DRAGONFLY: IN SITU EXPLORATION OF TITAN'S ORGANIC CHEMISTRY AND HABITABILITY.

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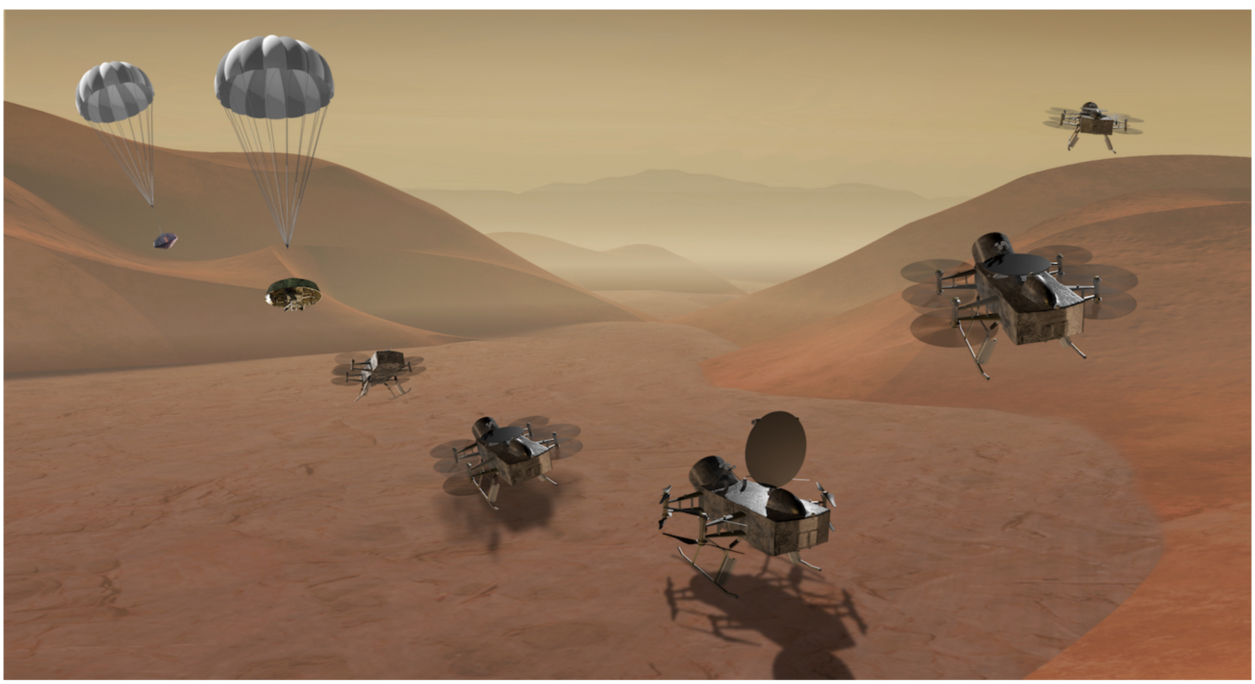
Introduction: Titan's abundant complex carbon-rich chemistry, interior ocean, and past presence of liquid water on the surface make it an ideal destination to study prebiotic chemical processes and document the habitability of an extraterrestrial environment [*e.g.*, 1-6]. In addition to the level of organic synthesis that Titan supports, opportunities for organics to have interacted with liquid water at the surface (*e.g.*, sites of cryovolcanic activity or impact melt [4]) increase the potential for chemical processes to progress further, providing an unparalleled opportunity to investigate prebiotic chemistry, as well as to search for signatures of potential water-based or even hydrocarbon-based life.

The diversity of Titan's surface materials and environments [7] drives the scientific need to be able to sample a variety of locations, thus mobility is key for *in situ* measurements. Titan's dense atmosphere provides the means to access different geologic settings over 10s – 100s of kilometers apart, via exploration by a vehicle with aerial mobility. *Dragonfly* is a rotorcraft lander mission currently being studied in Phase A under NASA's New Frontiers Program that would take advantage of Titan's unique natural laboratory to understand how far chemistry can progress in environments that provide key ingredients for life.

