DEVELOPMENT OF THE *DRAGONFLY* MASS SPECTROMETER (DRAMS) FOR TITAN. M. G. Trainer[1], W. B. Brinckerhoff[1], A. Grubisic[1], R. M. Danell[1,2], D. Kaplan[1,3], F. H. W. van Amerom[1,4], X. Li[1,5], C. Freissinet[6], C. Szopa[6], A. Buch[7], J. C. Stern[1], S. Teinturier[1,8], C. A. Malespin[1], P. W. Barfknecht[1], P. R. Stysley[1], D. B. Coyle[1], M. W. Mullin[1], B. L. James[1], E. I. Lyness[1,9], R. S. Wilkinson[1,10], J. W. Kellogg[1], K. Zacny[9], D. C. Wegel[1], E. P. Turtle[10], and the *Dragonfly* Team. [1]NASA Goddard Space Flight Center, Greenbelt MD (melissa.trainer@nasa.gov), [2]Danell Consulting, Winterville NC, [3]Kapscience, Tewksbury MA, [1,4]Mini-Mass Consulting, Hyattsville MD, [5]University of Maryland Baltimore County, Baltimore MD, [6]LATMOS, Guyancourt, France, [7]LPGM, Gif-sur-Yvette, France, [8]Universities Space Research Association, Columbia MD, [9]Microtel, Greenbelt MD, [10]ATA Aerospace, Greenbelt MD, [11]Honeybee Robotics, Altadena CA, [12]Johns Hopkins University Applied Physics Laboratory, Columbia MD.

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 habitability of an extraterrestrial environment [*e.g.*, 1-4]. NASA's *Dragonfly* New Frontiers mission is a rotorcraft lander [5] designed to perform wide-ranging *in situ* exploration on this moon of Saturn by flying to different geologic settings up to ~180 km apart. Multidisciplinary science measurements at each landing site will reveal the compositions of the solid materials on Titan's surface, which are still essentially unknown [6-8].

Two primary science goals of the *Dragonfly* mission are to identify chemical components and processes at work that may produce biologically relevant compounds, and to search for potential molecular biosignatures. These objectives are addressed by the *Dragonfly* Mass Spectrometer (DraMS), which performs molecular analysis on surface samples that are acquired and delivered by the Drill for Acquisition of Complex Organics (DrACO).

The *Dragonfly* Mass Spectrometer (DraMS): DraMS is a linear ion trap mass spectrometer, most closely related to the Mars Organic Molecule Analyzer (MOMA) [9], part of the ExoMars *Rosalind Franklin* Rover set to launch in 2022. For solid sample analysis, DraMS features two modes: Laser Desorption Mass Spectrometry (LDMS) for the broad compositional survey of surface materials including refractory organics, and Gas Chromatography Mass Spectrometry (GCMS) for the separation and identification of key prebiotic molecules and measurement of enantiomeric excesses (if present). LDMS mode allows for structural disambiguation of surface molecules using ion isolation and tandem mass spectrometry (MS/MS). GCMS mode uses pyrolysis or derivatization to volatilize, separate, and identify molecules of interest. Much of the gas processing system (valves, pyrolysis oven, etc.) and electronics are also inherited from the Sample Analysis at Mars (SAM) instrument onboard *Curiosity* [10].

Hardware Developments: *Dragonfly* was selected by NASA in June 2019, and technical development activities related to DraMS through the first part of Phase B have focused on areas in which the unique

Table 1. DraMS Specifications

Characteristic	Predicted Performance
Mass Sensor	Linear Ion Trap
Mass Range	**15 – 1950** Da [a]
Mass Resolution	**0.4** – 3 Da (FWHM) [b]
Mass Accuracy	**± 0.4 Da**
Ion polarity	Positive and Negative ion detection [c]
Limit of detection	**100 ppbw** organics in surface sample
GC Columns	Two; General and Chiral separation

Bold = Exceeds requirements
[a] Composite range, individual modes access a subset of this range
[b] Resolution decreases above required maximum mass range (550 Da), impacts LDMS mode.
[c] Negative ion detection only in LDMS mode

aspects of the Titan environment and *Dragonfly* science [11] differed from the heritage Mars instruments.

Cold Zone-Warm Zone interface. The surface temperature on Titan is a relatively steady 94 K, but the interior of the lander is held closer to 273 K (0°C). DraMS is coupled to the DrACO sample handling system, which has been designed to handle a variety of potential Titan surface materials [12]. DrACO leverages the thick Titan atmosphere [1.5 bar, primarily N_2/CH_4 (95:5)] to pneumatically transfer fines generated by one of two redundant drills to sample collection cups designed for either GCMS or LDMS mode. During transport through the pneumatic system, surface materials entrained in a stream of ingested atmosphere are held within ~10 degrees of Titan ambient. This minimizes phase changes, mitigating against surface adhesion or clogging. After transfer into the specialized sample cups, the samples are moved around a 60-cup carousel and delivered into one of two ports for DraMS analysis.

