The Science Case for Surface Mobility on Icy Worlds

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Summary

Icy worlds such as Enceladus and Europa are compelling targets to explore, as these moons provide the opportunity to test the hypothesis of whether life can exist or emerge in a habitable environment, or if this is unique only to Earth. These worlds show a remarkable diversity of surface features, ranging from smooth bands and ridges to chaos terrain and plume-ejecting crevasses. As on Earth, a limited set of science questions can be addressed by a stationary platform; only by visiting multiple terrain types (and multiple locations within a single terrain) can a more holistic picture of the history, evolution and habitability of these worlds be obtained. Surface mobility enables access to scientifically compelling terrains that might be too hazardous to qualify as landing sites (due to roughness, slope, etc.). Surface mobility also provides an option to avoid contamination from landing, and address unique science questions via the ability to perform transects and sampling across various spatial scales. This is especially beneficial for chaos terrain or to characterize differing sample compositions emitted from vents. NASA should consider surface mobility as a key factor when evaluating mission architectures to explore icy worlds.

Introduction

Icy worlds in our solar system are typically moons of Jupiter, Saturn, Uranus and Neptune with surfaces composed largely of water-ice. Many of these worlds—including but not limited to Europa, Enceladus, and Titan—have evidence of global, subsurface liquid water oceans underneath their icy shells. Data from remote sensing and in situ observations indicate that—for Europa and Enceladus in particular—these subsurface oceans might be habitable, making these two icy worlds ideal targets for astrobiology investigations (Hendrix et al., 2019).

Enceladus and Europa have a wide variety of surface features. Europa's inventory of geologic units includes ridged plains, craters, band material and chaos terrain (Leonard et al. 2018). At Enceladus, terrain types include troughs, scarps, chasmata, ridges, and bands (Nahm and Kattenhorn, 2015). Enceladus also famously hosts a plume, sourced from its subsurface ocean and emanating from four giant fissures in the South Polar Terrain (Schenk et al., 2018, and references therein).

While certain surface features (e.g., chaos terrain of Europa) appear to be younger than others, and therefore more likely to contain biosignatures (if they exist), ultimately all should be explored to provide a holistic picture of the history and evolution of each icy world. Further, while landing ellipses tend to be smaller for airless bodies (due to absence of atmospheric wind and drag), they are still large enough that one cannot guarantee landing on the ideal site for a particular science investigation. Surface mobility would enable access to multiple locations on the surface of an icy world, providing greater flexibility in sampling

and opening missions to science investigations comparing multiple terrain types. **While various in situ architectures exist, we suggest that a platform with surface mobility would greatly enhance science return while retiring key risks.**

Surface Mobility Enhances Science Return

Compared to stationary architectures, the science return from surface missions with mobility is typically enhanced, due largely to greater access to sampling locations. For example, the Viking landers were only able to collect surface samples from an annular area about 1.5 m across (Arvidson et al., 1989), whereas the Mars Science Laboratory rover collected over 17 samples along its first 10 km of transit (ChemMin is capable of analyzing up to 74; Grotzinger et al., 2012). Benefits of mobility include the ability to reach multiple terrain types, which enables comparative geology, geochemistry and possibly biochemistry between the different sites. The Dragonfly mission, with an anticipated landing date on Titan in 2034, is designed to fly approximately 175 km across Titan's surface and would visit multiple terrain types on this large moon including an impact crater and its ejecta, as well as dunes and interdune regions (McGee et al., 2018). By visiting multiple terrain types (and multiple locations within a single terrain), a mission such as Dragonfly can generate a more complete picture of the history, evolution and habitability of this icy world.

Surface mobility also enables access to sites on planetary surfaces that are not possible with stationary landers. Landing sites are typically selected to have as few hazards—such as boulders and crevasses—as possible; many of these features may indicate recent activity on an icy world, and would be targets for exploration, in particular for astrobiology investigations. Surface mobility enables access to hazardous but astrobiologically-compelling terrain following landing in a safer area. This capability might mark the difference between identifying life on an icy world (under a scarp or in a crevasse, for instance) or erroneously marking its absence. A potential example of such case is represented by the Enceladus vents: While we know that, the closer we get to the vent source, the more likely is to find interesting evidence, it is also true that, the combination of high velocity jets, absence of atmosphere, and extremely low gravity, makes the landing attempt more risky the closer we get to the vents themselves.

