

Dragonfly:

New Frontiers mission concept study in situ exploration of Titan's prebiotic organic chemistry and habitability

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APPLIED PHYSICS LABORATORY

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:

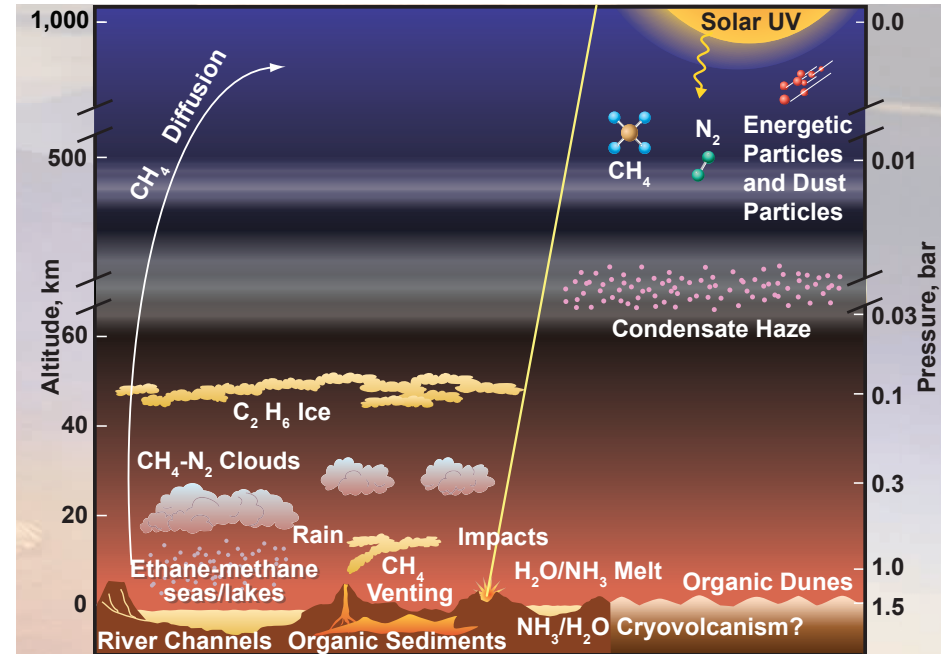
Energy: Sunlight, photochemistry

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



Titan's atmosphere:

- Surface pressure = 1.5 bar
- Surface temperature = 94 K
- Troposphere ~94% N₂, ~6% CH₄, 0.1% H₂
- Complex photochemistry in upper atmosphere → H & N compounds

