Science Objectives from Europa Orbit

Europa Focus Group
(Modifications of OPAG Europa Subgroup Objectives)
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Goal:

Explore Europa and Determine its Potential for Life

Nearly 400 years after Galileo Galilei's discovery of Jupiter's moons advanced the Copernican Revolution, one of these moons, Europa, has the potential for discoveries as profound. Europa's icy surface is believed to hide a global subsurface ocean with volume nearly three times that of Earth's oceans. The moon's surface is young, with a nominal age of 60 million years, implying that it is most likely geologically active today. The primitive materials that nourish life have rained onto Europa throughout solar system history, are created by radiation chemistry at its surface, and may pour from vents at the ocean's deep bottom. On Earth, microbial extremophiles take advantage of environmental niches arguably as harsh as within Europa's subsurface ocean. If the subsurface waters of this Galilean moon are found to contain life, the discovery would spawn another scientific revolution, this time in our understanding of life in the universe.

The potential for habitability of Europa has been revealed in recent years through spectacular data from the Galileo spacecraft. Though an ocean beneath Europa's surface ice was once thought to be a remote possibility, the combination of geological, gravitational, and magnetic field observations made by the Galileo spacecraft make it appear quite likely that liquid water exists beneath Europa's icy surface today. However, the Galileo spacecraft was not designed to characterize Europa's ocean and ice shell. Thus, new objectives arise for the exploration of Europa, and to determine its potential to support microbial life. Although it is now recognized that water may exist within several of the solar system's icy satellites, Europa's relatively thin ice shell and potentially active surface-ocean exchange elevate its priority for astrobiological exploration. A Europa mission is the first step in understanding the potential for icy satellites as abodes for life.

The following set of six science objectives are recommended as guiding a mission to explore Europa and determine its potential for life. Each is considered part of the science floor, and all are intended to be of equal importance.

Objectives:

- **Characterize the ocean through its effects on potential fields and its dynamic relationship with the ice shell.**
- **Characterize processes operating within the ice shell, and the nature of ice-ocean exchange.**
- **Determine surface compositions and chemistry, especially as related to habitability.**
- **Understand the formation of surface features, including sites of recent or current activity, and identify candidate sites for *in situ* exploration.**
- **Characterize the magnetic environment and moon-particle interactions.**
- **Determine how the components of the Jovian system operate and interact, leading to potentially habitable environments in icy moons.**

Each of these objectives implies a set of sub-objectives. Here each objective is elaborated upon, and its sub-objectives are enumerated in roughly priority order.

- **Characterize the ocean through its effects on potential fields and its dynamic relationship with the ice shell.**
    1. Determine the amplitude and phase of the gravitational tide.
    2. Determine the induction response from the ocean over multiple frequencies.
    3. Characterize surface motion over the tidal cycle.
    4. Determine the amplitude of libration.

Determining the nature of Europa's ocean, including the fundamental confirmation of its existence, can be achieved by observing its effects on potential fields and the dynamics of the overlying ice shell. To achieve this, it is essential that multiple complementary approaches be taken. A comprehensive study of the ocean and ice shell would consist of potential field (gravitational and magnetic) and geodetic analyses based on orbital measurements. Constraints on the thickness and rigidity of the ice shell can be obtained from orbit using measurements of the long wavelength topography and gravity field, amplitude and phase of the electromagnetic response, and librations of the surface. Higher resolution gravity and topography data can reveal variations in density within the ice shell and may be sensitive to topography at the bottom of the ocean. Observation of Europa's electromagnetic induction signature over time scales of days to weeks may be able to constrain the thickness of the ocean layer. These methods should be combined with active electromagnetic sounding of the ice shell, described below. Instruments on the surface could make measurements that complement and enhance those made from orbit, as well as unique measurements (such as acoustic sounding) that could directly address this objective.

- **Characterize processes operating within the ice shell, and the nature of ice-ocean exchange.**
    1. Characterize the distribution of any shallow subsurface water.
    2. Search for an ice-ocean interface.
    3. Correlate surface features and subsurface structure.
    4. Characterize the physical properties of the regolith and possible links to the interior.

