**TITAN'S SURFACE FROM DRAGONFLY: BRIDGING THE GAP BETWEEN COMPOSITION AND ENVIRONMENT.** S. M. MacKenzie[1], J. I. Núñez[1], E. P. Turtle[1], R. D. Lorenz[1], S. M. Hörst[4], A. Le Gall[3], J. Radebaugh[4], M. G. Trainer[5], J. W. Barnes[6], S. Murchie[1], and the Dragonfly Team. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD (shannon.mackenzie@jhuapl.edu), [2]Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD, [3]LATMOS/IPSL, UVSQ Université Paris-Saclay, [4]Department of Geological Sciences, Brigham Young University, Provo, UT, [5]NASA Goddard Space Flight Center, Greenbelt, MD, [6]Univ. Idaho, Moscow, ID.

**Exploration of Titan with *Dragonfly*:** With a thick atmosphere producing complex organics that fall onto the water-ice crust overlying a subsurface ocean, Saturn's moon Titan is a highly carbon-rich ocean world [1]. As an easily accessible natural laboratory, Titan offers a unique opportunity to explore prebiotic chemistry and habitability beyond Earth. The *Dragonfly* mission concept, currently in Phase A development as part of the New Frontiers 4 competition, would fly a rotorcraft lander to determine the composition of Titan's organic and water-ice rich surface materials at multiple sites [2 ,3]. *Dragonfly* would therefore elucidate the chemistries possible on Titan today, which have implications for the prebiotic conditions on the early Earth [4], potentially habitable niches in transient liquid environments [5], and potential habitable conditions for hydrocarbon-based life [6].

*Dragonfly*'s primary science goals are focused on determining the organic and inorganic chemical composition of Titan's surface materials [2]. But the Earth-like geological and atmospheric processes at work on Titan make understanding the geological context of the detailed chemistry measurements critical to evaluating the habitability potential of this ocean world.

**Chemical composition:** *Dragonfly* data will reveal not only what species are present but how they are distributed across the surface. *Dragonfly*'s suite of cameras (DragonCam) serves as a bridge between the in-depth point measurements made by the Dragonfly Mass Spectrometer (DraMS) and the surrounding terrain. A rotary-percussive drill on each skid [7] extracts surface samples for analysis with DraMS as well as a microscopic imager with an LED array of targeted wavelengths [8] is focused on the drill sites and equipped. Illuminating the surface with specific wavelengths in the visible-near-infrared enables *Dragonfly* to distinguish between water-ice and organic-rich materials at the microscale (Figure 1). UV illumination would reveal the presence of organics like polycyclic aromatic hydrocarbons via fluorescence [9]. Such spectral data provide microtextural, compositional context, creating a bridge between the sample-scale measurements of DraMS to lander- and landing site-scale images taken by the other DragonCam cameras. Extrapolating between these scales facilitates building hypotheses concerning the geological provenance of the samples and thus the processes responsible for distributing and reworking compounds for prebiotic (or potentially even biotic [5]) chemistry.

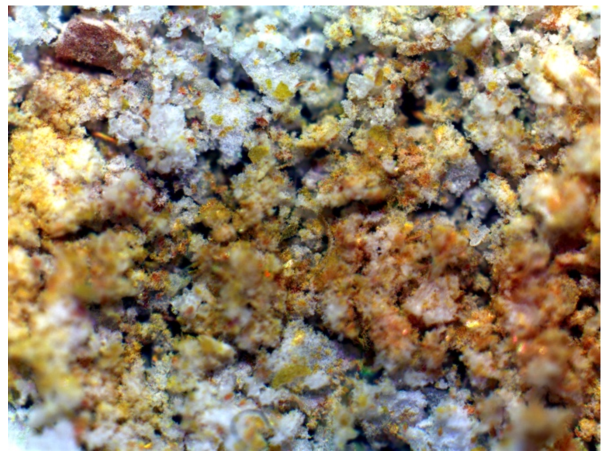

**Figure 1.** False-color tholin-water ice mixture illuminated with R=0.935, G=0.770, B=0.455 μm wavelength LEDs and imaged at ~ 6 μm pixel scale (FOV ~14 x 10 mm). Two kinds of tholins (made with 5% and 10% methane in nitrogen respectively) are prominently distinguishable from each other (yellow and orange) and from water ice (white) in this enhanced color image [8].

