Sampling Titan's Diverse surface with a (relocatable) Lander

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Next step in seeking answers to fundamental questions

What makes a planet or moon habitable?
What chemical processes led to the development of life?

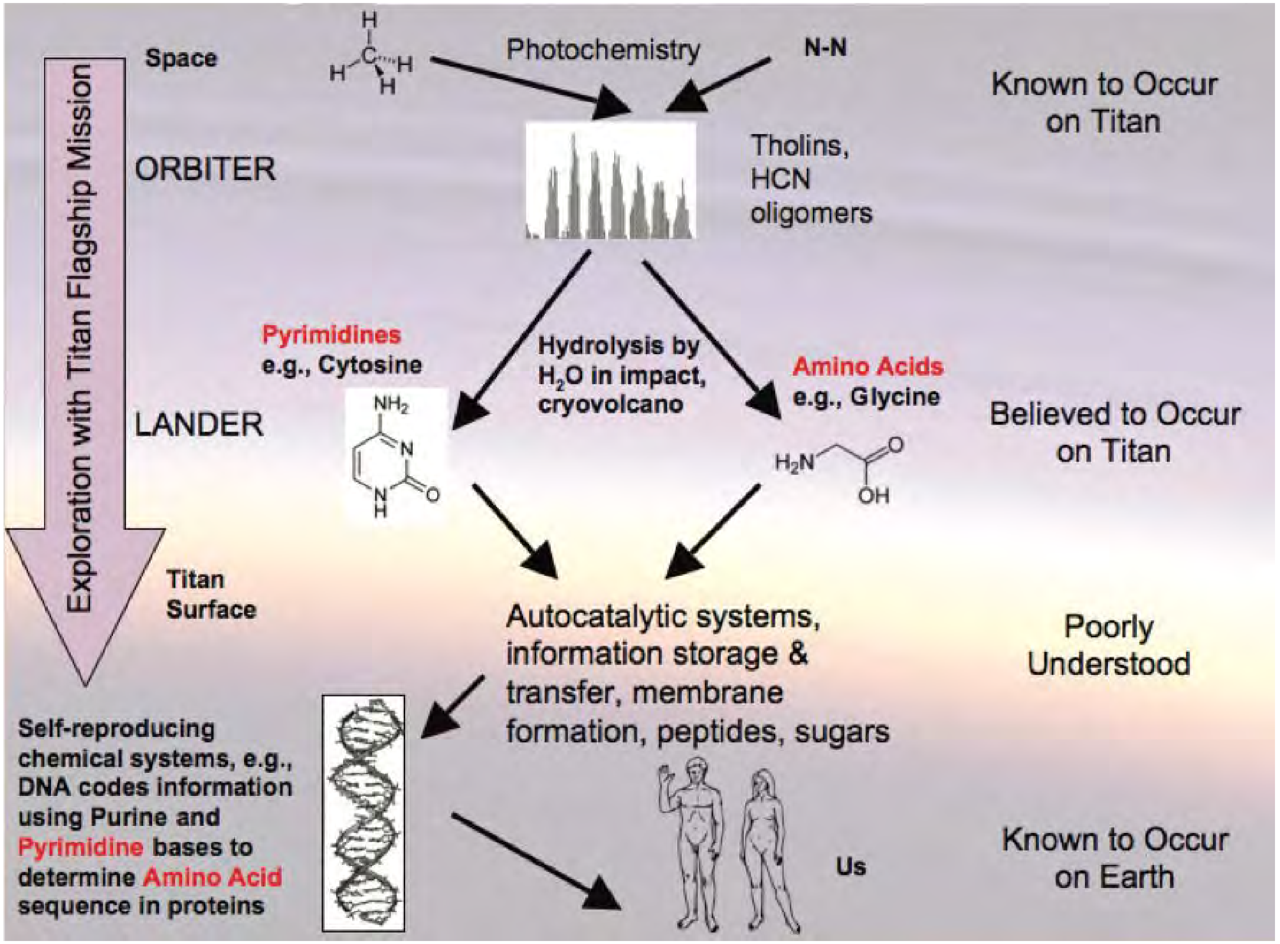
- Titan is an ideal destination to answer these questions because it has the key ingredients known to be necessary for life:

