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 to search for signatures of 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, making mobility a key aspect of an *in situ* measurement strategy. Conveniently, Titan's dense atmosphere (4x that at Earth's surface) and low gravity (1/7th Earth's) make heavier-than-air mobility highly efficient, providing the means for long-range exploration by a vehicle with aerial mobility [e.g., 9, 13-15]. And recent developments in autonomous flight enable a lander with aerial mobility to convey a capable instrument suite to explore multiple locations.

NASA's *Dragonfly* New Frontiers mission is a rotorcraft lander designed to perform wide-ranging *in situ* exploration by flying to different geologic settings up to ~180 km apart, performing multidisciplinary science measurements at each landing site.

Exploration Strategy and Landing Site: 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. Moreover, the equatorial 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.

Dragonfly's initial landing site within the longitudinal dunes to the south of Selk Crater (Figure 1) provides access to multiple types of materials in close proximity, including organic sediments as well as materials with a water-ice component. During science operations over ≥2.7 years — at least 60 Titan days (Tsols) — *Dragonfly* will perform a series of flights covering several kilometers each, ultimately traversing from the interdunes at first landing to investigate deposits associated with the 80-km-diameter impact crater. Sites where liquid water may have interacted with the abundant photochemical products that litter the surface [2] are of particular interest [4]. By using a "leap-frog" exploration strategy, it will be possible to scout and select potential landing sites in advance based on aerial observations.

Science Objectives: The 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. 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's science objectives are to:

- Sample materials and 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, 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

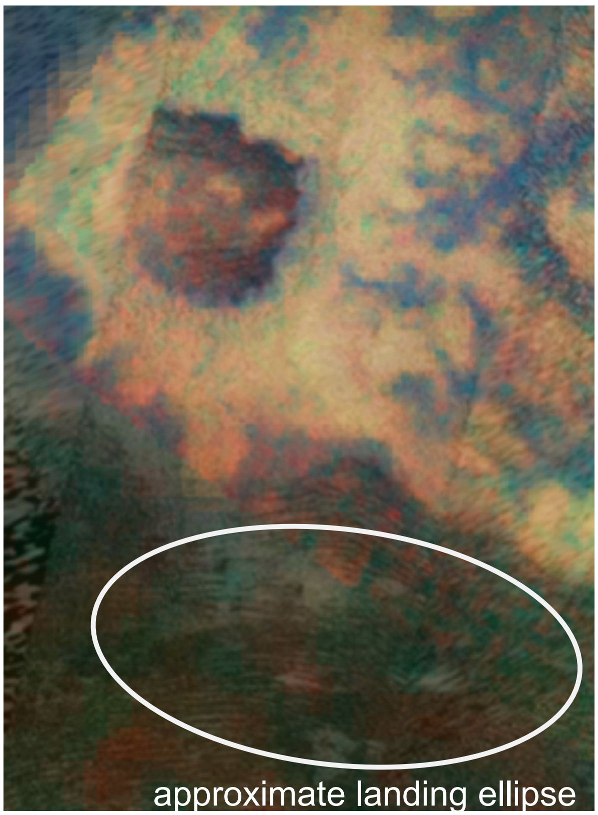

Figure 1: Combined Cassini VIMS and RADAR imaging of the region to be explored by Dragonfly. The initial landing site is targeted in the northwestern area of the Shangri-La Sand Sea, to the south of the 80-km-diameter Selk Crater, providing access to materials with a variety of compositions and geological histories.

Science Instruments and Measurements: Surface material is sampled [23] and ingested into the *Dragonfly* mass spectrometer, DraMS [16, 24], which supports both laser desorption (LDMS) and pyrolysis gas chromatography (GCMS) modes. The sampling system, DrACO [23], has one drill on each skid for sample diversity and redundancy and provides rotary and rotary-percussive modes. Pneumatic transfer ensures material is maintained at near-ambient Titan temperatures, with particular attention to avoid cross-talk between samples.

A novel element of the payload is a neutron-activated gamma-ray spectrometer, DraGNS [16, 25], to quickly identify bulk elemental composition and shallow stratigraphy (10s of cm), and inform decisions about sampling and DraMS measurements.

Dragonfly's geophysical and meteorology sensor package, DraGMet, will characterize Titan's atmosphere, surface properties, and seismic activity [11, 20-22]. Remote sensing observations will be performed on the surface and in flight by a suite of cameras, DragonCam, with resolutions ranging from grain-size at the DrACO sampling sites to decimeter-scale imaging of the surrounding terrain and meter-scale aerial views.

The *Dragonfly* [26] rotorcraft lander is designed to take advantage of Titan's environment to explore dozens of diverse sites in this unique natural laboratory, covering up to ~180 km during its ≥2.7-yr mission, to characterize Titan's habitability and determine how far organic chemistry has progressed in environments that provide key ingredients for life.

References: [1] Raulin F. *et al.* (2010) Titan's Astrobiology, in *Titan from Cassini-Huygens* Brown *et al.* Eds. [2] Thompson W.R. & Sagan C. (1992), C. Organic chemistry on Titan: Surface interactions, *Sympos. on Titan, ESA SP-338*, 167-176. [3] Neish C.D. *et al.* (2010) *Astrobiology 10*, 337-347. [4] Neish C.D. *et al.* (2018) *Astrobiology 18*, 571-585. [5] https://astrobiology.nasa.gov/research/life-detection/ladder/ [6] Hand K. *et al.* (2018) *LPSC 49*, #2430. [7] Barnes J.W. *et al.* (2018) *LPSC 49*, #2721. [8] Chyba, C. *et al.* (1999) *LPSC 30,* #1537. [9] Lorenz, R.D. (2000) *J. British Interplanetary Soc. 53*, 218-234. [10] Leary J. *et al.* (2008) Titan Flagship study https://solarsystem.nasa.gov/multimedia/downloads/Titan_Explorer_Public_Report_FC_opt.pdf [11] Stofan E. *et al.* (2013) *Proc. Aerospace Conf. IEEE*, DOI: 10.1109/AERO.2013.6497165. [12] Golombek M.P. *et al.* (1997) *JGR 102*, 3967-3988. [13] Lorenz R.D. (2001) *J. Aircraft 38*, 208-214. [14] Barnes J.W. *et al.* (2012) *Exp. Astron. 33*, 55-127. [15] Langelaan J.W. *et al.* (2017) *Proc. Aerospace Conf. IEEE*. [16] Trainer M.G. *et al.* (2018) *LPSC 49*, #2586. [17] Lorenz R.D. *et al.* (2018) *LPSC 49*, #1647. [18] MacKenzie S.M. *et al.* (2019) *LPSC 50.* [19] Lorenz R.D. *et al.* (2019) *LPSC 50*. [20] Wilson C.F. & Lorenz R.D. (2017) *LPSC 48*, #1859. [21] Lorenz R.D. *et al.* (2012) *Int'l Workshop Instr. Planet. Missions, LPI Contrib.* 1683, p.1072. [22] Lorenz R.D. & Panning M. (2018) *Icarus 303*, 273-279. [23] Zacny K. *et al.* (2020) *LPSC 51*. [24] Trainer M.G. *et al.* (2017) *LPSC 48,* #2317. [25] Lawrence D.J. *et al.* (2017) *LPSC 48*, #2234. [26] Lorenz R.D. *et al.* (2018) *APL Tech Digest 34*, 374-387.