**Modes of transport:** DragonCam imaging will reveal the distribution of grain sizes at each *Dragonfly* landing site. Saltation threshold wind speeds will be determined via passive observations (similar to those made by Curiosity [e.g. 10]) and a controlled saltation threshold and transport rate experiment using a rotor [11]. Coupling these data with the compositional measurements will show what kinds of materials are redistributed across the surface via aeolian transport. Furthermore, comparing the chemical composition of sand grains to their transportability and the conditions of the surrounding environment may reveal changes in the structure or reactivity of the regolith. Saltating sand grains on Earth and Mars, for example, experience physical and chemical alteration [e.g. 12].

**Material properties:** Observations of the interactions between the rotorcraft and the surface can also provide evidence for deducing the physical properties of the regolith, much like the investigations by *Viking* [13]. The slopes of conical piles of drill tailings will allow us to measure the angles of repose while the morphology of the drilled hole provides insight into material cohesion. By monitoring the force applied during drilling, Dragonfly can also investigate regolith bulk hardness. Material properties are especially important for constraining sources and relative ages of Titan's organic sands [14, 15].

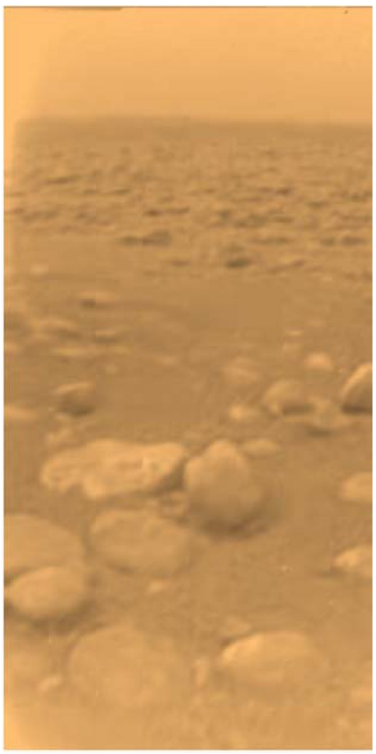

**Figure 2.** *Huygens*' 128x256 pixel image from Titan's surface (ESA/NASA/U. Arizona). *Dragonfly* will acquire larger-scale views of its surroundings, which, combined with higher-resolution images of the sampling sites, will be used to establish the connection between samples analyzed with DraMS and the geological processes at work on sediments at each landing site.

**Dampness and porosity:** *Dragonfly* will land in Titan's equatorial desert, but evidence from *Huygens* (Figure 2) [16] and *Cassini* [17, 18] suggest that liquid hydrocarbons have been present at times (more likely around Titan's equinoxes than solstice near which *Dragonfly* would arrive). The ephemeral availability of liquids to transport or modify local sediments is therefore an important environmental consideration for interpreting the provenance of sampled materials. By monitoring near-surface humidity and determining the dampness of the near-subsurface and the porosity of regolith, *Dragonfly* will determine whether other sites in the equatorial region have the capacity of multiple sites for retaining moisture by monitoring near-surface humidity and determining the dampness of the near-subsurface and the porosity of regolith. The Dragonfly Geophysics and Meteorology Package (DraGMet) measures methane humidity via differential near-IR absorption. DraGMet also measures the regolith's dielectric constant and thermal inertia, analogous to experiments conducted by Phoenix [19]. These properties are related to dampness and porosity and have broader implications for the exchange of energy between the atmosphere and the surface [20-22]. Monitoring of drill noise by the seismic instrumentation will also shed light on the physical structure of the regolith beneath and near the lander [23], another bridge between observations at the microscopic and macroscopic scales.

**Context is key:** Just as detection of biological activity would require multiple lines of evidence [24], determining whether a world or even localized environments are potentially habitable requires more than just a survey of what oxidants, reductants, or CHNOPS-bearing molecules are present. *Dragonfly* is specifically designed to gather the evidence necessary to robustly characterize Titan's regolith environment and interpret the chemical analyses in the proper context.

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