There are strong scientific reasons for studying the near-surface physical properties and sub-surface structure of Europa's shell. Because the dielectric losses in very cold ice are low, yet highly sensitive to increasing temperature and water/impurity content, much can be learned through orbital electromagnetic sounding of the ice shell, especially when coupled to observations of surface landforms. In particular, the sub-surface signatures of ongoing or relatively recent upwelling of liquid water or brines would identify areas for *in situ* exobiological exploration or more focused orbital studies. In addition, the implications for direct exchange between the ocean and the overlying ice would be significant if a shallow ice/ocean interface were detected. Similarly, the lack of a shallow interface would test hypotheses regarding indirect exchange with any ocean through the convective movement of deep ductile ice into the cold brittle shell. The presence of major cracks, faults, and topographic anomalies observed at the surface, when correlated with subsurface structures, can provide critical information on tidal response, including localized heating, the magnitude of tectonic stress, and associated strain release. Variations of the physical properties of the near-surface ice may arise due to relative age differences, tectonic deformation, mass wasting, or impact gardening. An intimate knowledge of these shallow physical properties and their stress, strain, and fracture context will be essential for understanding any liquid water or ductile ice migration in the shallow subsurface.

- **Determine surface compositions and chemistry, especially as related to habitability.**
    1. Characterize surface organic and inorganic chemistry.
    2. Relate compositions to geological processes, especially communication with the interior.
    3. Determine the radiation effects on surface materials.
    4. Characterize exogenic material associated with the Jovian plasma.
    5. Characterize magnetospheric sputtering interactions with the surface.
    6. Search for compositional indicators of past or present life.

The overall goal of exploring Europa and determining its potential for life requires extensive high-resolution compositional mapping of the surface. Remote sensing over a range of wavelengths will provide vital insight into the distribution of surface materials and their chemical nature. Determining composition will constrain the chemistry of Europa's subsurface ocean, and its potential habitability. It is possible that chemical signs of life, or potentially organic materials, could be identified. Compositional remote sensing allows understanding of exogenic and endogenic species on Europa, and their geologic and chemical relationships. Exogenic processes such as sputtering and implantation of species from the Jovian plasma can have profound effects of the surface composition and chemistry, including the creation of new chemical species. The relationship between charged particle bombardment and surface materials must be thoroughly investigated to understand the implications for the survivability of organic materials. Compositional maps may reveal correlations between surface materials and geological features that suggest relationships between the surface and subsurface layers. The transfer of materials--particularly organic species, acids, salts, and oxidants--between the surface and the interior has important implications for past and present habitability, especially within a subsurface ocean. In particular, regions of probable recent geologic activity are key regions to look for evidence of communication between the surface and interior, and a thorough grasp of surface chemistry in these regions is imperative.

- **Understand the formation of surface features, including sites of recent or current activity, and identify candidate sites for *in situ* exploration.**
    1. Characterize magmatic, tectonic, and impact features.
    2. Search for areas of recent or current geological activity.
    3. Investigate global and local heat flow.
    4. Assess surface ages.
    5. Assess processes of erosion and deposition.

Remote sensing observations of the surface will improve understanding of Europa's geological processes, constraining how the satellite evolved and the relationship between the icy surface and the subsurface ocean. Geological mapping constrains how surface features, whether through fracturing, icy volcanism, or impact cratering. This will provide constraints on models of

Europa's evolution and current state, including the action of tides and the possible role of a subsurface ocean in creating surface features. The size-frequency distribution of impact craters enables surface age to be estimated, and their shapes yield clues as to the character and thickness of Europa's ice shell during their formation. Orbital measurements of surface temperature can also help us understand how, and where, Europa loses its heat. Remote sensing permits an understanding of the small-scale processes occurring on the surface, such as landslides, sublimation and deposition of ice, sputtering by charged particles, and micrometeorite bombardment. Remote sensing investigations can locate sites that might be active or have been recently active, and that may have recently communicated with the subsurface. This information will help us to link Europa's surface geology to subsurface processes, the role of an ocean, and whether and where Europa is active today. It will also identify the most promising sites for *in situ* exploration, to best characterize Europa's potential for life.