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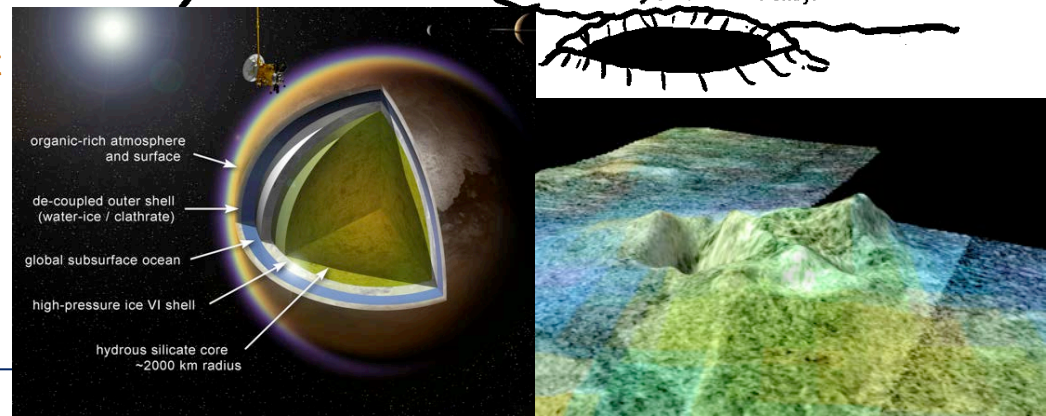
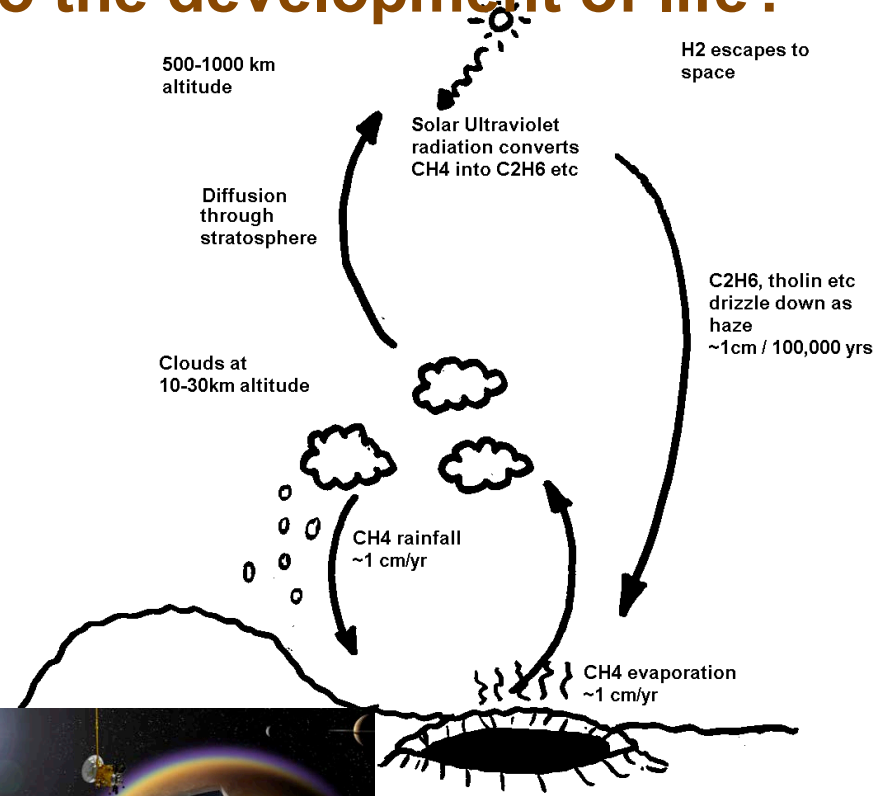
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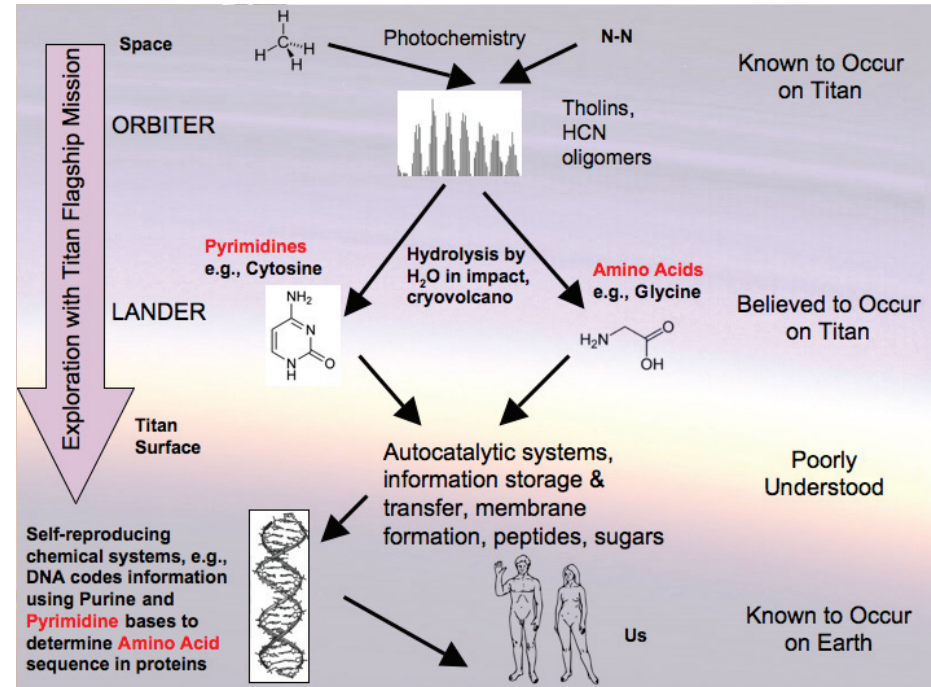
