EPSC Abstracts
Vol. 13, EPSC-DPS2019-366-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Investigations of Moon-Magnetosphere Interactions by the Europa Clipper Mission

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1. Introduction

The influence of the Jovian space environment on Europa is multifaceted, and observations of moon-magnetosphere interaction by the Europa Clipper will provide an understanding of the satellite's interior structure and compositional makeup among others. The variability of Jupiter's magnetic field at Europa induces electric currents within the moon's conducting ocean layer, the magnitude of which depends on the ocean's location, extent, and conductivity. Europa is also embedded in a flow of corotating plasma, which continuously impacts and sputters the surface to produce the moon's atmosphere. In addition, micrometeorite impacts eject particles of the surface to wrap Europa in a cloud of dust. The neutral atmosphere is readily ionized by energetic particles to produce an ionosphere, which gives rise to current systems electromagnetically connecting Europa to Jupiter. The Europa Clipper mission will observe the causes and effects of Europa's interaction with its space environment using a suite of in-situ and remote-sensing instruments. We present the highlights of the moon-magnetosphere interaction science we seek to unravel with the Europa Clipper mission and the primary investigations involved in these studies.

2. Relevant Investigations

2.1 Europa Clipper Magnetometer

In March 2019, NASA directed that the Interior Characterization of Europa using Magnetometry (ICEMAG) be terminated in favour of a facility-managed instrument. The facility magnetometer, referred to as the Europa Clipper Magnetometer (ECM), will measure magnetic fields generated by currents induced in Europa's subsurface ocean and the electromagnetic coupling of the moon to Jupiter. Jupiter's tilted dipole magnetic field and Europa's eccentric orbit expose the moon to time-varying magnetic fields inducing eddy currents in the ocean. By measuring the induced field response at multiple frequencies, the ice shell thickness and the ocean layer thickness and conductivity can be uniquely determined. The ECM consists of four fluxgate sensors mounted on a 5-m-long boom and a control electronics hosted in a vault shielding it from radiation damage. The use of four sensors allows for dynamic removal of higher-order spacecraft-generated magnetic fields on a boom that is short compared with the spacecraft dimensions. At the time of writing of this abstract, the technical capabilities of the new ECM configuration have yet to be established.

2.2 Plasma Instrument for Magnetic Sounding

The Plasma Instrument for Magnetic Sounding (PIMS) will measure ions and electrons in Europa's ionosphere to quantify magnetic fields associated with electric currents driven by dynamic pressure gradients, which are produced by the interaction of corotating Jovian plasma with Europa and its neutral atmosphere. PIMS will further measure the particle population precipitating onto Europa to model surface sputtering rates and constrain the effects of space weathering. In addition, PIMS will characterize the distribution of electrons carrying field-aligned currents coupling Europa to Jupiter's ionosphere. The PIMS instrument consists of two sensors each hosting two Faraday cups with a 90° field of view. The instrument measures electrons and ions with energies of up to 2 keV and 7 keV/q, respectively, with an energy resolution of <15% and a temporal resolution of 1−4 s. From the energy distribution functions, the ion density, temperature, and velocity as well as the electron energy and temperature can be inferred. The plasma observations are complemented with measurements of energetic particles up to 40 MeV by the engineering Radiation Monitor, which consists of a charge monitor stack and eight dosimeters distributed around the spacecraft.

2.3 Mass Spectrometer for Planetary Exploration

The MAss Spectrometer for Planetary Exploration (MASPEX) measures trace neutral species to determine the composition of Europa's atmosphere. The atmosphere is produced by particles sputtering off the surface, is augmented by possible contributions from plumes, and is altered by radiolysis. Species expected to be abundant are H_2O, H_2, O_2, and CO_2, and likely anticipated organic compounds are CH_4, C_2H_2, C_2H_4, C_2H_6, HCN, and CH_3OH. MASPEX will determine the distribution of major volatiles and key organic compounds with respect to latitude and longitude, altitude, solar local time, and will distinguish endogenic and exogenic sources. MASPEX is a multi-bounce time-of-flight mass spectrometer for species with atomic mass ranging from 2 to 500 u. The instrument's high mass resolution $m/\Delta m$ of up to 17,000 enables measurement of individual fragment ions generated by electron impact ionization of parent molecule. MASPEX is also equipped with a cryotrap for sample storage and analysis of trace species in an operational environment that is better suited than that encountered during the Europa flybys.

2.4 Surface Dust Analyzer

The SUrface Dust Analyzer (SUDA) will map the chemical composition of particles ejected from Europa's surface by hypervelocity impacts of micrometeoroids. The dust particles have a typical size of 0.5−1 μm and exhibit a near isotropic distribution and only weak temporal variations. Small fluctuations are expected from variability of exogenous sources, resulting, e.g., from the orbital motion of sources on Io and the stochastic nature of volcanic activity. SUDA is a time-of-flight mass spectrometer for species with atomic mass ranging of up to 200 u and is capable of detecting up to 40 ejecta per second. Owing to the deterministic nature of the ballistic trajectories of the ejected particles, the composition measurements at spacecraft altitude can be correlated with geologic features on the surface. It has been demonstrated that trace amounts of complex organic species embedded in ice grains with abundances <0.1 ppm can be detected. In addition to micrometeorite ejecta, SUDA will measure the makeup of potential plumes by directly sampling microscopic particles.

2.5 Europa Ultraviolet Spectrometer

The Europa Ultraviolet (UV) Spectrometer (Europa-UVS) is the mission's primary plume hunter. The instrument will search for plumes by spatial and spectral imaging of UV emissions (airglow) and transmission (stellar occultations) in the wavelength range of 55−210 nm and a spectral resolution of 0.6 nm. Europa-UVS has a standard- and a high-spatial-resolution mode to allow for global search as well as detailed imaging of surface and plume structures. The distribution, structure, composition, and variability of active plumes will be determined from the observations. In addition, composition, physics, and chemistry of Europa's surface, atmosphere, and plasma environment will be studied with this investigation.

3. Mission Concept

The current mission design consists of 46 flybys of Europa while the spacecraft is in orbit about Jupiter. The flybys are numbered E01 through E46 in Figure 1 and extend over a ~3.5 year period. The altitudes of closest approach typically range from 25 km to 100 km. The tour is divided into two principal campaigns, visiting first the anti-Jovian hemisphere followed by observations of the sub-Jovian hemisphere. As seen in Figure 1, flybys occur over a wide range of latitudes and longitudes and are also well distributed in true anomaly and solar local time. The tour is thus well-suited for characterization of the ice shell and ocean and of the atmosphere and ionosphere created through Europa's interaction with Jupiter's magnetosphere.

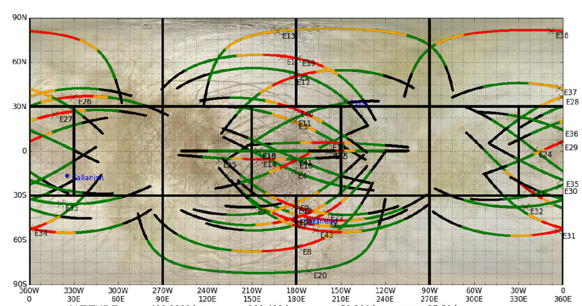

Figure 1: Planned Europa Clipper close approach ground tracks below 1000 km altitude (black), 400 km (green), 100 km yellow, and 50 km (red).