Mobile planetary exploration platforms also enhance science return by providing the ability to perform studies along transects, and sampling across different spatial scales. This enables detection of chemical or physical gradients across a terrain, or comparing in situ data at high spatial scale to lower-resolution orbital data. If gradients exist due to an active source (i.e., one of the >100 jets at Enceladus' south pole), a mobile platform could identify the source through repeated measurements and move to sample in that area, potentially accessing the most likely sample to contain biosignatures. Surface mobility also enables a mission to be responsive to new discoveries, such as identification of a recent plume deposit, perhaps in an area not identified as a safe landing site.

Avoiding Contamination

One potential pitfall of a stationary mission is contamination from the landing process. In particular for airless bodies such as most icy worlds (Titan is a special case), landing cannot be accomplished with parachutes and thus descent thrusters are needed. Hydrazine (N_2H_4) is commonly used as a monopropellant in descent stage thrusters. Hydrazine is a strong base and powerful reducing agent, and is known to react with organics via a Wolff-Kishner reduction (Furst et al., 1965). Further, one of the primary decomposition products of hydrazine is ammonia (NH_3), which may compromise geochemical investigations and life detection analyses. For example, unambiguous detection of NH_3 (along with Ar) in an icy moon environment can help determine the original molecular carrier of nitrogen (as either NH_3 or N_2), and comparison of the level of NH_3 to N_2 and nitrates can also yield the available redox energy in that environment. In terms of life detection, many microfluidics-based techniques use fluorescent molecular tags that chemically react with primary amines (to detect biosignature molecules such as amino acids - see Mora et al., 2012); these tags also react with ammonia and could generate a false positive measurement (or a false negative if the fluorescent reagents are consumed by the excess of NH_3 in the sample). While descent thrusters can be canted outward to reduce the deposition of the thruster plume on the landing site, this contamination cannot be avoided. Contamination from the spacecraft could also include other condensed volatiles, all of which could be avoided by moving away from the landing site. A spacecraft with surface mobility can simply traverse out of this contaminated area prior to conducting geochemical or biosignature detection analyses.

Other potential drawbacks of being confined to a landing site include the loss of unmodified physical surface properties, such as grain size distribution. In an unconsolidated surface environment (i.e., the South Polar Terrain of Enceladus where plume grains are continuously falling onto the surface), smaller grains may be ‘blown away’ during landing, so a measurement of grain size would be biased towards larger diameters. Thermal exchange between the spacecraft and the surface over long timescales could also modify surface properties.

Extraordinary claims require extraordinary evidence

While surface mobility would enhance any science investigation, those focused on detecting evidence of life require an even greater burden of proof than traditional science goals. While some astrobiological measurements can be made in situ from orbital or flyby architectures (i.e., sampling the plume of Enceladus or possibly Europa), we must reach the surfaces of these worlds (and ultimately their subsurface oceans) to understand and contextualize a positive detection of life. Surface mobility provides greater access, and therefore more sampling opportunities. Multiple sampling sites would provide increased confidence for life detection measurements; a series of positive detections, for example, showing an increase in concentration with proximity to a plume source, would be a robust result. Mobility enables a mission architecture that can be responsive to new discoveries and opportunistic science.

Conclusion

Given the diversity of surface terrain types observed at ocean worlds, **sampling from a single landing location is not enough** to provide a holistic understanding of that world. Surface mobility for a mission to an icy world would enhance science return multi-fold, in addition to avoiding contamination and enabling increased confidence for difficult measurements such as those for life detection. Recent technology advancements demonstrate multiple types of mobility (i.e., hopper (Hockman et al. 2016, Meirion-Griffith et al. 2019), wheeled rover (Nayar et al. 2019), snake-like (Ono et al. 2019, Carpenter et al. 2019), an actively articulated wheel-on-limb rover (Reid et al. 2019), and a steam-propelled hopper (Meirion-Griffith et al., 2019)) that could be appropriate for most terrains identified on icy worlds. **We encourage NASA to consider such architectures to maximize capability and science return on future missions to Enceladus, Europa, Triton and beyond.**

Figure 1. Examples of various robotic concepts capable of surface mobility on icy worlds. **Top left:** Rotation of internal flywheels allows surface reaction forces to make a rover tumble/hop (Hockman et al. 2016). **Top right:** RoboSimian wheel-on-leg platform using active suspension to navigate Europa analog terrain in Death Valley, CA (Reid et al. 2019). **Bottom left:** The Exobiology Extant Life Surveyor (EELS) concept uses counter-rotating Archimedes screw propulsion units to move around obstacles and through unconsolidated media such as plume deposits (Carpenter et al., 2019). **Bottom right:** An ice harvesting steam-propelled hopper could utilize in situ resources for mobility (Meirion-Griffith et al. 2019).

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