DRAGONFLY: EXPLORING TITAN'S PREBIOTIC ORGANIC CHEMISTRY AND HABITABILITY.

E. P. Turtle[1], J. W. Barnes[2], M. G. Trainer[3], R. D. Lorenz[1], S. M. MacKenzie[2], K. E. Hibbard[1], D. Adams[1], P. Bedini[1], J. W. Langelaan[4], K. Zacny[5], and the Dragonfly Team, [1]Space Exploration, Johns Hopkins Applied Physics Lab., Laurel, MD 20723 (Elizabeth.Turtle@jhuapl.edu), [2]Department of Physics, University of Idaho, Moscow, ID 83844, [3]NASA Goddard Space Flight Center, Solar System Exploration Division, Greenbelt, MD 20771, [4]Aerospace Engineering, Pennsylvania State University, University Park, PA 16802, [5]Honeybee Robotics, Pasadena, CA 91103.

Introduction: Titan offers complex and diverse carbon-rich chemistry in abundance on an ice-dominated ocean world [*e.g.* 1, 2], making it an ideal destination to study prebiotic chemistry [*e.g.* 3] and document habitability of an extraterrestrial environment [4]. Moreover, Titan's thick atmosphere provides the means to access different geologic settings over tens to hundreds of kilometers apart, via exploration by an aerial vehicle.

Exploration Priorities and Strategies: It has long been recognized that Titan's rich organic chemical environment provides a unique opportunity to explore prebiotic chemistry (for example the Campaign Strategy Working Group (CSWG) on Prebiotic Chemistry in the Outer Solar System [5, 6]), 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 severe challenge to such vehicles. Thus, the 2007 Titan Explorer Flagship study [7] advocated a Montgolfière balloon for regional exploration with high-resolution (~1 m) surface imaging, but assigned exploration of surface chemistry and investigation of interior structure via seismology (to characterize the ice thickness above Titan's internal water ocean) to a Pathfinder-like lander, notionally to land in the equatorial organic-rich dune fields.

Although Titan's hydrocarbon seas are an appealing target and presented an exciting and cost-effective mission opportunity for the Titan Mare Explorer (TiME) capsule in the 2010 Discovery competition [8], the Titan northern winter season in the 2020-2030s precludes Earth view and thus direct-to-Earth communication in this time frame. Furthermore, although the opportunities in 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 (as articulated in the 2007 Flagship study [7]) may represent a 'grab bag' site of materials sourced from all over Titan (much as the rocks at the Mars Pathfinder landing site were intended to collect samples from a wide area [9]) and thus may contain aqueously altered materials. However, as in the exploration of Mars, the approach with the lowest scientific risk is to obtain samples directly from multiple locations, informed by context information at higher resolution than that afforded by *Cassini* data. The limited range of surface rovers and the uncertain trafficability of Titan's surface makes either multiple landers, or a relocatable lander, the most desirable option.

Given Titan's thick atmosphere (density at the surface is 4x that of Earth) and low gravity (1.35 m/s^2), heavier-than-air mobility at Titan is highly efficient [6, 10], and improvements in autonomous aircraft in the two decades since the CSWG make such exploration a realistic prospect. While multiple *in situ* landers could address Titan's surface chemical diversity (Fig. 1), this is an inefficient approach since it requires multiple copies of what must be versatile 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.), particulates like sand, possibly damp or wet material; chemical structure of what may be high-molecular-weight material; chirality; mixtures of amino acids, etc. A much more efficient approach is to convey a single instrument suite to multiple locations on a lander with aerial mobility much like a helicopter [6].

In fact, enabled by modern control electronics, a multi-rotor vehicle [11] is mechanically simpler than a helicopter, as the proliferation of terrestrial quadcopter drones in recent years attests. A multi-rotor vehicle can be made to be failure tolerant, and can be packaged efficiently in an entry vehicle. Although for a given vehicle mass and rotor diameter, the shaft power required to hover on Titan is 38x less than on Earth [6, 11], this is still too high for continuous flight if powered by an MMRTG. However, flight duration of a few hours is possible using power from a battery, which can be recharged via an MMRTG in less than a Titan day. In fact, once rotors are adopted as a substitute for the retrorockets used to effect soft touchdown on Mars landers, the ability to take off and land elsewhere follows with little incremental cost but with tremendous science enhancement. Furthermore, unlike a fixed-wing vehicle flying continuously [12], a relocatable lander is robust to power source underperformance or to science energy demands – the system merely takes longer to recharge between flights.

Thus the *Dragonfly* mission concept is a quadcopter designed to take advantage of Titan's environment to be able to sample materials and determine the surface composition in different geologic settings (Fig. 1).

Science Objectives: The compositions of the solid materials on Titan's surface are still essentially unknown. Measuring the composition of materials in different geologic settings will reveal how far prebiotic chemistry has progressed in environments that provide known key ingredients for life. Areas of particular interest are sites such as impact melt sheets [13] and potential cryovolcanic flows where transient liquid water may have interacted with the abundant (but oxygen-poor) photochemical products that litter the surface [2].