- **Characterize the magnetic environment and moon-particle interactions.**
    1. Characterize the magnetic environment at multiple frequencies.
    2. Determine the structure and dynamics of the ionosphere and neutral atmosphere.
    3. Characterize relationships between the magnetic field and plasma.
    4. Investigate the deep interior.
    5. Characterize the radiation environment.

Observation of an electromagnetic induction signature from Europa at the synodic rotation period of Jupiter provides the primary evidence of a current-day ocean within Europa. The exospheric environment, reflecting composition of the sputtered surface, is a product of the moon/plasma interaction. If there is deep vertical transport of materials from surface to the ocean, then oxidants and other radiolytically generated chemicals could be critical in the evolution and sustenance of life forms within the ocean and at the ice-ocean boundary. Because field and particle environments are intimately connected, an integrated set of magnetic field, plasma, and energetic particle investigations in the vicinity of Europa are required to address science goals in two broad areas. In the area of surface and exospheric studies, the objectives are to determine the effects of the field, plasma, and energetic particle environment on Europa's surface, quantify plasma-dust-surface interactions, and characterize the satellite's ionosphere and atmosphere. In the area of geology and geophysics, the goals are to characterize the liquid ocean, investigate subsurface geology, and probe the deep interior (rocky mantle and iron core) of the moon from inversion of long period electromagnetic waves (many weeks to months). The magnetic environment is profoundly affected by the local production of charge particles and by currents generated when plasma interacts with Europa. Similarly, charged particle processes such as ion sputtering from the surface, aurora generation from impacting particles, and the shielding of the electric field around Europa are affected by the strength and configuration of the local magnetic field. An integrated set of magnetic field, plasma, and energetic particle measurements is required to achieve each of these objectives. Finally, a better understanding of the radiation environment is required to quantify its long term effects on organic and inorganic surface materials and on future spacecraft and lander systems that would be operating near or on Europa.

- **Determine how the components of the Jovian system operate and interact, leading to potentially habitable environments in icy moons.**

1. Determine the nature and history of the internal heat sources and interior evolution of the Galilean satellite system.
2. Investigate the geological processes and surface evolution of the Galilean satellite system.
3. Study the Jovian system as a model for other potentially habitable planetary systems.

Europa cannot be understood if studied in isolation, as it is intimately linked to the rest of the Jovian system. Resonance with Io and Ganymede maintains Europa's eccentric orbit, which induces the tidal heating that is sufficient to maintain an ocean within Europa, and which could power life-supporting hydrothermal vents. The orbital and thermal evolution of the three resonant Galilean satellites may be intimately linked. Comparative evolution of the geological processes, cratering histories, compositions, and interior structures of the Galilean satellites provides a deeper understanding of Europa and its potential for life. Europa's parent planet Jupiter, its sibling Galilean moons, and rings, dust, gas, particles and fields in the Jupiter system influence each other in many complex ways, and provide the context that is necessary to properly understand Europa, including its general implications for potentially habitable environments in icy moons. Jupiter's elemental abundance ratios help determine the nature, distribution, and history of volatile and organic compounds in the Jovian system; Jupiter’s atmosphere serves as input to the magnetosphere; and the dynamics of Jupiter’s atmosphere and magnetic field provide insight into the giant planet's deeper structure. Jupiter’s ring particles and magnetosphere interact with Europa and the other Galilean moons through particle bombardment, which modifies their surface chemistry, produces tenuous atmospheres and ionospheres, and produces gas and dust; particle bombardment is generally destructive to organic material, but could be a major source of energy for possible habitats in Europa's ocean. Jovian auroral processes are linked to the interplanetary solar wind and field-aligned current flow around the Galilean moons. The induced and intrinsic magnetic fields of the Galilean moons reveal information about their interiors, including the presence of subsurface oceans, placing Europa's interior structure into the context of the other Galilean satellites. The interiors, surfaces, atmospheres, and magnetospheres of the Galilean satellites, along with the properties and dynamics of the greater Jovian system, provide the context critical to understanding Europa. By studying the Jupiter system as a whole, we better understand the type example for habitable planetary systems within and beyond our solar system.