of ~1 year to provide a precise determination of its orbit. Astrometric precision of better than 30 km is required.	E18b. Wide-, medium- and/or narrow-angle cameras with a clear or very broad-band filter	3			
			E18c. Search for dust belts throughout the Jovian system (from the rings to beyond the orbit of Callisto) down to optical depths of ~10^{-9} (or reflectivities of ~10^{-8}). Emphasize high phase angles and edge-on viewing geometry to achieve the most stringent detection limits. Study any belts detected from at least 10 phase angles, ranging from less than 10 degrees to greater than 170 degrees, to constrain particle sizes. At a few phase angles, measure the color in the visual and near-IR for additional limits on size and composition.	E18c. Wide-, medium- and/or narrow-angle cameras with several very broad-band filters	3			
			E18d. Profile the radial structure of the entire ring system (from the inner halo to beyond the orbit of Thebe) down to a spatial resolution of ~10 km and a sensitivity to reflectivities of 10^{-8}. Obtain at least 10 phase angles from less than 10 degrees to greater than 170 degrees, and use several visual and near-IR broad-band filters. Requires a viewpoints at least a few degrees out of the ring plane.	E18d. Wide-, medium- and/or narrow-angle cameras with a clear or very broad-band filter (especially CH_4)	3			
			E18e. Determine ring and inner moon surface composition with a sensitivity to reflectivities of ~10^{-7}. Obtain this level of sensitivity in each of more than 200 spectral bands from the visual to beyond ~ 3 microns. Observe near backscatter to emphasize the surface composition of the larger embedded bodies in the system.	E18e. Vis-IR imaging spectrometer	2			
		E19. Identify the dynamical processes that define the origin and dynamics of ring dust.	E19a. Determine the ring's 3-D structure, including the vertical structure of the halo and gossamer rings, via imaging from a variety of viewing geometries. Requires complete mosaics of the system from Jupiter out to beyond the orbit of Thebe, with resolution of better than 100 km/pixel. Images of the faintest ring components must be sensitive to reflectivities below 10^{-8}. Images must be obtained at a variety of opening angles and phase angles in order to decouple the ring's variations depending on radius, vertical distance from the ring plane, and phase angle. Note that imaging of the halo along the boundary of Jupiter's shadow provides optimal vertical resolution.	E19a. Wide-, medium- and/or narrow-angle cameras with a clear or very broad-band filter (especially CH_4)	3			
			E19b. Identify and characterize time-variable phenomena, including clump formation and evolution, via repeated, complete rotational profiles of the main ring with a resolution of better than 100 km/pixel. Obtain at least 20 complete profiles, sampling a wide variety of time scales from ~ days to ~ 1 year.	E19b. Narrow-angle camera with a clear or very broad-band filter	3			
			E19c. Search for warps and asymmetries on scales of 10–30 km via imaging of the system from nearly and exactly edge-on perspectives. Encompass the entire region from the halo out to beyond the orbit of Thebe, using cameras that are matched to the spatial scales of each region.	E19c. Wide-, medium- and/or narrow-angle cameras with appropriate filters (especially CH_4)	3			

Origins	Evolution	Processes	Habitability	Life

SI = Science Investigation

0	1	2	3	4
Does not address SI	Touches on SI	May address Partial SI	Definitely addresses Partial SI	May ad… Full…

JEO Model Payload

ser Altimeter	LA
dio Science	RS
Penetrating Radar	IPR
y	
-IR Imaging Spectrometer	VIRIS
Spectrometer	UVS
and Neutral Mass Spectrometer	INMS
ermal Instrument	TI
rrow Angle Camera	NAC
le Angle Camera and Medium Angle Camera	WAC + MAC
d Particles	
gnetometer	MAG
ticle and Plasma Instrument	PPI

- Model payload is a proof-of-concept exam
  - Other instrument choices r viable
- Emphasizes accomplis Europa investigations
- Enables robust Jupiter science
- The final selected payl almost certainly be diffe