  Energy: Sunlight, photochemistry

  Organic material: Abundant carbon and complex organics

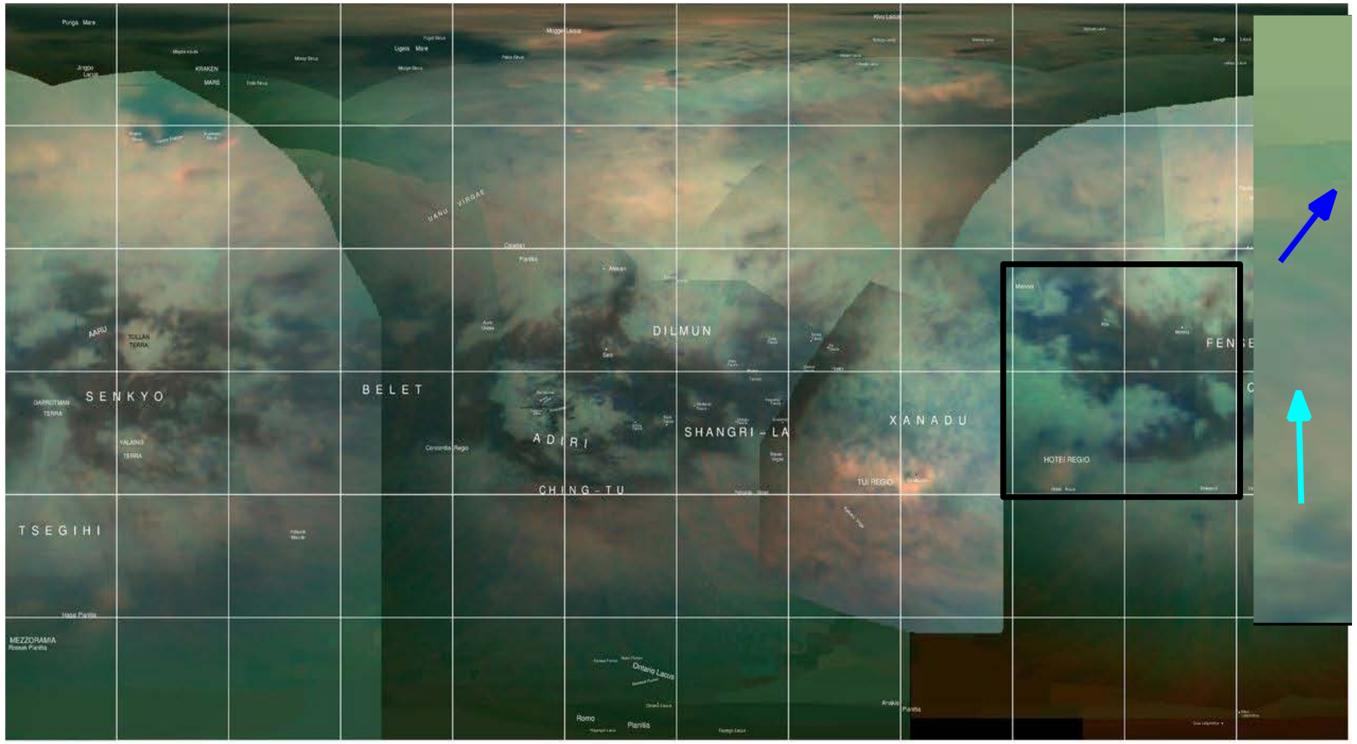
  Solvents: Liquid water, as well as methane

  - Potential for organics to interact with *liquid water at the surface*, e.g., cryovolcanism, impact craters
  - Potential for exchange of surface organics with vast *Interior ocean*
  - Earth-like world with an active methane cycle instead of Earth's water cycle
    - *Liquid methane* could support development of alternate biological systems
- Titan is an **ocean world** laboratory to investigate primitive chemistry and to search for biosignatures



(Lorenz, Waite, Leary, Reh, *et al.*, 2007,
Titan Explorer Flagship Mission Study Report)

Diversity of surface materials
→ scientific priority to sample diverse locations



- *Cassini* VIMS map illustrates the spectral diversity of Titan's surface
  - Red = 5 μm, green = 2 μm, blue = 1.3 μm
  - Dark blue = higher water-ice content
  - Dark brown = organic sands (Barnes *et al.* 2007; Soderblom *et al.* 2007)
  - Orange = 5-μm bright unit with characteristics consistent with evaporitic material (MacKenzie *et al.* 2014)

Combines strategies considered previously for in situ Titan exploration

- **Helicopter** *(Lorenz 2000)*
- **Airship** *(helium or hydrogen; Levine & Wright 2005; Hall et al. 2006)*
- **Montgolfière** hot-air balloon *(Reh et al. 2007)*
- **Airplane** *(Levine and Wright 2005; Barnes et al. 2012)*
- **Sea lander** *(TiME, Stofan et al. 2013)*

