***DRAGONFLY*: INVESTIGATING THE SURFACE COMPOSITION OF TITAN.**

M. G. Trainer[1], W. B. Brinckerhoff[1], C. Freissinet[2], D. J. Lawrence[3], P. N. Peplowski[3], A. M. Parsons[1], K. Zacny[4], E. P. Turtle[3], J. W. Barnes[5], R. D. Lorenz[3], S. M. Hörst[6], J. M. Soderblom[7], A. M. Stickle[3], and the *Dragonfly* Team. [1]Goddard Space Flight Center, Greenbelt MD 20771, melissa.trainer@nasa.gov, [2] Laboratoire Atmosphères, Milieux, Observations Spatiales, Guyancourt, France, [3]Johns Hopkins Applied Physics Lab., Laurel, MD 20723, [4]Honeybee Robotics, Pasadena, CA 91103, [5]University of Idaho, Moscow, ID 83844, [6]Johns Hopkins University, Baltimore, MD, [7]Massachusetts Institute of Technology, Cambridge, MA 02139.

Introduction: *Dragonfly* is a rotorcraft lander mission, selected as a finalist in NASA's New Frontiers Program, that is designed to sample materials and determine the surface composition in different geologic settings on Titan [1-3]. This revolutionary mission concept would explore diverse locations to characterize the habitability of Titan's environment, to investigate how far prebiotic chemistry has progressed, and to search for chemical signatures that could be indicative of water-based and/or hydrocarbon-based life [4].

Here we describe *Dragonfly's* capabilities to determine the composition of a variety of surface units on Titan, from elemental components to complex organic molecules. The compositional investigation includes characterization of local surface environments and finely sampled materials. The *Dragonfly* flexible sampling approach can robustly accommodate materials from Titan's most intriguing surface environments [5].

Diverse Sample Environments: Titan offers complex and diverse carbon-rich chemistry in abundance on an ice-dominated ocean world [*e.g.* 6,7], making it an ideal destination to study prebiotic chemistry [*e.g.* 8,9] and document habitability of an extraterrestrial environment [10]. The *Dragonfly* rotorcraft will descend to and study the composition of Titan's organic dune fields and interdunes [11]. Dune sands, an endmember of Titan's sedimentary processes, are ideal materials through which to reveal local conditions, history and process [12]. Interdune flats show a water-ice spectral component that indicates mingling of organic materials with crustal water ice [13,14]. Over its prime mission (>2 years), *Dragonfly* will travel to and explore a wide variety of additional surface sites, including locations where there is evidence of past liquid water, and therefore where there may be biologically relevant compounds [9].

The *Dragonfly* surface composition investigation provides the first comprehensive in situ study of Titan's chemical diversity and complexity. This extended, close-up view of Titan will transform our understanding of this exotic, yet Earth-like locale. *Dragonfly* will also redefine our knowledge regarding the limits and possibilities of prebiotic chemistry, habitable environments, and astrobiological processes on a planetary scale.

Elemental Composition and Surface Layering: *Dragonfly* will determine the bulk elemental composition in the landing area immediately below the rotorcraft, detecting and quantifying the abundance of water ice, organic material, and minor elements of interest for biochemistry, without any sampling operations.

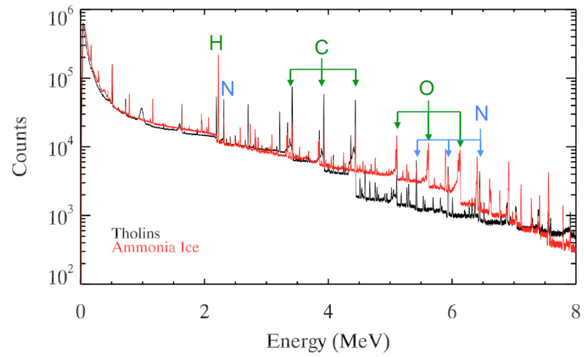

Figure 1. This simulated PNG-induced gamma-ray spectrum shows elemental spectra achieved for two different types of materials (tholins in black and ammonia ice in red) that might be present at the surface of Titan. Gamma-ray lines from H, C, O, and N are labeled [15]. "Tholins" are laboratory-generated analogs of Titan's ubiquitous organic haze material [e.g., see 25].

