THE EUROPA CLIPPER GRAVITY / RADIO SCIENCE INVESTIGATION. E. Mazarico[1], D. R. Buccino[2], J. Castillo-Rogez[2], A. Dombard[3], A. Genova[4], H. Hussmann[5], W. Kiefer[6], J. I. Lunine[7], W. McKinnon[8], F. Nimmo[9], R. S. Park[2], P. Tortora[10], P. Withers[11], J. H. Roberts[12], H. Korth[12], D. A. Senske[2] and R. T. Pappalardo[2], [1] NASA Goddard Space Flight Center (erwan.m.mazarico@nasa.gov), [2] JPL/Caltech, [3] University of Illinois at Chicago , [4] University of Roma La Sapienza (Italy) , [5] German Aerospace Center (DLR, Germany) , [6] Lunar and Planetary Institute , [7] Cornell University , [8] Washington University in St. Louis , [9] University of California Santa Cruz , [10] Alma Mater Studiorum - Università di Bologna (Italy) , [11] Boston University , [12] Johns Hopkins University Applied Physics Laboratory.

Introduction: The Galilean moon Europa has long been a fascinating planetary body because of the presence of a subsurface ocean and its young icy surface. Implications for habitability in the solar system and beyond hold high appeal for astrobiology, and have made Europa the subject of intense scientific inquiry and of many past mission studies. The NASA flagship mission Europa Clipper [1] is currently in development with a launch readiness date of 2024. After arrival at Jupiter, it will conduct more than 40 flybys of Europa over the course of several years [2]. The scientific payload is uniquely suited to this flyby tour strategy, providing remote sensing and *in situ* observations of Europa and its relationship to Jupiter [3].

The primary objective of the Europa Clipper mission is to assess the habitability of Europa, an overarching goal that rests on improving our understanding of Europa's interior structure, composition, and geologic activity. Here we describe the Gravity and Radio Science (G/RS) investigation, which will make important observations to address key science objectives.

System and Operations: The Europa Clipper spacecraft communicates with the NASA Deep Space Network (DSN) with its telecom subsystem which allows commanding, data downlink, and navigation. In planetary and deep space missions, radiometric tracking (*e.g.*, Doppler and range) is typically leveraged for scientific study. In some cases, additional hardware is used to augment standard telecom equipment. Because of the nadir observation mode at close range to Europa, the tracking within 2 hours of the closest approach cannot be performed by the large X/Ka-band high-gain antenna (HGA). Instead, three X-band fanbeam antennas (FBAs) and two X-band low-gain antennas that are strategically placed around the spacecraft offer coverage of that critical time period for most flybys (Figure 1). The low gain of the FBAs will result in low signal-to-noise ratios and represents a challenge. Open-loop recording at the DSN sites allows signal strengths as low as 4 dB-Hz to be processed in order to extract the Doppler observables used for the G/RS investigation.

Gravity Science: The Europa Clipper flyby tour is carefully designed to provide as extensive a spatial coverage as possible [2]. This is particularly important for gravity science as the ability to sense the gravitational signature of Europa is limited to the immediate encounter window.

The design of the trajectory for the whole tour also takes into consideration the sampling of Europa's tidal phase. This enables the measurement of the tidal Love number k_2 [5,6], which characterized the gravitational response of Europa to the tidal forcing exerted by Jupiter, and is diagnostic of the presence of a global subsurface ocean. The estimation of the physical response of Europa to tidal forcing, described by the Love number h_2, will rest on the combination of the tracking, radar and imagery datasets. Together, k_2 and h_2 can constrain the ice shell thickness [7] complementary to subsurface sounding by the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) [8] and the Europa Clipper Magnetometer (ECM) [9] investigations.

An important question left open by the Galileo mission due to the equatorial geometry of its flybys [10,11] is whether Europa is in hydrostatic equilibrium, as currently assumed in interior modeling. Improved measurements of the gravitational J_2 and C_{22} coefficients from dozens of flybys over a wide range of latitudes will constrain potential non-hydrostatic contributions from Europa's rocky mantle and core. Europa's rotation state, particularly its pole position and longitudinal libration, will also contribute to our knowledge of the Europa interior. The Europa Imaging System (EIS) cameras [12] will be owing to their higher resolution compared to gravity science. If Europa can be verified to be in a Cassini state, its moment of inertia factor can be derived from the gravitational J_2 and C_{22} and place robust constraints on Europa's density profile, a critical contribution to the development of coupled geochemical and physical models.