Flagship mission studies:

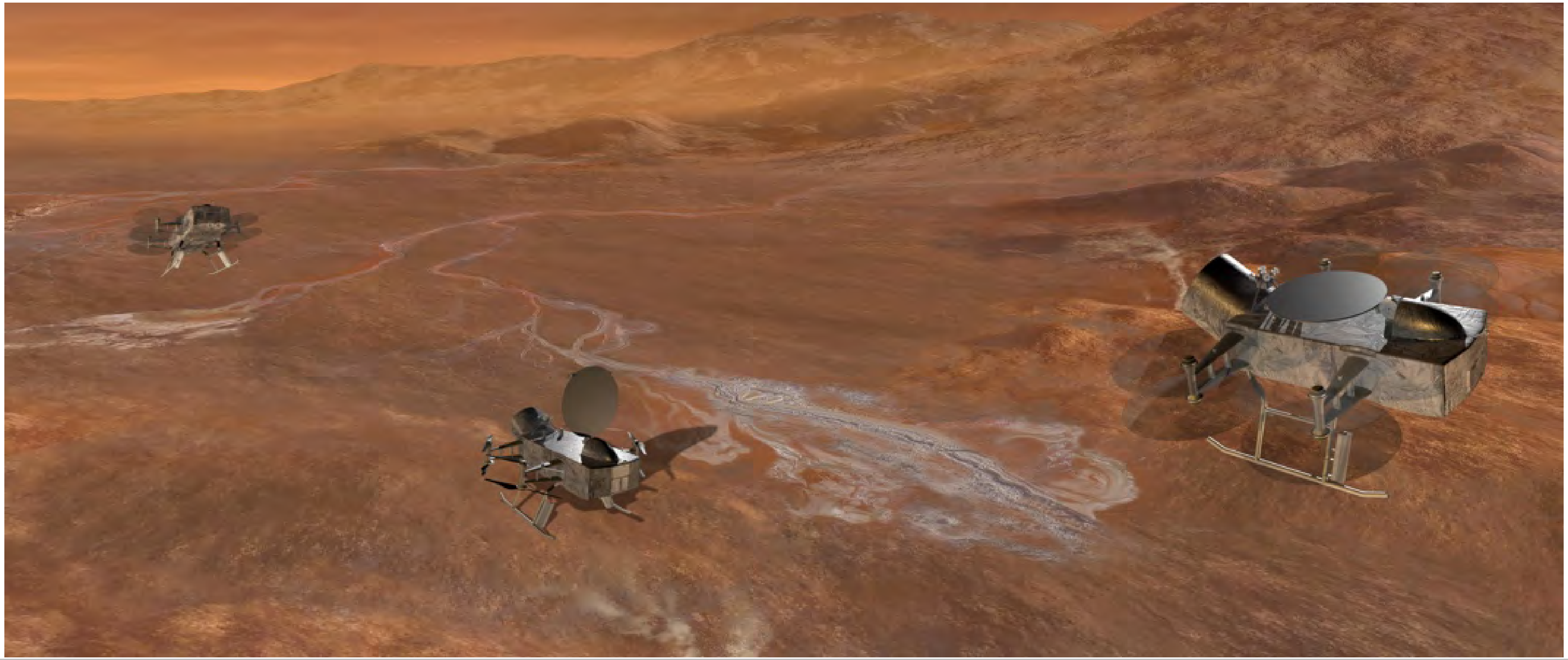
- NASA Titan Explorer Flagship *(Leary et al. 2007)*
  - Lander + Montgolfière-type balloon
  - Two landers
- NASA-ESA Titan Saturn System Mission *(TSSM; Lunine, Lebreton et al. 2008):*
  - Montgolfière + lander

Dragonfly addresses the challenge of Titan's diverse landscape with a lander with aerial mobility → a relocatable lander

- Enables sampling at multiple targeted locations
- Acquires context for samples & in situ measurements
- Ability & adaptability to find & access interesting material
- Explore an alien environment on human scale

Diversity of surface materials → scientific priority to sample diverse locations

- Titan's atmosphere provides the means to access different geologic terrains 10s to 100s of kilometers apart
  - Titan's atmosphere 4x denser than Earth's → reduces wing/rotor area required to generate a given amount of lift → all forms of aviation are easier (lighter- and heavier-than-air)
  - Titan's gravity 1/7th Earth's → reduces the required magnitude of lift → powerful factor in favor of heavier-than-air vehicle
  - Equivalent mass/rotor disk area vehicle requires 38x less power at Titan (Lorenz 2000, 2002; Langelaan *et al.* 2017)
  - Given rotor span, speed operates at higher Reynolds number on Titan (much more efficient e.g. than at Mars)
  - Modern control electronics make a multi-rotor vehicle (Langelaan *et al.* 2017) mechanically simpler than a helicopter, *cf.* proliferation of terrestrial quadcopter drones; straightforward to test on Earth
  - Pick up the whole lander and relocate. Need soft-landing system anyway..



