In Situ Exploration of Titan's Organic Chemistry and Habitability

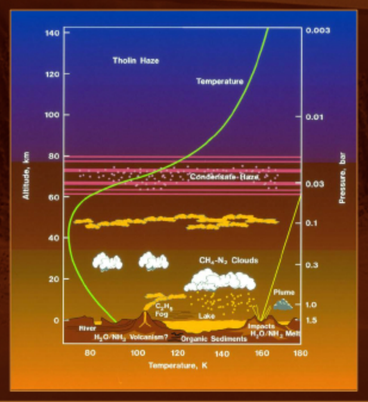
Zibi Turtle, Melissa Trainer, Jason Barnes, Ralph Lorenz, Ken Hibbard, Doug Adams, Peter Bedini, Will Brinckerhoff, Morgan Burks, Morgan Cable, Carolyn Ernst, Caroline Freissinet, Kevin Hand, Alex Hayes, Sarah Hörst, Jeff Johnson, Erich Karkoschka, Jack Langelaan, David Lawrence, Alice Le Gall, Juan Lora, Shannon MacKenzie, Chris McKay, Rich Miller, Scott Murchie, Catherine Neish, Claire Newman, Jorge Nunez, Jose Palacios, Mark Panning, Ann Parsons, Patrick Peplowski, Lynnae Quick, Jani Radebaugh, Scot Rafkin, Mike Ravine, Sven Schmitz, Jason Soderblom, Kristin Sotzen, Angela Stickle, Ellen Stofan, Cyril Szopa, Tetsuya Tokano, Colin Wilson, Aileen Yingst, Kris Zacny

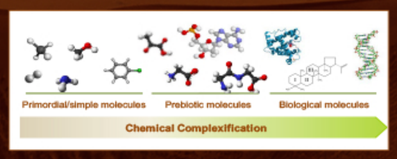
A Carbon-Rich Ocean-World

Titan offers abundant complex organics on the surface of a water-ice-dominated ocean world, making it an ideal destination to study prebiotic chemistry and document the habitability of an extraterrestrial environment [1-7].

What makes a planet or moon habitable?

What chemical processes led to the development of life?





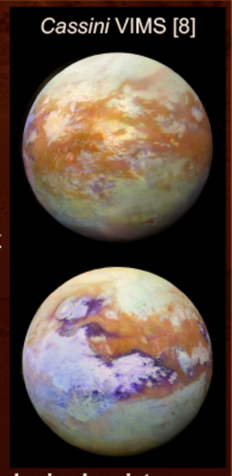
Organic-rich Titan supports complex chemical cycling and opportunities for organics to have interacted with liquid water at the surface in the past. *Dragonfly* will investigate the chemical processes at work and determine how far organic synthesis has progressed in environments that provide all the key ingredients for life.

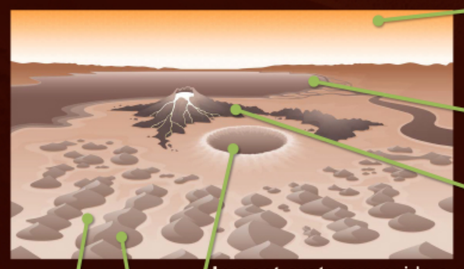
Diverse Surface Environments

Titan is an Earth-like world with active geological processes and a global methane cycle

- Widespread re-distribution of materials
- Liquid methane could support development of alternate biological systems
- Potential for organics to interact with liquid water at the surface, e.g., impact craters and cryovolcanism
- Potential for exchange of organics with interior ocean

Cassini VIMS [8]





Atmospheric chemistry produces very complex organic molecules that fall out onto the surface

Active methane cycle fills hydrocarbon lakes and seas and subsurface reservoirs

Cryovolcanoes bring interior liquid water into contact with surface materials

Impact craters provide surface oases where warm liquid water mixes with organics for 10^3-10^5 years [4,9-10]

Dune sands collect widely sourced organic material

Interdune areas expose water-ice-rich bedrock

The *Dragonfly* Science Investigation

Dragonfly is a New Frontiers Phase-A study of a rotorcraft lander designed to perform wide-ranging in situ exploration and discovery to determine how far chemistry has progressed in environments providing key ingredients for life.