Exploration Priorities and Strategies: It has long been recognized that Titan's rich organic chemical environment provides a unique opportunity to explore prebiotic chemistry [*e.g.*, 9,10], and development of Titan mobile aerial exploration was identified as a desirable next step after *Cassini-Huygens*. Early Titan studies emphasized airships and balloons, but access to surface materials for *in situ* chemical analysis presented a challenge. Thus, the 2007 Titan Explorer Flagship study [10] advocated a Montgolfière balloon for regional exploration and a *Pathfinder*-like lander to land in the



equatorial organic-rich dune fields for investigation of surface chemistry and interior structure.

Although Titan's hydrocarbon seas are an appealing target [11], Titan's northern winter in the 2020-2030s precludes direct-to-Earth communication in this time frame. Furthermore, although the physical oceanography and the intriguing but uncertain prospects of chemical evolution in a nonpolar solvent are significant, the environments that offer the most likely prospects for chemical evolution similar to that on Earth occur on Titan's land. The dune sands themselves may represent a 'grab bag' of materials sourced from all over Titan [10] (much as the *Mars Pathfinder* landing site collected rocks from a wide area [12]) and thus may contain aqueously altered materials. However, as in Mars exploration, the approach with the lowest scientific risk is to obtain samples directly from multiple locations.

Multiple landers could address Titan's surface chemical diversity, but are an inefficient approach, requiring multiple copies of instrumentation and sample acquisition equipment able to address many aspects of composition analysis: organic and inorganic; solid (*e.g.* 'bedrock' ice, impact melt, evaporite, etc.) or particulate; chemical structure of what may be high-molecular-weight material; chirality; mixtures of amino acids, etc. Given Titan's dense atmosphere (4x that at the surface on Earth) and low gravity (1.35 m/s^2), heavier-than-air mobility is highly efficient [9,13], and recent developments in autonomous aircraft make such exploration a realistic prospect. A much more efficient approach is to convey a single capable instrument suite to multiple locations on a lander with aerial mobility [9].

Enabled by modern control electronics, a multi-rotor vehicle [14] is mechanically simpler than a helicopter, as the recent proliferation of terrestrial quadcopter drones attests. A multi-rotor vehicle can be made to be failure tolerant and can be packaged efficiently in an entry vehicle. For a given vehicle mass and rotor diameter, the shaft power required to hover on Titan is 38x less than on Earth [9,14], but still too high for continuous flight if powered by an MMRTG. However, flight durations of up to a few hours are possible using power from a battery, which can be recharged via an MMRTG. Adopting rotors as a substitute for the retrorockets used for landing on other planets, the ability to take off and land elsewhere follows with little incremental cost but with tremendous science enhancement. An advantage compared to a fixed-wing vehicle flying continuously [15] is that a relocatable lander is robust to power source underperformance or to science energy demands – the system merely takes longer to recharge between flights.

Science Objectives: Compositions of the solid materials on Titan's surface are still essentially unknown. Compositional measurements [16] in different geologic settings [7,17] will reveal how far organic chemistry has progressed. Sites where transient liquid water [4] may have interacted with the abundant photochemical products that litter the surface [2] are of particular interest.

At each landing site, bulk elemental surface composition can be determined by a neutron-activated gamma-ray spectrometer [16,18]. Surface material can be sampled with a drill and ingested using a pneumatic transfer system [19] into a mass spectrometer [16,20] to identify the chemical components available and processes at work to produce biologically relevant compounds. Meteorology and remote sensing measurements can characterize Titan's atmosphere and surface [11,21,22] – Titan's Earth-like system with a methane cycle instead of water cycle provides the opportunity to study familiar processes under different conditions. Seismic sensing can probe subsurface structure and activity [23].

The *Dragonfly* mission concept [24] is a dual-quadcopter designed to take advantage of Titan's environment to explore dozens of diverse sites, covering 10s – 100s of kilometers during its >2-yr mission, to characterize Titan's habitability, investigate prebiotic chemistry, and search for chemical signatures indicative of water-based and/or hydrocarbon-based life.

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