Dual-quadcopter rotorcraft lander

- Most of time (~99%) spent on ground making measurements, flight used to explore different sites and provide context measurements of the surroundings
- Flight uses battery power, recharged by an MMRTG between flights and science activities (as in Lorenz, 2000 concept)
- In situ operations strategies similar to rovers on Mars
  - Flexible operations with more relaxed pace with 16-day Titan-sols
  - Science activities on ground and some measurements in flight
  - Aerial scouting to identify sites of interest per ground analysis
  - On-board autonomy performs flight along pre-determined path, executes safe landing
- Direct-to-Earth communication via steered High-Gain Antenna

Science Objectives

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

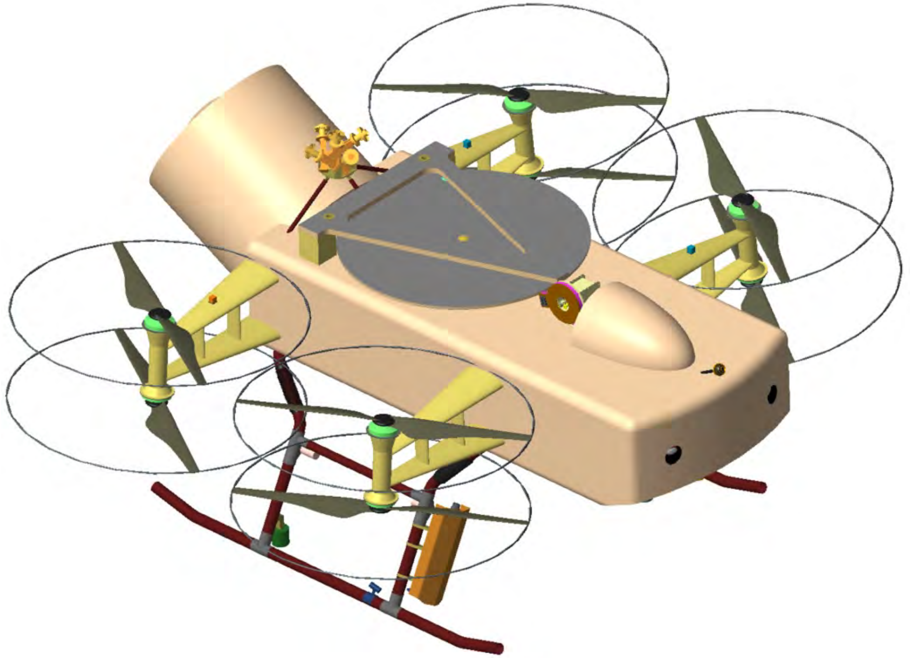
Science payload:

DraMS (GSFC): Mass spectrometer

DraGNS (APL & GSFC): Gamma-ray and neutron spectrometer

DraGMet (APL): Meteorology, seismic, and other geophysical sensors

DragonCam (MSSS): Camera suite



Science measurements

- On surface:
  - DraMS: Sample material and perform detailed analyses of chemical components and progression of organic synthesis

    Building off of *Curiosity* rover's SAM instrument (Sample Analysis at Mars), which has pyrolysis and gas chromatographic analysis capabilities
  - DraGNS: Measure bulk elemental surface composition, allowing rapid classification of surface material and detection of minor inorganic elements