A lander with aerial mobility enables sampling of materials and detailed measurement of surface compositions at dozens of sites in different geologic settings 10s – 100s of km apart.

Dragonfly would perform multidisciplinary science at each site and in flight to understand the compositional measurements in the context of Titan's meteorology and methane cycle, the local geologic setting and material properties [11], and geophysical measurements of the subsurface [12].

Science Objectives:

- *Analyze chemical components available and processes at work that produce biologically relevant compounds [13-16]*
- *Measure atmospheric conditions, identify methane reservoirs, and determine transport rates [17-19]*
- *Constrain processes that mix organics with past surface liquid water reservoirs or subsurface ocean*
- *Search for chemical evidence of water- or hydrocarbon-based life*

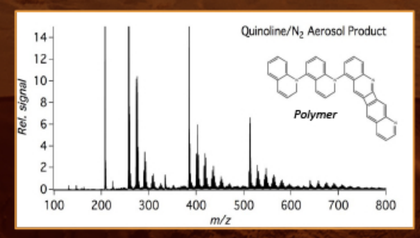
Titan's dense atmosphere (4x that at Earth's surface) and low gravity (1.35 m/s^2), heavier-than-air mobility is highly efficient [20-23].

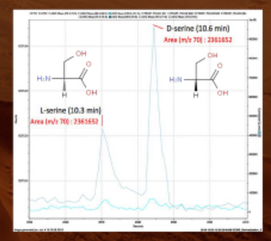
Mission Timeline and Operations

- 2025 launch; 2034 Titan arrival = ~1 Titan year after *Huygens'* first landing in equatorial dunes [24] characterized by *Cassini*
- In situ operations have relaxed pace with 16-day Titan-sols
- Flights using battery recharged by MMRTG [20,25]
- Direct-to-Earth communication
- Over 2 years of exploration (MMRTG output degrades slowly)

Titan as a Natural Laboratory to Investigate Prebiotic Chemistry and Habitability

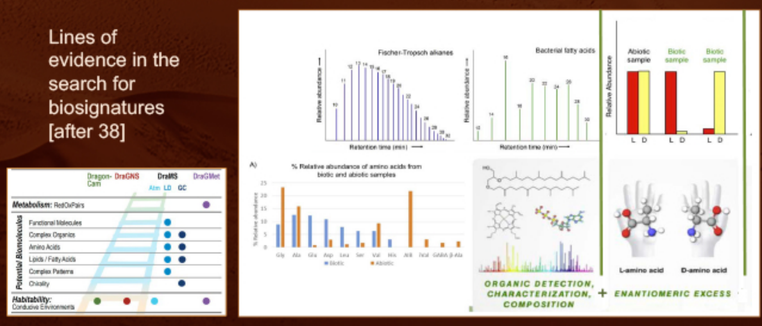
The *Dragonfly* Mass Spectrometer (DraMS) performs detailed analyses of chemical components, providing a broad compositional survey, organic molecular structural analysis including chirality, and selective, compound-specific measurements of primordial, prebiotic and biologically relevant molecules in surface samples [15, 26-35].



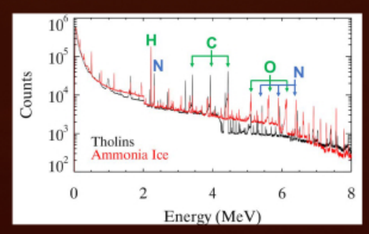


A broad-based search for multiple chemical biosignatures minimizes assumptions about the nature of any potential life. This strategy draws from the NASA Astrobiology 'Life Detection Ladder' and from other missions chartered to search for potential biosignatures [5, 36-38]. Evaluating relative abundance and distribution of organics is diagnostic for biology that uses liquid water as a solvent [39-40].

Lines of evidence in the search for biosignatures [after 38]



The neutron-activated *Dragonfly* Gamma-ray and Neutron Spectrometer (DraGNS) measures bulk elemental surface composition, allowing rapid classification of surface material and detection of minor inorganic elements [15,16].