Bulk elemental surface composition can be determined by a neutron-activated gamma-ray spectrometer [14] at each site. Surface material can be sampled with a drill and ingested using a pneumatic transfer system [15] into a mass spectrometer [16] 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 – Titan's Earth-like system with a methane cycle instead of water cycle provides the opportunity to study familiar processes in a different environment and under different conditions. Seismic sensing can probe subsurface structure and activity.

Dragonfly is a truly revolutionary concept providing the capability to explore diverse locations to characterize the habitability of Titan's environment, investigate how far prebiotic chemistry has progressed, and search for chemical signatures indicative of water-based and/or hydrocarbon-based life.

References: [1] Raulin F. *et al.* (2010) Titan's Astrobiology, in *Titan from Cassini-Huygens* Brown *et al.* Eds. [2] Thompson W. R. and Sagan C. (1992), C. Organic chemistry on Titan: Surface interactions , Symposium on Titan, ESA SP-338, 167-176. [3] Neish C. D. *et al.* (2010) *Astrobiology 10*, 337-347. [4] https://astrobiology.nasa.gov/research/life-detection/ladder/. [5] Chyba, C. *et al.* (1999) *LPSC 30,* Abstract #1537. [6] Lorenz, R. D. (2000) *Journal of the British Interplanetary Society 53*, 218-234. [7] Leary J. *et al.* (2008) Titan Flagship study https://solarsystem.nasa.gov/multimedia/downloads/Titan_Explorer_Public_Report_FC_opt.pdf. [8] Stofan E. *et al.* (2013) *Proc. Aerospace Conf. IEEE*, DOI: 10.1109/AERO.2013.6497165. [9] Golombek M. P. *et al.* (1997) *JGR 102*, 3967-3988. [10] Lorenz R. D. (2001) *Journal of Aircraft 38*, 208-214. [11] Langelaan J. W. *et al.* (2017) *Proc. Aerospace Conf. IEEE*. [12] Barnes J. W. *et al.* (2012) *Experimental Astronomy 33*, 55-127. [13] Neish C. D. *et al.* (2017) *LPSC 48.* [14] Lawrence D. J. *et al.* (2017) *LPSC 48*. [15] Zacny K. *et al.* (2017) *LPSC 48.* [16] Trainer M. G. *et al.* (2017) *LPSC 48*. [17] Barnes J. W. *et al.* (2007) *Icarus 186*, 242-258. [18] Soderblom L. A. *et al.* (2007) *Planet. Space Sci. 55*, 2025-2036. [19] MacKenzie S. M. *et al.* (2007) *Icarus 243*, 191-207.

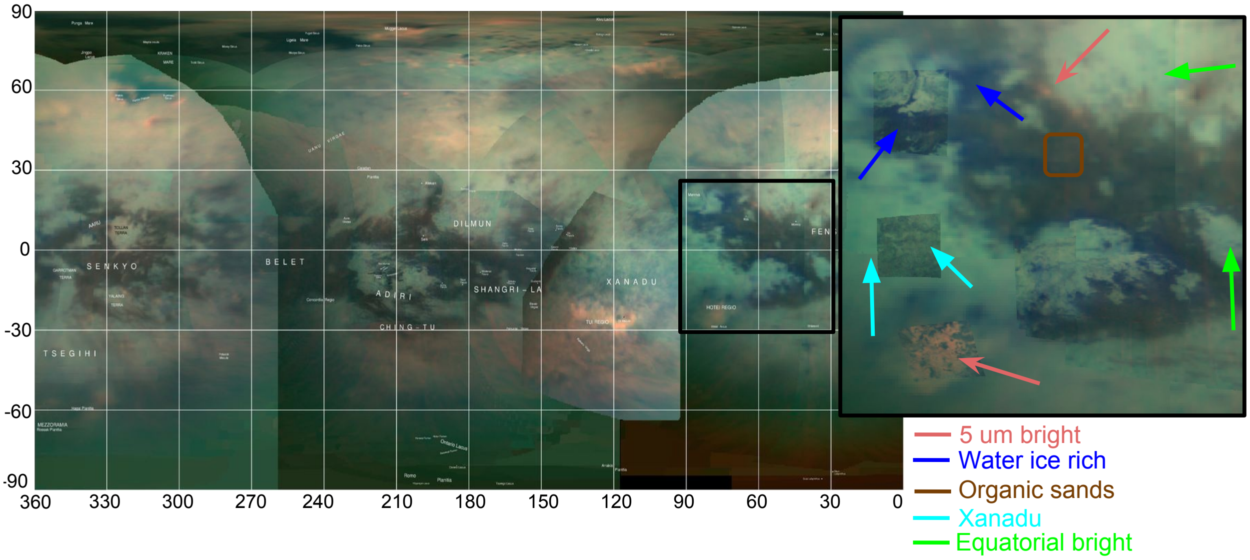

Figure 1. *Cassini* VIMS map of Titan showing the spectral diversity of the surface, with higher resolution inset from the T114 flyby in November 2015: red = 5 µm, green = 2 µm, and blue = 1.3 µm. Areas that appear dark blue indicate higher water-ice content compared to the dark organic sands and bright organic material seen elsewhere [17, 18]. The 5-µm bright unit has characteristics consistent with evaporitic material [19].