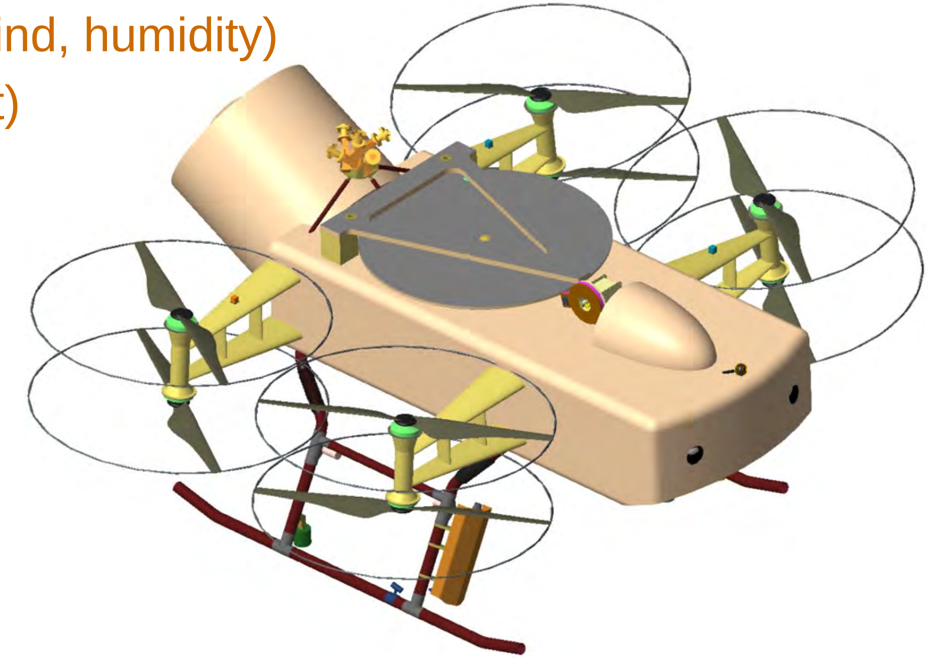
    Chemical reconnaissance informs sampling and detailed chemical analysis to be performed
  - DraGMet: Monitor atmosphere (pressure, temperature, wind, humidity)

    Surface conditions (thermal properties, dielectric constant)

    Seismic monitoring to detect subsurface activity

    Diurnal and spatial variations
  - DragonCam: Characterize geologic features

    Provide context for samples
- In flight:
  - Atmospheric profiles; diurnal, spatial variations
  - Aerial imagery for surface geology, context, and scouting future landing sites



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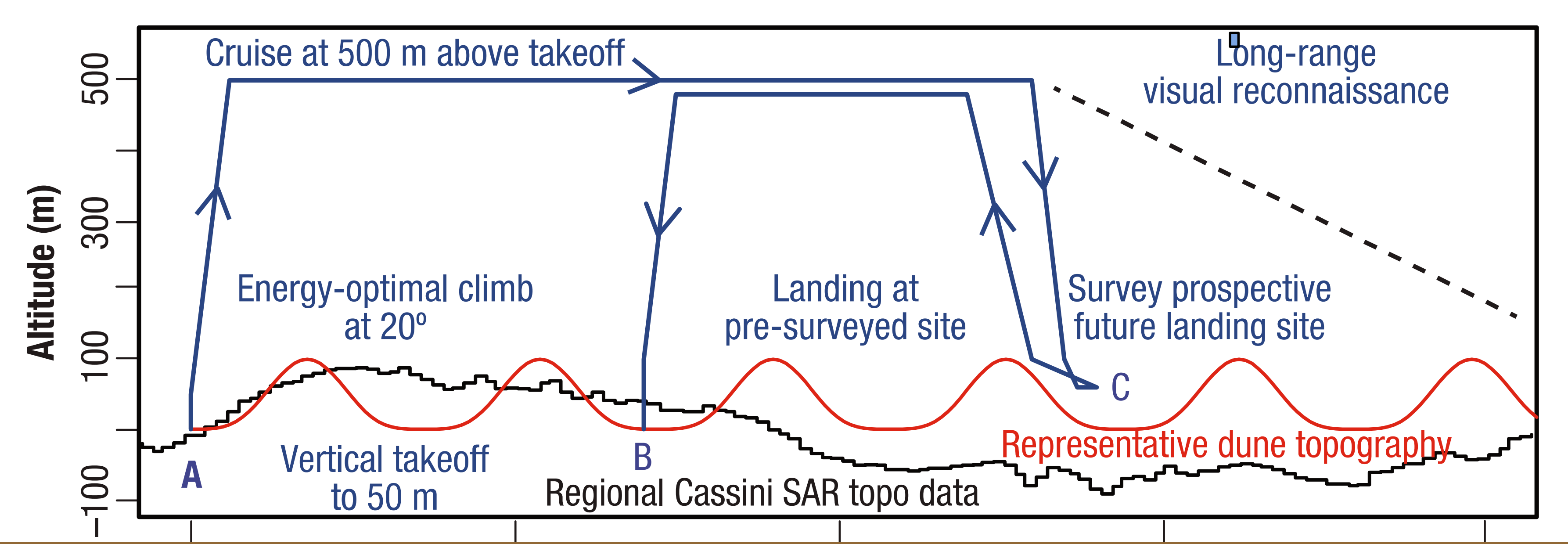
Mission timeline