The *Dragonfly* Geophysics and Meteorology package (DraGMet) measures surface and subsurface properties, including seismic monitoring [41], and atmospheric conditions, including searching for H_2 sinks.

The DragonCam camera suite acquires surface panoramas, hand-lens imaging, and aerial imaging to characterize geologic features and provide context for sampling [42].

References:

1. Raulin F. *et al.* (2010) Titan Astrobiology, in *Titan from Cassini-Huygens* Brown *et al.* Eds.
2. Thompson W.R. & Sagan C. (1992) *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. Chyba C. *et al.* (1999) *LPSC 30,* #1537.
8. Le Mouélic S. *et al.* (2019) *Icarus* **319**, 121-132.
9. Sagan C. *et al.* (1992) *ACR* **25**, 286-292.
10. O'Brien D. *et al.* (2005) *Icarus* **173**, 243-253.
11. MacKenzie *et al.* (2019) *LPSC 50*, #2885.
12. Lorenz *et al.* (2019) *LPSC 50,* #2173.
13. Trainer M. G. *et al.* (2017) *LPSC 48*, Abstract #2317.
14. Zacny K. *et al.* (2017) LPSC 48, Abstract #1366.
15. Trainer M. G. *et al.* (2018) *LPSC 49*, Abstract #2586
16. Lawrence D. J. *et al.* (2017) *LPSC 48*, Abstract #2234.
17. Wilson C. F. and Lorenz R. D. (2017) *LPSC 48*, Abstract #1859.
18. Lorenz R. D. *et al.* (2012) *Int'l Workshop on Instrumentation for Planetary Missions*, LPI Contrib. 1683, p.1072.
19. Stofan E. *et al.* (2013) *Proc. Aerospace Conf. IEEE*, DOI: 10.1109/AERO.2013.6497165.
20. Lorenz, R.D. (2000) *J. British Interplanetary Soc.* **53**, 218-234.
21. Lorenz R.D. (2001) *J. Aircraft* **38**, 208-214.
22. Barnes J.W. *et al.* (2012) *Experimental Astron.* **33**, 55-127.
23. Langelaan J.W. *et al.* (2017) *Proc. Aerospace Conf. IEEE*.
24. Lorenz R.D. *et al.* (2018) *LPSC 49*, Abstract #1647.
25. Lorenz R. (2017) *Proc. Nuclear and Emerging Technologies for Space (NETS)*, Abstract #21106.
26. Mahaffy P. R. *et al.* (2012) *Space Sci Rev* **170**, 401–478.
27. Pinnick V.T. *et al.* (2016) *LPSC 47*, #2770.
28. Brinckerhoff W.B. *et al.* (2013) *IEEE Aerospace Conf.* doi: 10.1109/AERO.2013.
29. Arevalo Jr. R. *et al.* (2015) *IEEE Aerospace Conf.* doi: 10.1109/AERO.2015.7119073.
30. Goesmann F. *et al.* (2017) *Astrobiology* **17**(6-7): 655-685.
31. Brinckerhoff W.B. *et al.* (2016) *3rd IPM* #4112.
32. Li X. *et al.* (2016) *LPSC 47*, #2707.
33. Li X. *et al.* (2014) *Astrobiology* **15**, 104-110.
34. Gautier T.J. (2017) *PSS*, doi:10.1016/j.pss.2017.03.012.
35. Buch A. *et al.* (2006) *PSS* **54**, 1592-1599.
36. Neveu *et al.* (2018) *Astrobiology* **18**, doi: 10.1089/ast.2017.1773.
37. Mustard J.F. *et al.* (2013) http://mepag.jpl.nasa.gov/reports/MEP/Mars_2020_SDT_Report_Final.pdf
38. Hand K. *et al.* (2017) https://solarsystem.nasa.gov/docs/Europa_Lander_SDT_Report_2016.pdf.
39. Lovelock J. E. (1965) *Nature* **207**(4997), 568-570.
40. McKay C.P. (2004) *PLoS Biol* **2**:E302.
41. Lorenz R.D. & Panning M. (2018) *Icarus* **303**, 273-279.
42. Lorenz R.D. *et al.* (2018) *APL Tech Digest* **34**, 374-387.