

THE EUROPA MULTIPLE-FLYBY MISSION: SYNERGISTIC SCIENCE TO INVESTIGATE

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Introduction: Europa is a complex geophysical and geochemical system, illustrating a wide range of processes relevant to understanding the Solar System's ocean worlds, including: ice tectonics, cryovolcanism, impact cratering, mass wasting, convection, tidal deformation and heating, surface-plasma chemical and physical interactions, exospheric processes, magnetospheric processes, and possibly plume dynamics. It is also a key target for astrobiological exploration because it may contain the so-called "ingredients" for life: liquid water, bioessential elements, and chemical energy; these ingredients may have persisted since early Solar System history.

Mission Goal, Objectives, and Investigations: The overarching science goal of the Europa mission is to explore Europa to investigate its habitability. Following from this goal are three Mission Objectives (bold roman numerals), from each of which flow several Mission Investigations (numbered items), as listed below. Also listed (abbreviations) are each of the instruments, plus Gravity and Radiation science, that synergistically address these Investigations and Objectives, which are defined and discussed in more detail in the next section. Folded into these three objectives is the desire to search for and characterize any current activity, notably plumes and thermal anomalies.

I. Ice Shell & Ocean – Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange.

1. Characterize the distribution of any shallow subsurface water and the structure of the icy shell (*EIS, REASON*);
2. Determine ocean salinity and thickness (*ICEMAG, MISE, PIMS, SUDA*);
3. Constrain the regional and global thickness, heat-flow, and dynamics of the ice shell (*E-THEMIS, EIS, Gravity, ICEMAG, PIMS, REASON*);
4. Investigate processes governing material exchange among the ocean, ice shell, surface, and atmosphere (*EIS, ICEMAG, MASPEX, MISE, REASON, SUDA*).

II. Composition – Understand the habitability of Europa's ocean through composition and chemistry.

1. Characterize the composition and chemistry of endogenic materials on the surface and in the atmosphere, including potential plumes (*EIS, Europa-UVS, ICEMAG, MASPEX, MISE, PIMS, REASON, SUDA*);
2. Determine the role of the radiation and plasma environment in creating and processing the atmosphere and surface materials (*EIS, Europa-UVS, MASPEX, MISE, PIMS, Radiation, REASON, SUDA*);
3. Characterize the chemical and compositional pathways in the ocean (*EIS, ICEMAG, MASPEX, MISE, SUDA*).

III. Geology – Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities.

1. Determine sites of most recent geological activity, including potential plumes, and characterize localities of high science interest and potential future landing sites (*E-THEMIS, EIS, Europa-UVS, MASPEX, MISE, PIMS, Radiation, REASON, SUDA*);
2. Determine the formation and three-dimensional characteristics of magmatic, tectonic, and impact landforms (*EIS, REASON*);
3. Investigate processes of erosion and deposition and their effects on the physical properties of the surface (*E-THEMIS, EIS, Europa-UVS, PIMS, Radiation, REASON, SUDA*).

Exploring Europa Through Synergistic Investigations: To address the science requirements of Europa mission, a highly capable suite of nine instruments was selected by NASA to comprise the mission's scientific payload. This payload includes five remote-sensing instruments that observe the wavelength range from ultraviolet through radar, and four *in situ* instruments that measure fields and particles. In addition, gravity science can be achieved via the spacecraft's telecommunication system in combination with radar altimetry. Moreover, valuable scientific data could come from the spacecraft's planned radiation monitoring system.

Europa Ultraviolet Spectrograph (Europa-UVS). Operating at ultraviolet wavelengths, Europa-UVS is designed to interrogate the composition and chemistry, sources and sinks, and structure and variability of the tenuous Europa atmosphere. In addition, Europa-UVS data can permit better understanding of the plasma environment, notably the energy and mass flow into Europa's atmosphere, neutral cloud, and plasma torus. Europa-UVS can be used to search for and characterize the distribution, structure, composition, and variability of any active plumes. Europa-UVS data can constrain surface composition and microphysics and relationships to endogenic and exogenic processes.