Capable model payload with a conservative approach

Model Payload

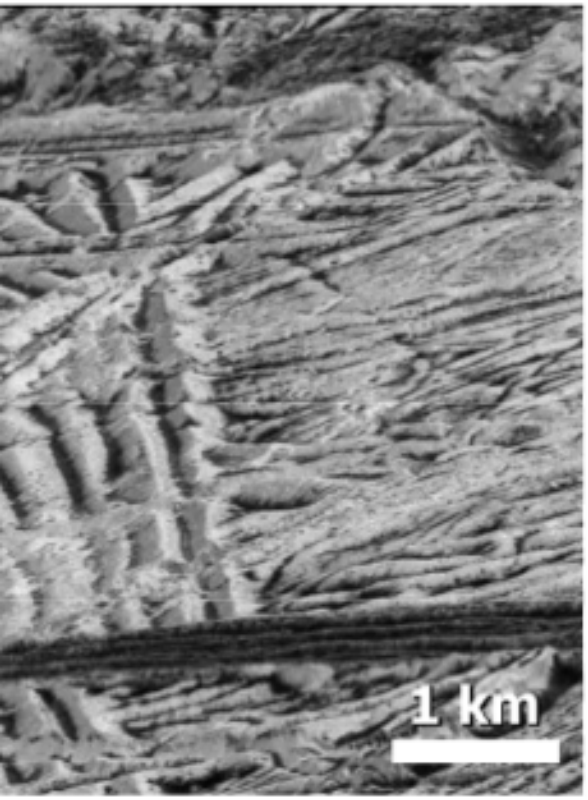
Team Investigations/Instruments	Characteristics (from 100 km altitude)
Ocean Team	
Laser Altimeter (LA)	Single-beam, 50 m spot; 1.064 µm
Radio Science (RS)	2-way Doppler with Ka translator; USO; X- & Ka-band via telecom subsystem
Ice Team	
Ice Penetrating Radar (IPR)	Shallow-mode 5 MHz & deep-mode 50 MHz with 1 and 10 MHz bandwidths, vertical depths of 3 and 30 km
Chemistry Team	
VIS-IR Imaging Spectrometer (VIRIS)	0.4 to >5.2 µm, 5 nm spectral resolution below 2.6 µm, and 10 nm above 2.5 µm; pushbroom with along-track scan mirror; 25 m resolution
UV Spectrometer (UVS)	70 – 200 microns; IFOV I mrad; scan system for stellar occultations; 100 m resolution
Ion and Neutral Mass Spectrometer (INMS)	1 – 300 daltons; FOV 10° x 40°
Geology Team	
Thermal Instrument (TI)	8 – 20 µm and 20 – 100 µm, 5 pixels cross-track, 250 m resolution
Narrow Angle Camera (NAC)	Panchromatic pushbroom plus nine color framing mode for OpNav; IFOV 0.01 mrad; 1 m resolution
Wide Angle Camera and Medium Angle Camera (WAC+MAC)	Wide-Angle: 3-color+panchromatic; IFOV of 1 mrad, pushbroom; Medium-Angle: panchromatic and 0.1 mrad, pushbroom modes
Fields and Particles Team	
Magnetometer (MAG)	Dual sensors; 10 m boom; 0 – 3000 nT
Particle and Plasma Instrument (PPI)	10 eV to 30 keV electrons and ions