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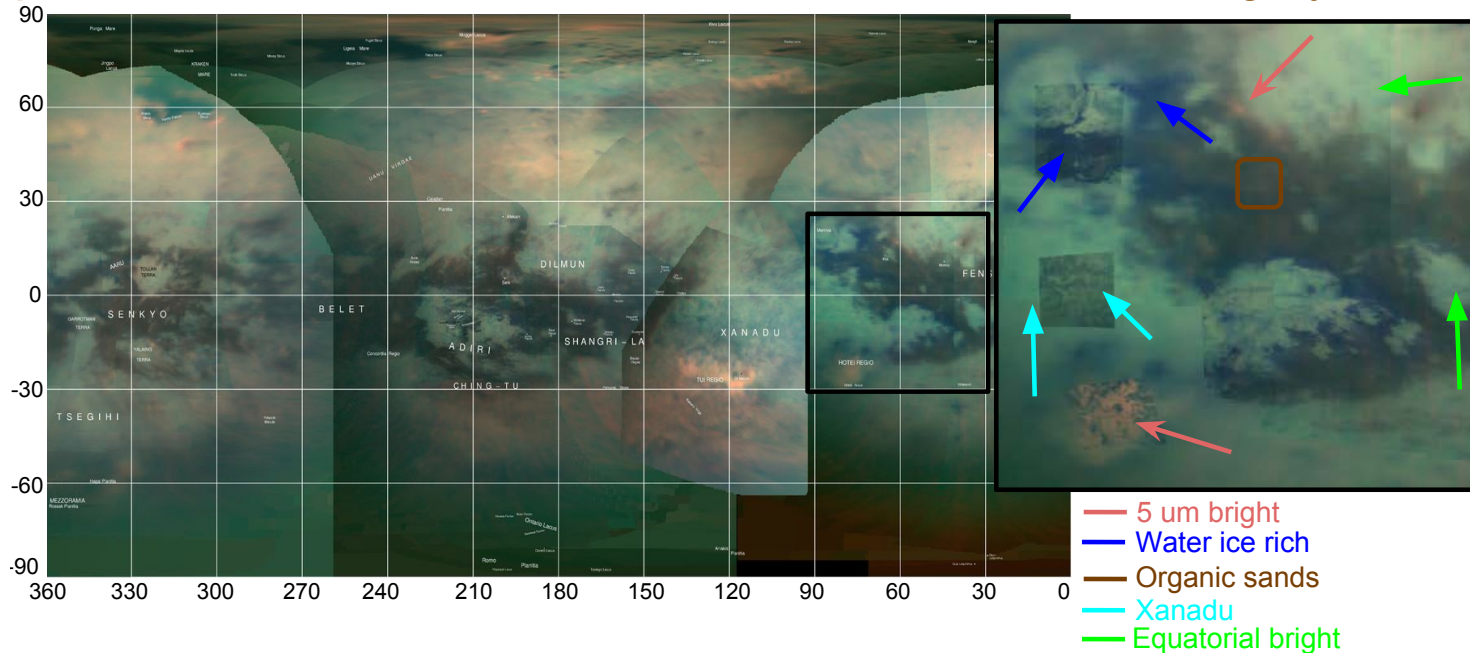
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(Lorenz, Waite, Leary, Reh, *et al.*, 2007, Titan Explorer Flagship Mission Study Report)