Europa Imaging System (EIS). Composed of a narrow- and wide-angle camera with stereo and color imaging capability, EIS can map Europa globally at 100 m resolution and image almost any point on the surface at better than 20 m resolution, providing constraints on the formation of surface features. Very high-resolution imaging (meter-scale or better) addresses small-scale regolith processes and can characterize sites amenable for a future lander. Distant imaging would search for active plumes and provide a means to characterize the ice shell through modeling of the limb shape.

Mapping Imaging Spectrometer for Europa (MISE). Operating in the 0.8–5.0 μm wavelength range, MISE data can be used to assess the habitability of Europa's ocean through examination of the inventory and distribution of surface compounds, including any biologically relevant deposits. MISE data can be used to identify and map the distributions of organics, salts, acid hydrates, water ice phases, altered silicates, radiolytic compounds, and warm thermal anomalies at global, regional, and local scales on Europa.

Europa Thermal Imaging System (E-THEMIS). The E-THEMIS investigation permits detection and characterization of thermal anomalies that may indicate recent activity. Thermal inertia information derived from E-THEMIS temperature measurements can be used to characterize regolith particle size, block abundance, and subsurface layering. This investigation can also aid characterization of any active plumes.

Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON). REASON data will permit mapping of Europa's vertical crustal structure and the search for subsurface water. REASON data can be used to study the distribution of shallow subsurface water and to search for the deeper ice-ocean interface, while characterizing the ice shell's global thermophysical structure. REASON data can provide insight regarding material exchange among the ocean, ice shell, surface, and atmosphere. Solid body geophysical measurements can constrain the amplitude and phase of the tides. Derived dielectric and other physical

properties support characterization of the scientific value and hazards of sites for a potential future lander.

Interior Characterization of Europa using Magnetometry (ICEMAG). ICEMAG can measure magnetic fields to infer magnetic induction at multiple frequencies. This, in turn, would permit the location, thickness, and salinity of Europa's ocean to be estimated. In addition, ICEMAG data can be used to identify sources and loss processes of Europa's atmosphere, coupling of Europa to Jupiter's ionosphere, and coupling of any plumes to flowing plasma.

Plasma Instrument for Magnetic Sounding (PIMS). PIMS data can be used to identify plasma contributions to Europa's magnetic field and to understand mechanisms of weathering and release of material from Europa's surface into the atmosphere. PIMS data can facilitate an understanding of how Europa influences its local space environment and Jupiter's magnetosphere.

MAss Spectrometer for Planetary Exploration /Europa (MASPEX). MASPEX can perform *in situ* analysis of neutral gases to determine the distribution of major volatiles and key organic compounds in Europa's exosphere and possible plumes, and their association with geological features. MASPEX data can be used to derive the relative abundances of key compounds, to constrain the chemical conditions and biological suitability of Europa's ocean including isotopologues, radiolysis products, and organic molecules.

SURface Dust Analyzer (SUDA). The SUDA investigation can map Europa's surface composition by direct compositional analysis of particles ejected by micrometeoroid impacts. SUDA data can be used to characterize the alteration of Europa's surface via exogenous dust and to determine the composition of particles in active plumes to determine ocean properties.

Gravity science. Using the spacecraft telecommunication system, gravity measurements can be used to characterize Europa's time-varying gravitational tides. Combined with altimetric data from REASON, these geophysical measurements can provide confirmation of the existence of Europa's subsurface ocean.

Radiation. The spacecraft's planned radiation monitoring system could be used to measure the mission-integrated radiation dose from high-energy particles, and to derive a crude estimate of the electron energy spectrum as a function of spacecraft position. Such assessments can contribute to understanding the particle environment near Europa and the relation to surface compositional and physical effects.

Taken together, the Europa mission's robust investigation suite can be used to test hypotheses and enable discoveries relevant to the interior, composition, and geology of Europa, thereby addressing the potential habitability of this intriguing ocean world.