(From Traceability Matrix, FO-1)	• Relationship of surface materials to geologic processes (B3c; C2a, C3c) • Effects of radiation environment (C3a) • Nature of exogenic materials (C4c) • Exposure age (D1f) • Recent activity (D2e)	vents (C1c) • Current activity through spatial and temporal variability of venting (D2b) • Effects of radiation, sputtering (C3b, C3e) • Relationship of surface materials to geologic processes (Imager; B3g; C2c; C3c, D2e) • Exposure age (Imager; D1f) • Nature of exogenic materials (Imager; C4d)	materials (C1b) • Effects of radiation, sputtering (C3d) • Nature of exogenic materials (C4b)	materials (C1b) • Effects of radiation, sputtering (C3d) • Nature of exogenic materials (C4b) • Recent activity (D2e)
Species of interest				
Identified	H_2O; CO_2, SO_2, H_2O_2, sulfate hydrates, CH compounds, CN compounds, O_2	• H, O (gas emission) • H_2O_2, SO_2 (solids)	• O_2 (~10^6 cm^{-3}); H_2; Na (~300 cm^{-3}); K; Cl+ (Atmosphere) • SO_2 (~1600 cm^{-3}); CO_2 (~700 cm^{-3}); H_2O (~10^5 cm^{-3}) (Surface)	• H_2O
Expected	HC, SH, SO, Fe^{2+}, S_8, HCHO, H_2S, $MgSO_4$, H_2SO_4, H_3O^+, $NaSO_4$, Na_2MgSO_4, CH_3OH, CH_3COOH	• OH, C, CO (gas emission) • H_2O (gas absorption)		• OH, C, CO (atmosphere) • H_2O (atmosphere)
Possible	$NaHCO$, $NaCO_3$, H_2CO_3, $MgCO_3$, $MgCl_2$, NaCl, OCS, HCN, OCN-, KOH, K_2O, SO_3, CH_2CO	• S, Cl, N (gas emission) • CO_2, SO_2, SO, O_3, hydrocarbons (gas absorption) • Water ice, salts, sulfates, acids, Tholins (solids)	• H_2O_2 (~200 cm^{-3}); sulfur, sulfate, carbon, carbonate, CN, organics, minerals	• CO_2, SO_2, SO, O_3, hydrocarbons salts, sulfates, acids, tholins • Sputtered species: e.g., Mg-sulfate ⇒ $MgSO_3$, MgO_2, MgS, MgO, Mg
Detection Limits	Surface: 0.1 to 10% abundance, varying with species and environmental conditions	Atmosphere: $1x10^{15}$ cm^{-2} H_2O column	~ 200 cm^{-3}	Atmosphere: Column abundance 10^{-3} to 30% relative to H_2O vapor for many possible species
Measurement requirements				
Spectral/mass range	0.4 - >5 µm (desired) ~1.2 - 4.8 µm (floor)	EUV (60-110 nm); FUV (110-200 nm); NUV (200-350 nm) (desired); FUV (110-200) (floor)	1 to ≥300 amu	IR: 5-50 µm mm: 110 ±20 GHz; 560 ±30 GHz,
Spectral/mass resolution	(Grating) 0.4-2.5 µm: 5 nm; 2.5-≥5 µm: 10 nm (desired) 1.2-4.8 µm: 10 nm (floor)	0.5 nm EUV, FUV; 3 nm NUV	• Mass resolution: Dm/m ≥500 • Pressure range: 10^{-6}-10^{-17} mbar • Sensitivity: 10^{-5} A/mbar	IR: 1-5 cm^{-1} mm: 100-250 kHz
Spatial resolution	25 m/pixel from 100 km (0.25 mrad) (desired) 100 m/pixel (1 mrad) (floor)	1 mrad/pixel (imager)	100-200 km (comparable to orbital altitude)	100-500 m
SNR	≥128 (0.4-2.6 microns), ≥32 (2.6-5 microns)	≥5	N/A	>50
Coverage	Global	Occultation profiles at ≤25 km	Regional	Regional

2.4-10. Hypothesis Tests to Address Selected Key Questions Regarding I
ry and Composition

