A RECONNAISSANCE STRATEGY FOR LANDING ON EUROPA, BASED ON EUROPA CLIPPER DATA.
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Introduction: Europa's ocean may contain all the ingredients for life as we know it — i.e., the right combination of chemical elements, liquid water, and energy sources — making it one of the best places to search for an extant biosphere in our Solar System. The top-level science goal of NASA's flagship Europa Clipper spacecraft, currently planned for launch in fall 2024, is to "Explore Europa to Investigate its Habitability" [1]. With dozens of close flybys and a payload of 10 scientific instruments, Europa Clipper will perform the most detailed remote characterization to date of an Ocean World, but it will not be able to perform in situ assessment of the habitability of Europa, nor search for biosignatures.

A Europa surface in situ mission, such as the Europa Lander mission concept [2,3], has not yet been selected for flight by NASA, but is the next logical step in the exploration of this Ocean World, and is necessary to provide in situ ground-truth and detailed measurements to address key questions including, but not limited to, astrobiology investigations [4,5,6].

Irrespective of whether or not the next mission to Europa follows the Europa Lander mission concept framework, the reconnaissance data collected by Europa Clipper will be critical for the identification of potential landing sites that satisfy criteria for engineering safety and maximize science value for a future landed mission to Europa. The Europa Clipper Project Science Group and the Europa Lander Pre-Project Science Group established a joint Reconnaissance Focus Group in 2018 to help ensure the collection of an appropriate reconnaissance dataset.

Europa Clipper will primarily collect its multi-instrument reconnaissance dataset during the close-approach portions of its flybys, where the instrument resolution is usually the highest (blue swaths in Figure 1). Consequently, one of the >40 closest approach locations has a high likelihood of being the landing site for a future landed mission to Europa. We have objectively designed specific measurement and coverage metrics (i.e., planning guidelines) that further restrict the reconnaissance dataset to a subset of flybys and portions of the closest approach ground tracks.

Reconnaissance Strategy: We have developed a framework to create a reconnaissance strategy for Europa. We consider the following aspects: 1) Science value of potential landing sites; 2) Engineering safety of potential landing sites, to ensure safe landing and operations; 3) Predicted Europa Clipper reconnaissance datasets from multiple instruments; 4) A framework for the landing site selection process that integrates Europa Clipper reconnaissance data; and 5) Lessons learned from previous landed planetary missions.

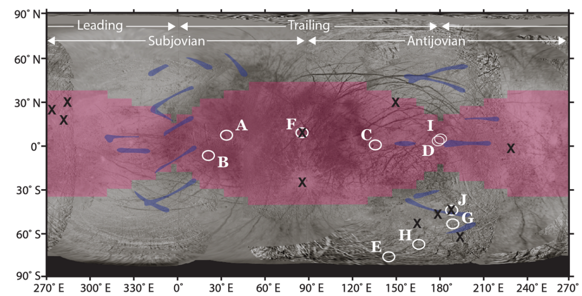

Figure 1: Assessment of potential landing sites. Blue swaths depict the predicted local scale coverage of Europa Clipper's EIS narrow angle camera at <1 meter/pixel for a potential Europa Clipper trajectory (21F31V3) when considering an average incidence angle of 30°–60°. Pink lenses show locations modeled by [7] that receive higher radiation processing by electrons to 100eV/16amu in less than 10My, to depths of 10 cm or greater. Black X's indicate selected chaos terrains of known locations, and white circles denote locations suggested as scientifically interesting areas by previous studies. See [8] for more info.

Science Value: Many aspects will go into the determination of science value of a particular potential landing site, and given the wide variety of possible criteria, lively debate is likely. Prioritizing sites that indicate potential for harboring possible biosignatures and without Europa Clipper having yet obtained data, our current best predictions suggest that we would prioritize potential landing sites based on those that: 1) receive less exogenic surface material processing (from radiation and impact gardening, Figure 1); 2) display enrichment of non-ice materials on the surface, such as salts and organics; 3) display indicators of potential connections to subsurface habitats, such as fracture systems and/or young geologic features near subsurface layers of various densities such as brines or water pockets; and/or 4) show evidence of recent activity including plumes and thermal anomalies. Assessing the overall scientific value of a region will include considering these factors and their potential for enabling the discovery of extraterrestrial biosignatures.