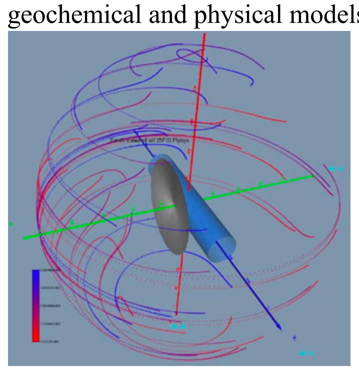

Figure 1. *Positions of the Earth in the spacecraft frame during example Europa encounters. The fanbeam and low-gain antennas enable radio tracking for the great majority of flybys. From [4].*

While the flyby tour geometry will not allow the determination of the global gravity field to very high spherical harmonics degrees, the low (l<10) degree coefficients will enable investigations related to the state of the interior of Europa. The lithospheric strength can be constrained by the magnitude of the gravity anomalies observed at these low degrees. In addition, regional-scale anomalies in the line-of-sight residuals may reveal details of the rock-water interface at the base of Europa's ocean [13]. Shorter-wavelength signals to which Europa Clipper will be sensitive nearest Europa will be best analyzed with local inversions of the line-of-sight residuals. Mass anomalies (mascons, either positive or negative) revealed in the ice shell or shallow seafloor may reveal unique environments such as ice upwellings beneath extensional bands, interstitial lakes or volcanic loads, which will be put in context with observations from other instruments (Figure 2).

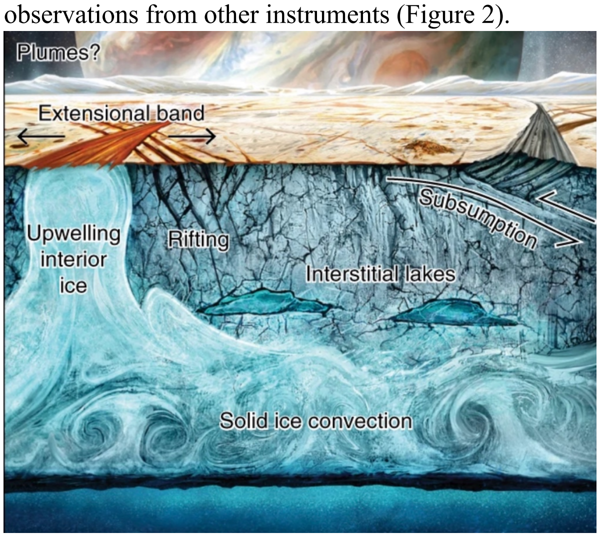

Figure 2. *Past and present geophysical processes expected in Europa's ice shell that may impact its habitability. From [3]. Credit: Jeff Nentrup.*

The orbit determination process to analyze the radio tracking will ensure the geodetic accuracy of the Europa Clipper datasets. With the newly-formed Geodesy Focus Group to help towards this aim, G/RS will support cross-investigation topics relevant to the shape, rotational parameters, and cartographic control of Europa. Together with G/RS-specific measurements, shell thickness variations would have implications for interpreting the tidal response and for identifying possible material transport and exchange with the subsurface ocean.

The repeated flybys of Europa will also allow better estimation of its orbit around Jupiter. Juno during its recently approved Extended Mission (EM) and JUICE will make similar measurements of the ephemerides of Io and Ganymede. The orbital state of the satellite system and thus their evolution in the Laplace resonance including dissipation in both Jupiter and the satellites will be characterized with high accuracy.

Radio Science: Europa Clipper will not carry an Ultra-Stable Oscillator (USO) as was used for radio occultation experiments by Mars Global Surveyor and Cassini for example. Coherent two-way radio tracking will be used to acquire highly accurate frequency measurements that can then be interpreted as column electron content to constrain models of the Europa ionosphere. Because of pointing considerations, the occultations conducted near Europa, when Clipper is nadir-pointed, will mostly be performed in the X-band with the fanbeam and low-gain antennas. Farther out, when Clipper's attitude is less constrained, the HGA may be used for measurements in X- or Ka-band. In combination with the measurements at VHF and UHF frequency by REASON, Europa's ionosphere can be better described; moreover, its impact on measurements of Europa's gravitational field and induced magnetic field will be ascertained. Observations of elevated electron content near Europa would also support the search for plumes performed with other remote sensing and *in situ* methods. Moreover, the radio system will uniquely sample the Io Plasma Torus (IPT) which can yield broad and elevated electron-induced path delays.

Future Activities: Given its late selection compared to the rest of the Europa Clipper team, the G/RS team is actively pursuing preparatory science activities and is developing collaborations within the whole Europa Clipper science team and project. Several G/RS team members are part of other Clipper investigations. Others with roles on Juno have refined models of the IPT with the X+Ka radio tracking data acquired from Juno's polar orbit. The approved Juno EM will conduct flybys of Ganymede, Europa, and Io and provide invaluable input for pre-arrival data analysis. Similarly, some G/RS cross-membership with the JUICE mission and anticipated collaborative efforts will benefit the planning, execution and analysis of the rich scientific data to be acquired by Europa Clipper.

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