Example Hypothesis Questions	Example Hypothesis Tests
here endogenic organic materials on pa's surface?	Examine surface and sputtered materials for absorptions and masses co with organic materials, especially in regions most protected from radiatio correlate distributions to likely endogenic materials.
emical material from depth carried to the ace?	Determine whether hydrates and other minerals that may be indicative o subsurface ocean are concentrated in specific geologic features, and co evidence for subsurface liquid water at these locations.
adiation the principal cause of alteration of pa's surface materials through time?	Determine the suite of compounds observable on Europa's surface, corr the local radiation environment and to the relative age of associated surf features.
naterials formed from ion implantation play a r role in Europa's surface chemistry?	Determine the distribution of sulfur-rich and other compounds and correl inferred implantation rates and the chemistry of material escaping from I

IR



3. Galileo SSI image of ridged
Europa at 6 m/pixel horizontal
he lineae in the central portion of
ve central troughs with deposits
rial ~100 m wide, but with bright,
icy ridges and walls close by.
ervations with at least 100 m
lution would be needed to
measure the bright and dark
ch measurements would address
questions regarding the compo-
gins of the dark material.

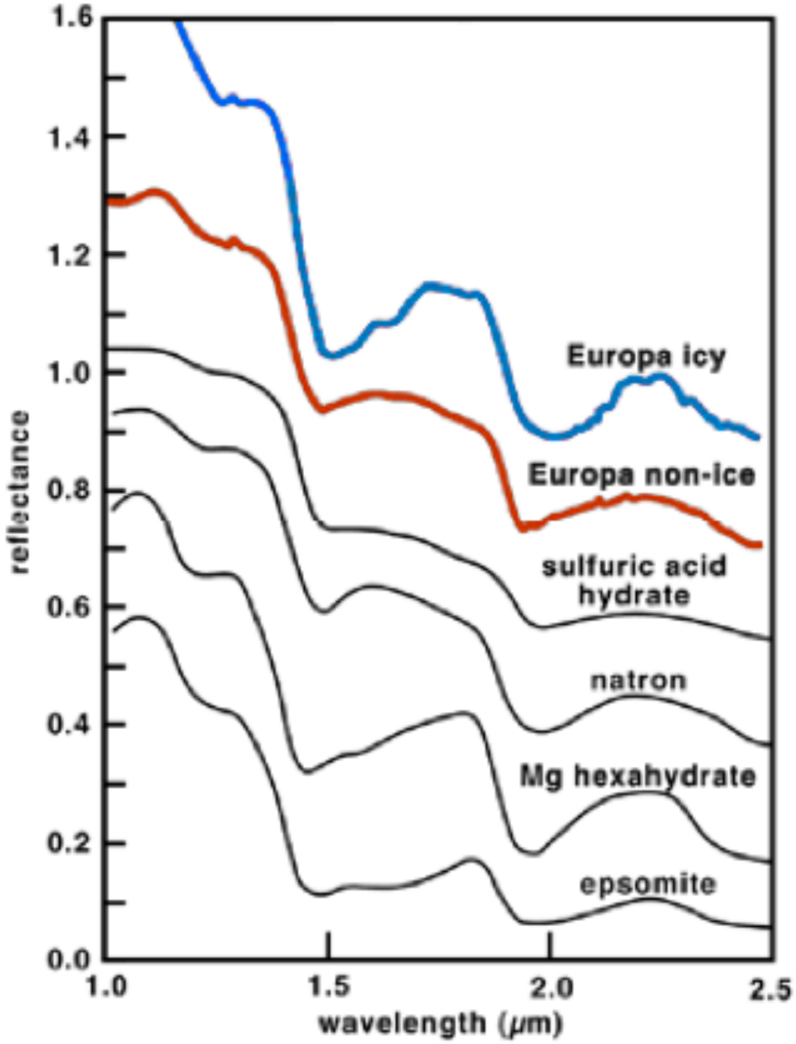


Figure 2.3-5. *Reflectance spectra of hydrated materials on Europa. Candidate materials for Europa's non-ice component include sulfuric acid hydrate ($H_2SO_4 \cdot nH_2O$) and various hydrated sulfate and carbonate salts [*McCord et al. 1999, 2002*].*