Elemental measurements are made by the *Dragonfly* Gamma-Ray and Neutron Spectrometer (DraGNS) instrument. Titan's atmosphere is sufficiently thick that cosmic rays cannot reach the surface; therefore gamma-ray measurements at Titan require the use of a pulsed neutron generator (PNG) (e.g. [16]). High-precision concentration and possibly organic-ice layering measurements of key elements (H, C, O, N) can be achieved using a HPGe sensor. A few-hour measurement can strongly discriminate between different types of materials thought to be at Titan's surface - for example, ammonia-rich water ice, pure ice, and carbon-rich dune sands (Fig. 1). DraGNS also permits the detection of minor inorganic elements such as sodium or sulfur. This quick chemical survey at each new site informs the *Dragonfly* science team as to which types of sampling (if any) and detailed analysis should be performed.

Sampling Approach: Following characterization of each new site, the science team may command acquisition of a surface sample for detailed compositional analysis. The *Dragonfly* sample acquisition system, provided by Honeybee Robotics, includes two sample acquisition drills, one on each landing skid. Titan's dense atmosphere permits the sample (whether sand, icy drill cuttings, or other material) to be conveyed pneumatically [17] by a blower—the material is sucked up through a hose and is extracted in a cyclone separator for delivery to the mass spectrometer instrument [2, 5]. The use of two drills provides redundancy, potential sample diversity at a single site, and the opportunity to limit cross-talk between samples, while the pneumatic transfer ensures samples remain cold and accommodates a wide range of surface materials. This approach reduces risk and complexity, and the mobility of the rotorcraft lends flexibility to the sampling approach. Depending on the heterogeneity of the surface (e.g., patches of sand), a small displacement of a few meters or tens of meters may enable the sampling of different materials.

Surface Chemical Composition: Acquired surface samples will be delivered to one of two delivery systems for transfer to the *Dragonfly* Mass Spectrometer (DraMS) instrument and subsequent chemical analysis. DraMS derives significant heritage from Sample Analysis at Mars (SAM) [18] and Mars Organic Molecular Analyzer (MOMA) [19] instruments, and is ideally suited to the analysis of a variety of Titan surface materials. The default analysis mode will be chemical characterization using laser desorption-mass spectrometry (LDMS),

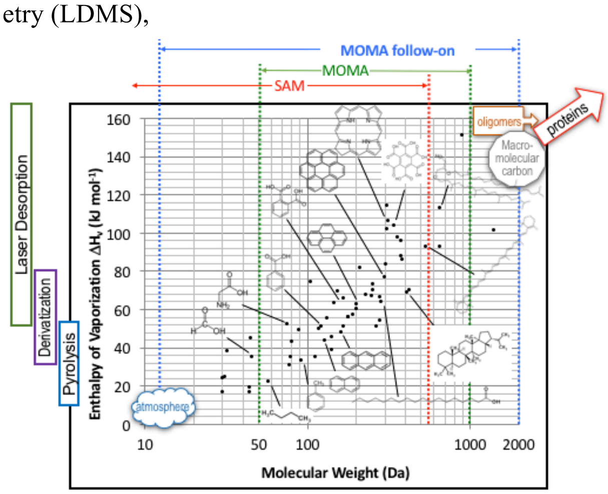

Figure 2. Laser desorption/ionization (LDI) greatly expands the mass range and types of organic molecules that can be probed with mass spectrometry. LDI at Titan would enable the detection and characterization of a broad range of chemical signatures with implications for prebiotic chemistry [21].

which can be executed multiple times per sample, for multiple samples per site. LDMS mode is designed to analyze compounds of moderate-to-low volatility, such as heavy molecular weight carboxylic acids, aromatic species, chain-like compounds, and macromolecular organics, without significant thermal degradation (Fig. 2) [20]. Though initially developed for flight at Mars, LDMS has been shown to be easily adaptable to Titan surface environment and highly capable of analyzing Titan-like surface materials [21].

Nature and Origin of Complex Molecules: Mobility on Titan provides an excellent opportunity to sample various materials for simple and complex organic matter characterization. DraMS can also operate using pyrolysis and derivatization gas chromatography/mass spectrometry (pyr/der-GCMS). Through these analytical modes, *Dragonfly* will not only detect and identify compounds over a wide range of molecular weights and volatilities, but also investigate their origin and biological relevance. Pyr/der-GCMS can distinguish abundance patterns, repeating structural patterns, and enantiomeric excesses [22,23]. Thus *Dragonfly* can perform a broad-based search for multiple chemical signatures that would be indicative of prebiotic or biological processes [24].

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