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]. Although pathways for the origin of life as we know it are poorly constrained, there is general agreement that liquid water, essential elements (especially CHNOPS), energetic disequilibrium, and a catalytic surface are required. In addition to the complex organic synthesis that Titan supports today, organic molecules may have interacted with liquid water at the surface in the past (*e.g.*, sites of cryovolcanic activity or impact melt [4]), increasing the potential for oxygenation and chemical processing to progress beyond the compositional functionalities observed in high-altitude organic species. Titan provides an unparalleled opportunity to investigate prebiotic chemistry, as well as search for signatures of potential water- or even hydrocarbon-based life.

The diversity of Titan's surface materials and environments [7] drives a scientific need to sample a variety of locations, thus mobility is key for *in situ* measurements. Titan's dense atmosphere provides the means for long-range exploration by a vehicle with aerial mobility. The *Dragonfly* mission concept, under study in NASA's New Frontiers Program, is a rotorcraft lander that would achieve wide-ranging *in situ* investigation by flying to access different geologic settings 10s – 100s of km apart, performing multidisciplinary science measurements at each landing site.

Dragonfly takes advantage of Titan's unique natural laboratory to understand how far chemistry can progress in environments that provide key ingredients for life.

Exploration Strategy: 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*. Although the hydrocarbon seas are an intriguing target [11], environments that offer the most likely prospects for chemical evolution similar to that on Earth occur on Titan's land [4] and Titan's northern winter precludes direct-to-Earth communication in the 2020-2030s. Furthermore. Moreover, the dune sands may represent a 'grab bag' of materials sourced from all over Titan [10] (similar to *Mars Pathfinder's* landing site [12]) and thus may contain aqueously altered materials. As in Mars exploration, the approach with the highest scientific potential is to obtain samples directly from multiple locations.

Given Titan's dense atmosphere (4x that at Earth's surface) and low gravity (1.35 m/s^2), heavier-than-air mobility is highly efficient [9,13,14]. Recent developments in autonomous flight enable a lander with aerial mobility to convey a capable instrument suite to explore multiple locations. Modern control electronics make a multi-rotor vehicle [15] mechanically simpler than a helicopter, as the recent proliferation of terrestrial drones attests. For a given vehicle mass and rotor diameter, the hover power required on Titan is 38x less than on Earth [9,15]. Flights of up to a few hours are possible using power from a battery recharged via an MMRTG. This strategy also has the advantage of flexibility to adjust to changes in power-source performance or science energy demands, merely taking longer to recharge between flights. 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 and tremendous science enhancement.

Science Objectives: Compositions of the solid materials on Titan's surface are still essentially unknown. So 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, *Dragonfly* can answer key scientific questions regarding habitability and prebiotic chemistry and put these measurements in the context of Titan's meteorology and methane cycle, local geologic setting and material properties [18], and geophysical measurements of the subsurface [19]. *Dragonfly* will:

- analyze chemical components available and processes at work to produce biologically relevant compounds;
- measure atmospheric conditions, identify methane reservoirs and determine transport rates [11,20,21];
- characterize geologic features and transport processes, seismic activity, and subsurface structure [22, 19];
- constrain processes that mix organics with past surface liquid water or potentially the subsurface ocean;
- search for water- or hydrocarbon-based chemical biosignatures.

Since the interior of the lander is maintained at constant benign temperatures using 'waste' heat from the MMRTG, only modest adaptation for Titan's environment (94-K, 1.5-bar nitrogen atmosphere) is needed.

Measuring Titan's Composition: Surface material is sampled with a drill and ingested using a pneumatic transfer system [23] into the mass spectrometer, DraMS [16,24]. The sampling system, DrACO, has one drill on each skid for sample diversity and redundancy and provides rotary and rotary-percussive modes. Supported in part by NASA's COLDTech program, the drill has been tested at Honeybee Robotics in a range of cryogenic ices and organic materials chilled with liquid nitrogen. Cuttings are collected by a pneumatic transfer system, which conveys the material rapidly into DraMS for analysis. Pneumatic transfer ensures samples are maintained at near-ambient Titan temperatures, with particular attention to avoiding cross-talk between samples.

DraMS supports both laser desorption (LDMS) and pyrolysis gas chromatography (GCMS) operating modes, with heritage from the *MSL* SAM and *ExoMars* MOMA instruments. Phase-A activities have included environmental testing of a scroll pump, which brings the internal atmosphere of the sample delivered by DrACO from 1.5-bar Titan to ~10 mbar, in family with Mars heritage inlet designs.

A novel element of *Dragonfly's* payload is a neutron-activated gamma-ray spectrometer, DraGNS, to quickly identify bulk elemental composition at landing sites [16,25] and inform decisions about sampling and DraMS measurements. DraGNS uses a high-purity germanium (HPGe) detector for superior spectral resolution and a pulsed neutron source to excite gamma-ray emission from surface and near-subsurface material. Previous applications required active cryocoolers, but for *Dragonfly* Titan's cold, dense atmosphere can be used to passively hold the detector at temperature. Phase-A activities have included demonstration of HPGe passive cooling and operation of a testbed with a commercial neutron source using compositional analogs to simulate Titan organics overlying water ice.

The *Dragonfly* [26] rotorcraft lander is designed to take advantage of Titan's environment to explore dozens of diverse sites, covering 10s – 100s km during its >2-yr mission, to characterize Titan's habitability and determine how far organic chemistry has progressed in environments providing key ingredients for life.

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