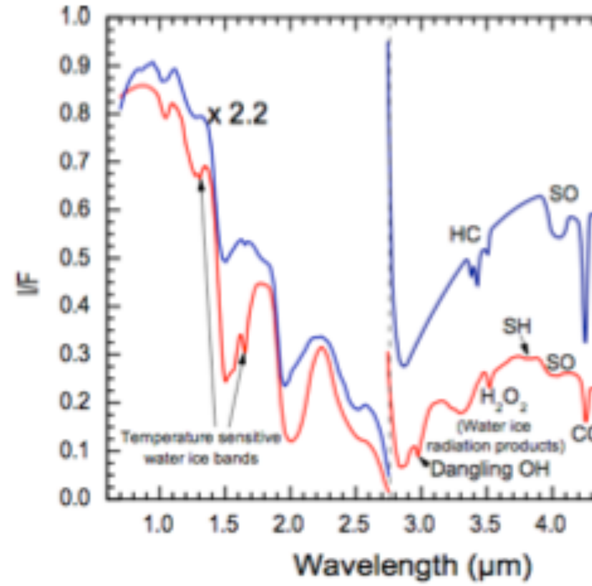


Figure 2.4-7. *Notional reflectanc
icy (lower) and non-ice (upper)
Europa (based on observations o
observed on other Jovian an
satellites) at 6 nm spectral resolut
5 μm spectral range. A variety
and molecules have been identifie
from the Galileo results. The sp
here are composites to illustrate t
variety of features found or ex
detailed spectral structure o
hydrates at high spectral reso
Figures 2.4-5–6) is not fully repr
The non-ice spectrum is scaled by
ice spectrum, and the 2.8–5 μm r
are scaled by 10 over the shorte
range. [Figure courtesy Tom McC*

INMS

4-8. Water Vapor Components, Isotopes, in Europa's Atmosphere To Be Measurable by INMS

Mass	Expected partial pressure (mbar) at 200 km
2.01	$>10^{-10}$
31.99	10^{-10}
15.9	10^{-12}
18.0	5×10^{-13}
33.9	2×10^{-13}
32.9	7×10^{-14}
3.02	$>10^{-14}$?
19.0	2×10^{-16}

***Table 2.4-9.** Calculated Densities of Sp Europa Surface Materials at 100*

Species	Predicted Densities @ 1
Na	60–1600 cm^{-3}
CO_2	170–580 cm^{-3}
SO_2	290–1800 cm^{-3}
H_2O_2	150–3000 cm^{-3}
L-Leucine (Mass 131)	$3 \times 10^6 F$ cm^{-3} where F is number fraction a

