DRAGONFLY: DIVERSITY OF MISSION SAMPLING TARGETS

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1 INTRODUCTION

Dragonfly is a Titan lander mission selected by the NASA New Frontiers program for Phase-A study. Its science themes include prebiotic chemistry, habitability, and a search for biosignatures [1]. To address these themes, *Dragonfly* will sample both water ice and organic sediments [2] within Titan's sand seas' dunes and interdunes [3]. Because prebiotic chemistry or prospective life on Titan might consist of familiar water-based pathways or use liquid methane/ethane as a solvent [4], sampling both ice and organics provides for a broad-based approach to either. *Dragonfly* carries a mass spectrometer to determine molecular masses of surface materials and a gamma-ray and neutron spectrometer to assess the bulk and inorganic atomic fractions within the regolith. *Dragonfly*'s aerial mobility makes it possible to explore a variety of targets, following up on discoveries that we make along the way like rovers do on Mars.

2 WATER-ICE

Titan's ubiquitous organic compounds created by photolysis of a methane-rich atmosphere set it apart from the other ocean worlds. On Titan, carbon can interact with liquid water **on the surface**. Cryolava flows and impacts create transient surficial liquid water environments. When organics (sitting on the surface or falling out of the atmosphere) mix with water, the resulting environment simulates what may have happened on the early Earth [10]. Analyzing previously liquid water that mixed with organics could therefore bring insights into prebiotic chemistry unattainable in the terrestrial laboratory and potentially shed light on the origin of life.

But not all water ice that we find on Titan will have been previously liquid. And not all previously liquid water will necessarily have been in contact with organics, or will have remained liquid for a significant period of time. Here are some types of water ice that *Dragonfly* might sample, along with the implications of each for prebiotic chemistry, habitability, and biosignatures.

Primordial Crust One potential origin for Titan's surface water ice might be the moon's original crust after it formed. The anorthositic highlands of Earth's Moon provide a known analog. While such floating solid may very well have crystalized from a liquid global ocean, we don't know what organics might have been available at Titan's formation or what the thermal conditions might have been. Titan's early atmosphere might, however, have been much warmer and more highly oxidizing than the atmosphere is today, leading to a strong similarity with early Earth. Bedrock ice exposures may be present on smaller scales than Cassini can resolve (VIMS/RADAR data show only a few candidates) but mechanical erosion by rivers may yield bedrock ice clasts, like the cobbles at the Huygens landing site, that could be chemically unaltered representatives of the primordial crust.

Cryovolcanic Flows Flows of liquid water emanating from Titan's interior [5] would make for particularly exciting sampling targets. Flow samples could test both (1) the chemical state of Titan's interior water ocean and (2) the extent to which mixing of extruded water and surface organics drives prebiotic chemistry [6]. The two might be differentiated based on flow thickness — thicker flows remain liquid for longer at Titan surface conditions. Present uncertainty in identifying cryovolcanic candidates makes targeting a cryoflow challenging, but flows or material eroded or derived from flows may be recognizable in *Dragonfly* imaging or chemical data.

Impact Plume Fallout Asteroidal and cometary impacts vaporize some of the target crust. At Titan, that vapor plume expands through the atmosphere and blows downwind. As the plume cools water condenses directly as ice particles, which settle on the surface in a characteristic parabolic pattern seen around Sinlap Crater [7]. While this material did not persist in a liquid state and thus has low prebiotic potential, it serves as an important control on the potential for chemical synthesis in impact shock. It may be recognized by fine grain size, chemical signatures, and spatial structure. Silicate and siderophile compounds from the impactor could seed the surface with trace elements that would be otherwise hard to obtain from below Titan's liquid water mantle.

Impact Melt A larger fraction of an impactor's energy melts target rock instead of vaporizing it [8]. Therefore impact melt is a top target for water-solvent prebiotic and/or biotic organic molecules on Titan [9, 10]. Many tens of impact craters have been detected on Titan from *Cassini* [11], providing potential targets with accessible previously liquid water.

3 ORGANIC SEDIMENTS

In addition to studying water ice deposits, we can also test for the possibility for complex chemistry using liquid hydrocarbon solvents. Although Earth-based life requires liquid water, it is not yet clear whether water is the *only* possible solvent for life. Titan's methane rain and methane/ethane seas allow us to constrain this possibility for "Life, Jim, but not as we know it". However, the best place to evaluate this chemistry is actually not within the seas themselves – the low solubility of complex organics in liquid methane/ethane makes direct sea measurements like looking for needles in a haystack. Instead we will sample organic sediments where those materials have been concentrated.

Atmospheric Fallout Titan's ubiquitous atmospheric haze contains a surprising complexity of organic molecules perhaps even up to and including amino acids [12]. These slowly fall toward the surface where they build up in a coating over at least parts of the surface (they don't coat all of the surface uniformly, as attested to by the observed diversity of surface properties [13]). Although these particular organics likely represent only the starting point for surface organic chemistry, their consistent deposition ought to make them straightforward to identify and sample.

Dune Sands The solid organic sands that make up the vast equatorial sand seas [14] represent a significant organic sink and perhaps the largest solid end product of Titan's methane cycle [15]. The dunes collect material from all over Titan, and thus by sampling them *Dragonfly* can gain access to particles generated far from its landing site [16], an approach applied with much success at Mars [17]. The sand provides a strong contrast to all of *Cassini*'s remote sensing instruments such that we know quite well where the sands are distributed globally [18]. Although we do not know what mechanism manufactures sand grains [19], their chemistry may represent an advanced chemical state owing to the dunes' apparent old age.

Evaporite Evaporite deposits represent the direct precipitation of solutes dissolved within Titan's seas [20]. The evaporite formation process purifies organics, separating more soluble from less soluble species [21]. Sampling evaporite deposits would serve as a proxy for the dissolved solid organic content of seas without the necessity of traveling to presently extant lakes at Titan's poles. That organic content might include elements of hydrocarbon-based life like azotosomes [22].

Lithified Sediments Given Titan's active surface aeolian and fluvial processes, substantial reworking of organics may rearrange them into different forms. In particular, any concentration and burial mechanism might lithify such organics beneath the overburden pressure of subsequent layers. However it would not be clear where to look for such reworked organic rocks given our present knowledge of Titan's surface geology.

4 CONCLUSION

Dragonfly will explore a wide variety of different types, chemistries, and origins of Titan surface materials. This surface diversity will enable the ability to sample both water-ice-rich and organic-rich surface solids to enable compositional science of astrobiologically relevant materials.

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