Engineering Safety: Landing safely on the surface of Europa will require prior assessments of local surface properties within the landing ellipse, such as topographic slope (e.g., <25 degrees), surface roughness, vertical topographic relief (e.g. <1m of relief over a lander workspace), and block abundance [9,3].

Specifically, the Europa Clipper spacecraft's Europa Imaging System (EIS) will provide high resolution visual observations of the surface with color and stereo imaging [8]. These images and the derived Digital Terrain Models (DTMs) will provide slopes, topography, block heights, and fracture hazards.

EIS stereo images at ≤22 m per pixel can be obtained between 50 km and 100 km altitudes for landing regions ≥22 km on all sides. These images will enable detailed landing site analysis and Terrain Relative Navigation (TRN) that could be used during the deorbit, descent, and landing (DDL) process to autonomously match observed surface features to those on onboard maps and precisely detect the planned landing site. The Mars 2020 mission successfully used TRN [10] as did OSIRIS-REx [11]. In addition to TRN, autonomous hazard avoidance will be needed to avoid boulders and steep slopes and to ensure a safe landing. Furthermore, a comprehensive Terrain Specification Document (TSD) that summarizes current knowledge regarding surface characteristics, chemical composition, environmental context, and more, is currently under development [12].

Reconnaissance Data from Europa Clipper: Fortunately, many top-level requirements of the Europa Clipper investigations are well-aligned with the needs of reconnaissance for future landing site selection. For example, integrated close-approach high-resolution datasets will yield important insights into the small-scale surface properties of Europa while also providing reconnaissance data. The design of the Europa Clipper spacecraft includes a common field of view for all remote sensing instruments [8]so during close approach, the observations of the EIS, MISE, E-THEMIS, Europa-UVS, and REASON instruments can be aligned and are overlapping, producing an integrated dataset at the full range of available wavelengths onboard Europa Clipper.

Datasets from all relevant Europa Clipper investigations will be used in combination to assess the science value and engineering safety of potential landing sites. While some instruments will have high spatial resolution, others may be able to localize variations in key parameters to a particular hemisphere, which will also aid the reconnaissance process. Therefore, EIS images of potential landing sites will be supplemented by compositional information from MISE and/or Europa-UVS; observables dependent on surface roughness, porosity, and block abundance from E-THEMIS and/or REASON; and any local-scale subsurface thermal or density anomalies from E-THEMIS, REASON, and/or Gravity/Radio science. In situ measurements of particle abundances and compositions from SUDA and MASPEX, localized over regions of interest, will also be useful [8].

Lessons learned from previous landed missions: While Europa is a very different environment from previous bodies on which we have landed, there are lessons we can learn from successful landings on Mars, the Moon, and even comets and asteroids [13,8,14].

Europa Landing Site Selection Process: We envision that a future landing site selection process for Europa will likely follow the precedents set by the Mars Exploration Program. Once a reconnaissance dataset is gathered for >40 potential landing sites, we will first work to identify the subset of landing sites that meet basic criteria for engineering safety. From those, we will then be able to assess the science value of each remaining viable site to create initial rankings. We envision a community-wide workshop to study the final list of candidate landing sites, before the final selection is made by a panel of officials. While we expect that Europa Clipper data will be the main dataset involved in this selection, we anticipate that data from all available missions will be considered.

Ideally, we will have at least three years between the end of Europa Clipper's prime mission and the landing site selection date for a future Europa Lander, but we should not let too much time pass. [5] argue that "...a long delay between Europa Clipper's observations and a landed mission puts increased uncertainty on the state of Europa's possibly dynamic surface at landing, including locations of potential plumes or hotspots." A long period between acquisition of Europa Clipper data and landing on Europa would increase the risks of landing on a potentially significantly less active or scientifically valuable surface.

Conclusions: Europa Clipper will collect a well-coordinated dataset that can serve as reconnaissance for a future landed mission to Europa, such as the proposed Europa Lander mission concept [3]. Ideally, such a follow-up mission will occur soon after the collection of the reconnaissance dataset. Such a mission would be able to take advantage of the investment in the collection of remote sensing data, provide ground truth for that data, and extend the search from habitability to in situ biosignature detection.

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