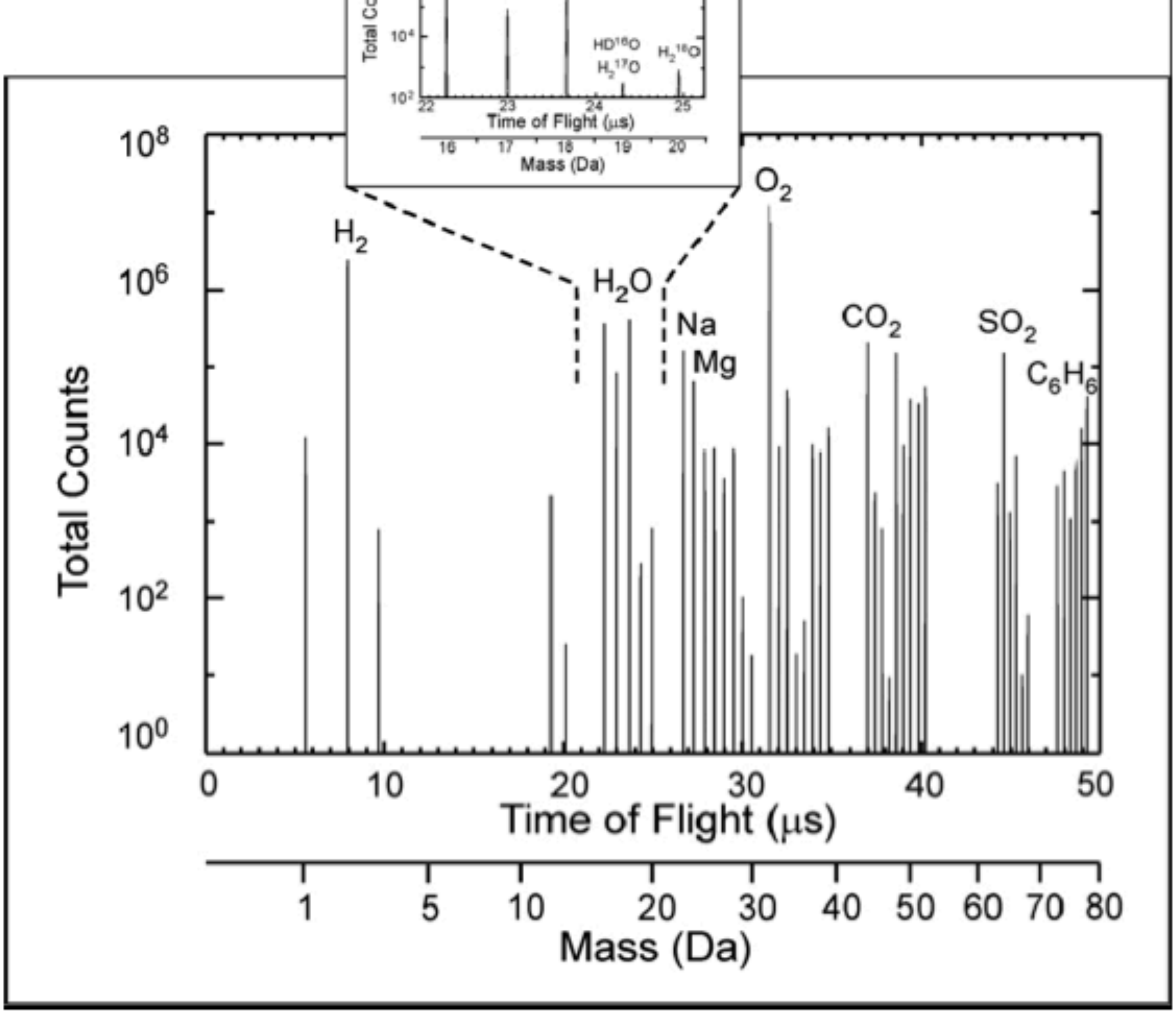


Figure 2.4-11. *Simulated mass spectrum of the anticipated Europa Ion Neutral Mass Spectrometer (INMS) results for neutral species at an orbit altitude of 100 km. The simulation is based on a surface composition given by 60% sulfuric acid hydrate: $H_2SO_4 \cdot 8H_2O$, 20% mirabilite: $Na_2SO_4 \cdot 10H_2O$, 10% hexahydrite: $MgSO_4 \cdot 6H_2O$, 5% epsomite: $MgSO_4 \cdot 7H_2O$, and 4% CO_2 combined with the modeled atmospheric composition and 1% heavy organic represented in this case by benzene (but similar for any heavy organic that may be present). This surface composition has been used as an input into a Monte Carlo ion sputtering/thermal*