- Launch in 2025
- Titan arrival in 2034
  - landing in equatorial interdunes
  - ~100-m-high, several-km spacing
  - well characterized by *Cassini*
  - similar latitude and time of year as descent of *Huygens* probe
  - Transit to other science targets

A Tsol (16 Earth days) in the life of Dragonfly

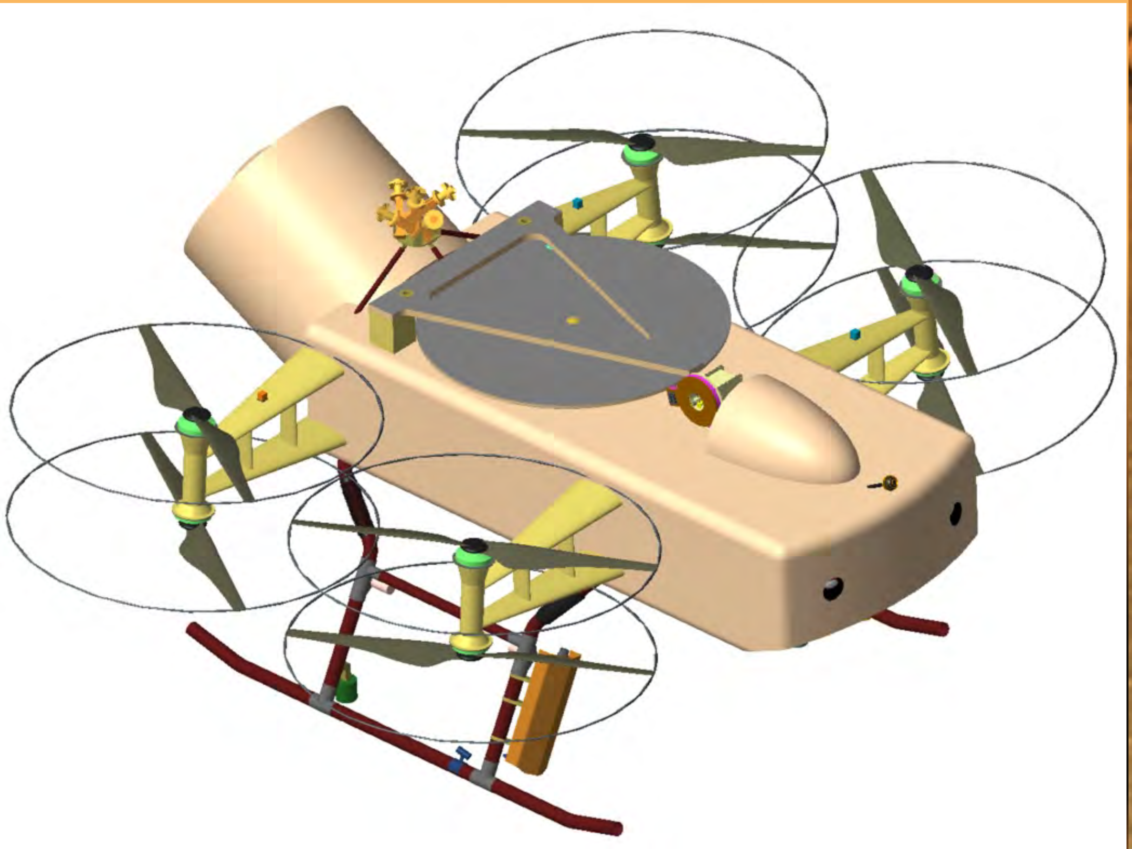
- Low-power monitoring (seismic, weather) and battery recharge by MMRTG overnight
- Night-time imaging using LED imaging to obtain color ; UV fluorescence of PAHs
- Sunrise/Earthrise - Downlink of data and uplink of direction from science team
- Weather measurements as part of pre-flight checklist
- Flight profile (typical; usually in morning but may do some pm flights for meteorological studies):
  - Take off from site A, survey landing zone B, return to site A, downlink data for science-team analysis and selection of landing site B
  - Take off from A, survey landing zone C, land at site B)



A Tsol (in the life of Dragonfly (con'td)