The DrACO carousel and sample cups reside within a portion of the lander that is thermally coupled to the Titan atmosphere – known as the "cold zone" of the attic (Figure 1). This region maintains samples at temperatures ≤ 165K to prevent melting of the bulk materials such as water ice or water-ammonia mixtures. The "Wonderwall" provides the mechanical and thermal interface between the cold sample zone and the warm instrument zone. Early Phase B design work focused heavily on the development of this interface with the goals of maintaining a large thermal gradient, minimizing mass, and allowing access to the sample during LDMS analysis with tight mechanical tolerances. A Wonderwall breadboard was assembled and tested at the end of 2020, successfully demonstrating that the sample temperature could be maintained in the cold zone.

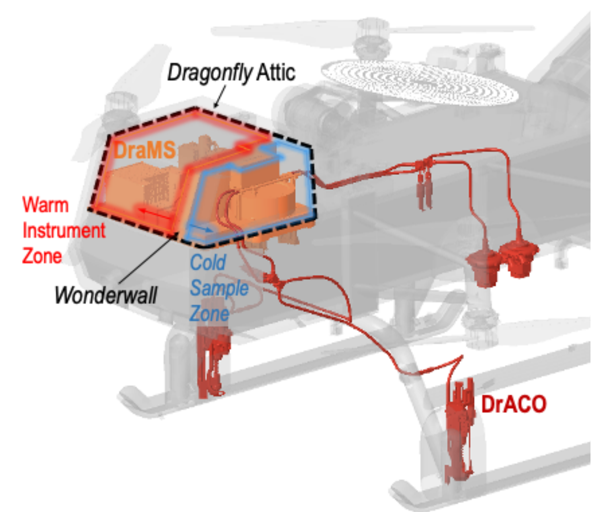

Figure 1. The *Dragonfly* "Attic" Cold Zone and Warm Zone.

Laser Desorption (LDMS) interface. For LDMS analysis, the sample resides behind a fine mesh slit window in a specialized sample cup. For analysis, the LDMS cup is inserted into a small chamber, with the mesh window positioned only a few mm away from the ion inlet tube of the DraMS instrument. The laser impinges on the sample through the mesh at Titan sub-ambient pressure (< 50 mbar) and sample temperature < 165 K, with the resulting ions ingested into the mass spectrometer.

The influence of mesh geometry parameters on LDMS detection of organic analyte coronene was quantified, with signal level observed to be proportional to percent sample area visible to the laser. Additionally, the role of Titan sub-ambient atmosphere on ionization and MS/MS performance has been explored.

Ultraviolet (UV) Laser. DraMS LDMS is accomplished using a compact solid-state 266-nm pulsed Nd:YAG laser. A brassboard has been developed and fully characterized for performance, including lifetime, emission of precise laser bursts (0–100 shots at up to 100 Hz), and energy attenuation capability [13]. Fluence at the sample is a critical parameter that has been evaluated for optimized analysis of a range of sample compositions (e.g., mostly organics to mostly water ice). The DraMS laser Engineering Test Unit (ETU) is currently in development for full TRL and environmental testing.

Pumping System. The high ambient pressure at Titan relative to Earth (1.5x) and Mars (150x) necessitates a robust pumping system to provide the required vacuum for mass spectrometer operation. The heritage wide range pump (WRP) used on SAM and MOMA exhausts to Mars-like pressures; on DraMS the WRP is backed by a rugged miniature scroll pump (MSP, Creare). A second MSP is used to evacuate the LDMS sample chamber to its operational pressure of ~40 mbar. A prototype MSP has been tested, demonstrating that it can meet environmental and performance requirements when operating at Titan surface pressure of 1.5 bar. Lifetime testing is underway.

Ion Trap Mass Spectrometer. The DraMS ion trap design includes a few enhancements over the MOMA-MS in order to optimize scientific return from Titan. For example, the DraMS instrument includes the capability to analyze negative as well as positive ions during LDMS mode. The detector system design was modified to include negative ion detection with minimized electrical complexity.

Gas Chromatography (GCMS) Operations. The varied and mostly unknown compositional units on the Titan surface require DraMS to have a flexible analytical strategy. For GCMS analysis, the pyrolysis and derivatization processes need to accommodate the potential range of abundances and compositions in the samples. Early testing of analog materials has commenced to aid in the determination of operational parameters.

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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] Lorenz R.D. *et al.* (2018) *APL Tech Digest 34*, 374-387. [6] Trainer M.G. *et al.* (2018) *LPSC 49*, #2586. [7] Barnes J.W. *et al.* (2018) *LPSC 49*, #2721. [8] Lorenz R.D. *et al.* (2018) *LPSC 49*, #1647. [9] Goesmann F. et al. (2017) *Astrobiology* 17(6-7): 655-685. [10] Mahaffy P. R. et al. (2012) *Space Sci Rev*, *170*, 401–478. [11] Turtle E. et al. (2018) *LPSC 49,* # 1958. [12] Zacny K. et al. (2020) *LPSC 51,* #1763. [13] Coyle D.B. et al (2018) *Proc of SPIE* 10636, doi.org/10.1117/12.2305223.