: Sulfur in many forms

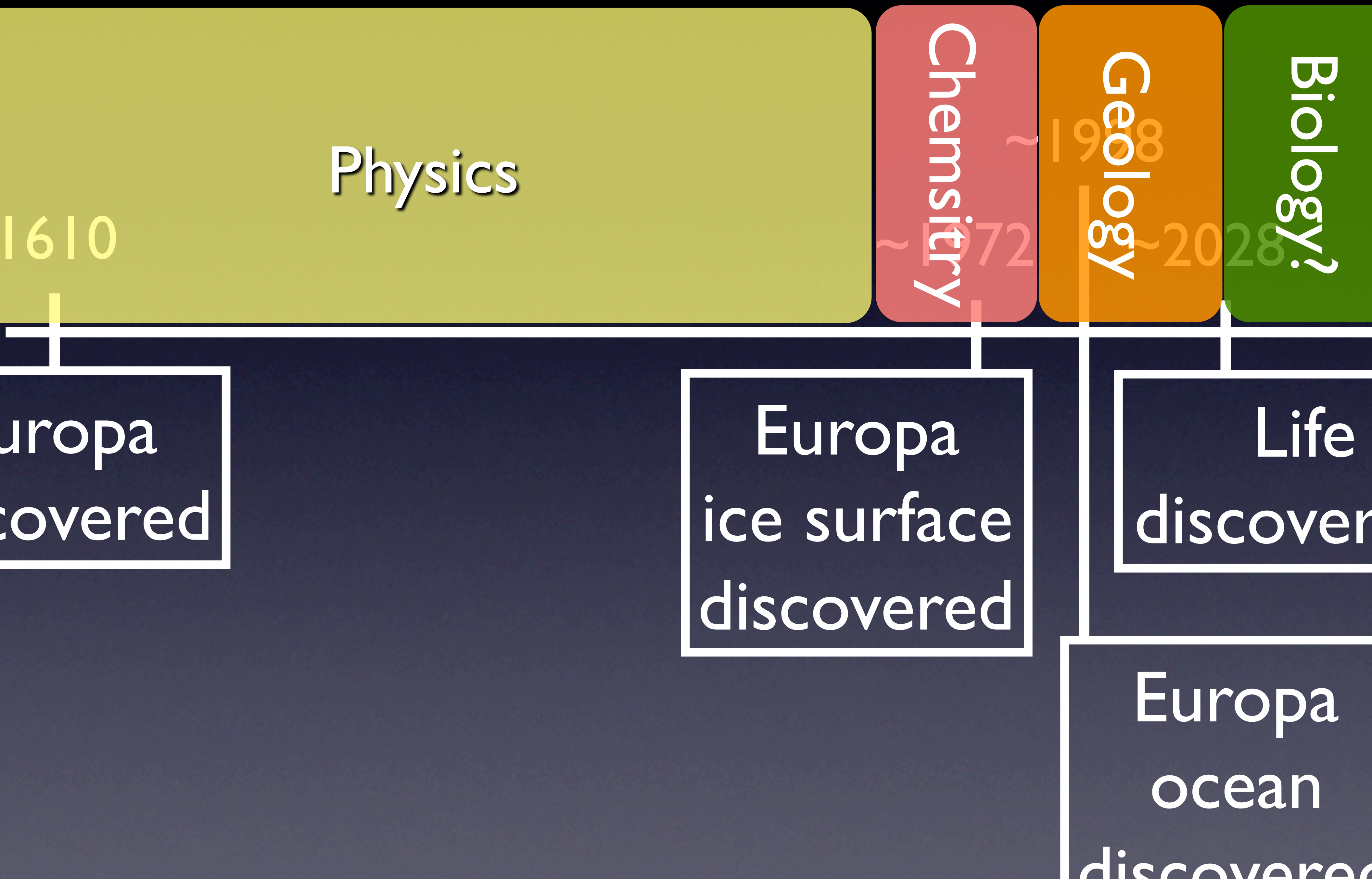
: CO_2, Oxidants, Oxidized sulfur, no
reductants

: C-H, C≡N, oxidants

: C-H, C≡N

MAPPIN

Europa/EJSM Astrobiology



Key Websites:

- Outer Planets Flagship Mission
  - opfm.jpl.nasa.gov
- Outer Planets Assesement Group
  - www.lpi.usra.edu/opag/
- Lander Workshop, Moscow, Russia
  - http://www.iki.rssi.ru/conf/2009elw/