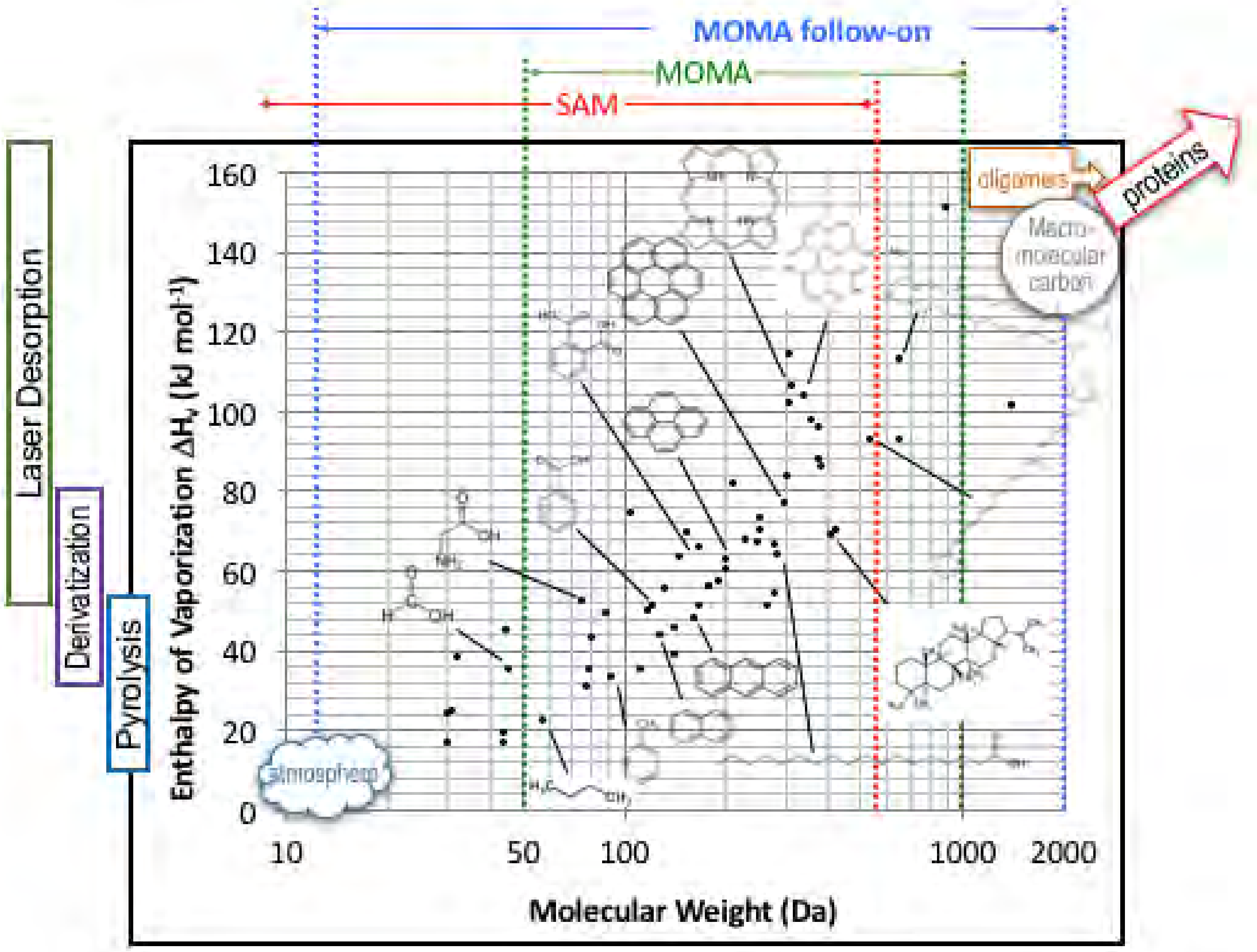
- Thermal and electrical measurements using DraGMet landing-skid sensors to estimate physical characteristics of surface material
- DraGNS measurement of bulk composition discriminates among basic surface types (*e.g.*, organic dune sand, solid H_2O ice, frozen NH_3-hydrate)
- DragonCam imaging of surroundings, workspace between skids, drill sites
- Probing of surface with drill ; application of wind stress (measure saltation threshold) by rotors

- (several 24-hour cycles of downlink, ground-in-the-loop science planning during regular office hours, before Titan sunset)
- Decide which (if any) drill to perform sampling with, depending on science intepretation of sample desirability and mechanical properties
- On many Tsols may choose not to fly (permits more downlinks, seismic monitoring etc.)



Sample Analysis on Titan

- Pneumatic sample transfer permits selection of either drill, and direction to chosen sample analysis instrumentation. Also permits sample to be kept chilled by ambient air during transfer.
- DraMS includes MOMA-like Laser Desorption/Ionization (LDI) for chemical reconnaissance of low-moderate volatility compounds
- Additionally, DraMS has a SAM-like pyrolysis-Gas Chromatograph front end for derivitization and analysis of compounds of specific biological relevance (e.g. amino acids)



New Frontiers mission concept: rotorcraft lander for in situ investigation of Titan's prebiotic chemistry and habitability

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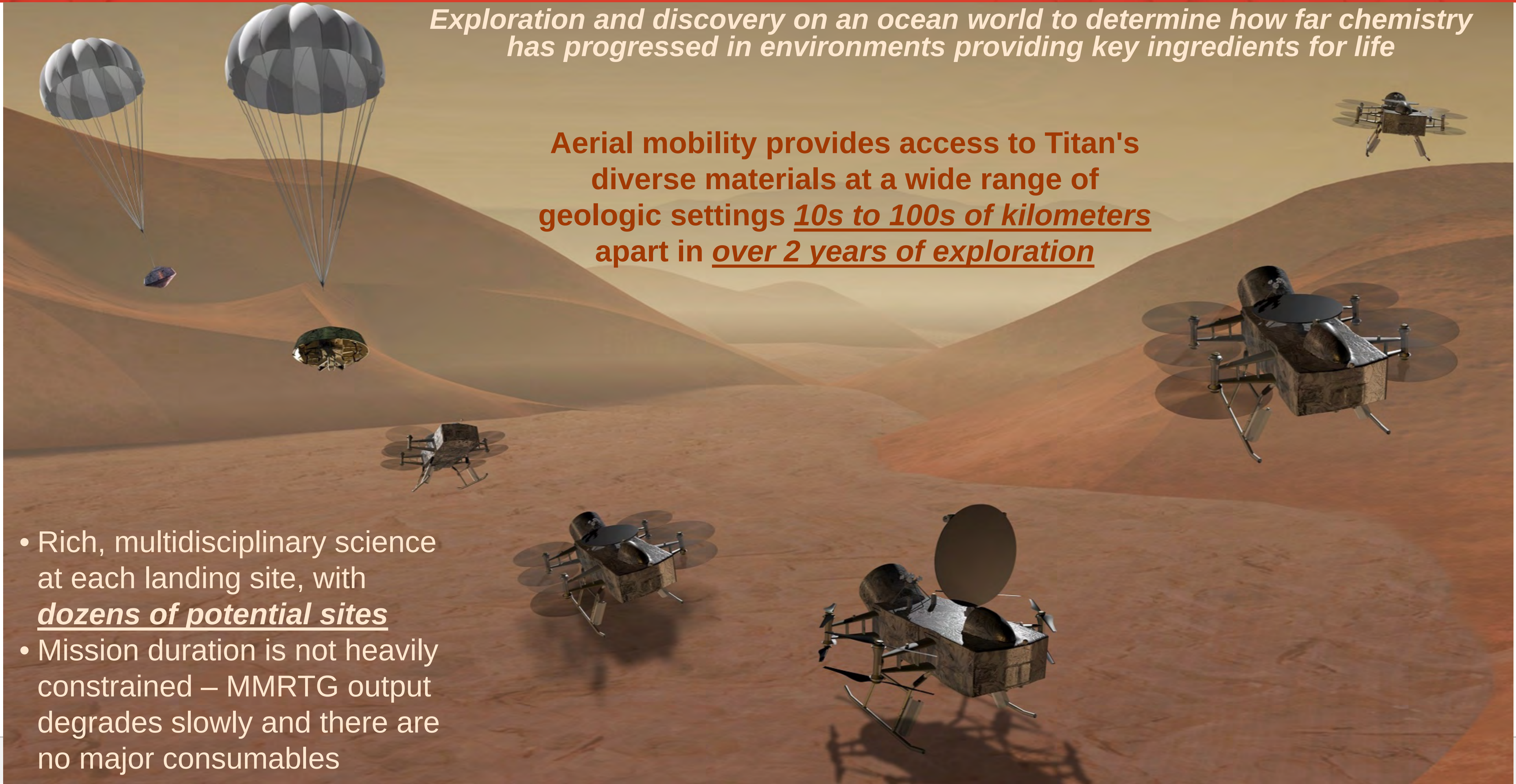

Exploration and discovery on an ocean world to determine how far chemistry has progressed in environments providing key ingredients for life

Aerial mobility provides access to Titan's diverse materials at a wide range of geologic settings *<u>10s to 100s of kilometers</u>* apart in *<u>over 2 years of exploration</u>*

- Rich, multidisciplinary science at each landing site, with ***dozens of potential sites***
- Mission duration is not heavily constrained – MMRTG output degrades slowly and there are no major consumables

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http://dragonfly.jhuapl.edu