Diversity of surface materials → scientific priority to sample diverse locations

- Compositions of solid materials on Titan's surface still largely unknown



- Cassini* VIMS map illustrates the spectral diversity of Titan's surface, higher-resolution inset from T114 flyby (Nov 2015)
 - 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)



Diversity of surface materials → scientific priority to sample diverse locations

- Challenge is to get a capable instrument suite to high-priority sites
 - Multiple landers are an inefficient strategy, requiring multiple copies of instrumentation and sample acquisition equipment
 - More efficient approach is to convey a single instrument suite to multiple locations
 - ➔ ***Mobility is key to accessing material in different settings***
- Titan's atmosphere provides the means to access different geologic terrains 10s to 100s of kilometers apart
 - Heavier-than-air mobility highly efficient at Titan (Lorenz 2000; Langelaan *et al.* 2017)
 - 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
 - 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

➔ ***Dragonfly, a lander with aerial mobility for wide-ranging in situ exploration***





Combines strategies considered previously for in situ Titan exploration

- *Helicopter (Lorenz 2000)*
- *Airship (He or H; 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**



- Most of time spent on ground making measurements, flight used to explore different sites and provide context measurements of the surroundings
- In situ operations strategies similar to Mars rovers
 - Flexible conops 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
- Flight uses battery power, recharged by an MMRTG between flights and science activities
- Direct-to-Earth communication

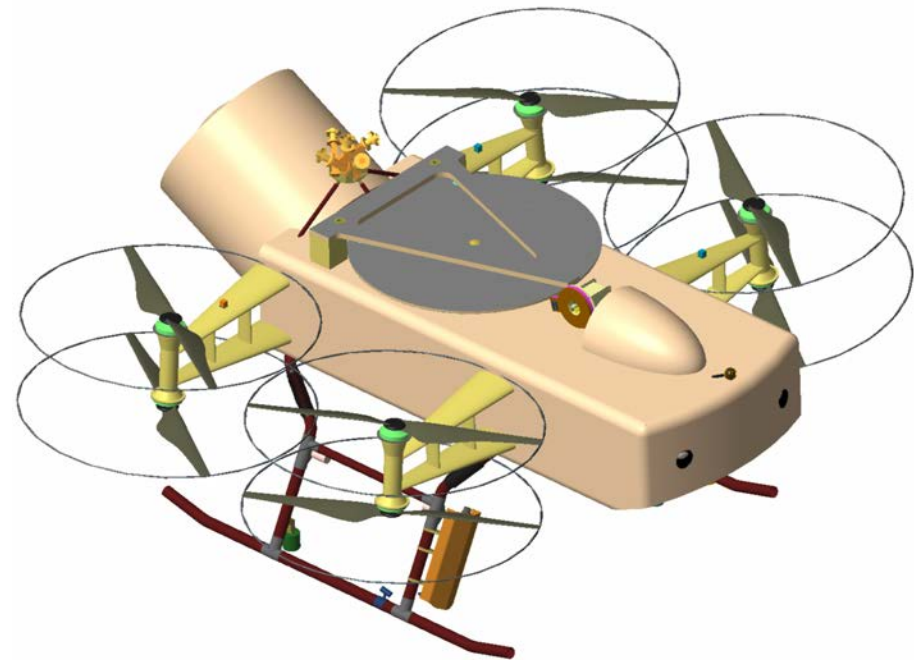
Science payload:

DraMS (GSFC): Mass spectrometer

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

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

DragonCam (MSSS): Camera suite



- 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

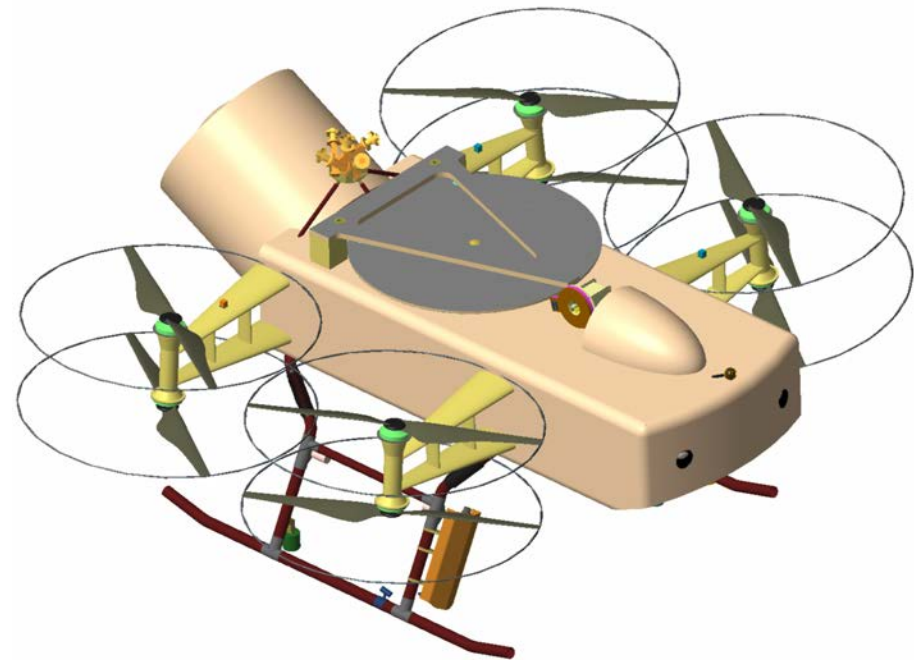
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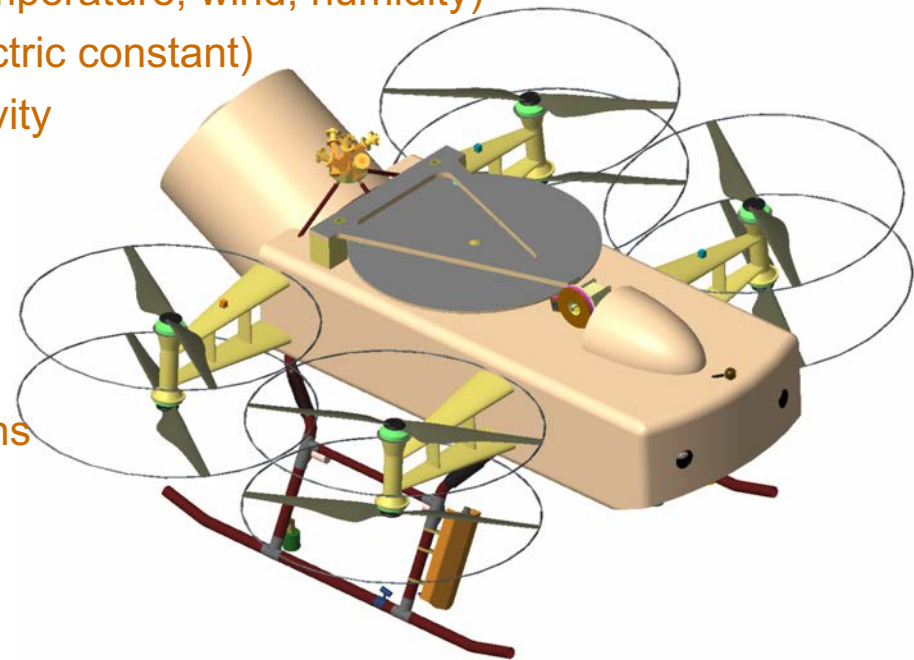


■ On surface:

- DraMS: Sample material and perform detailed analyses of chemical components and progression of organic synthesis
Heritage from *Curiosity* SAM (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



How far has chemistry progressed in environments providing key ingredients for life?

- Assess conditions necessary for habitability
- Identify astrobiological building blocks and processes that take those building blocks toward life
- Multiple techniques and approaches to perform a broad-based search for chemical signatures, minimizing assumptions and addressing different rungs on the life-detection ladder at different locations and past environmental conditions

<https://astrobiology.nasa.gov/research/life-detection/ladder/>

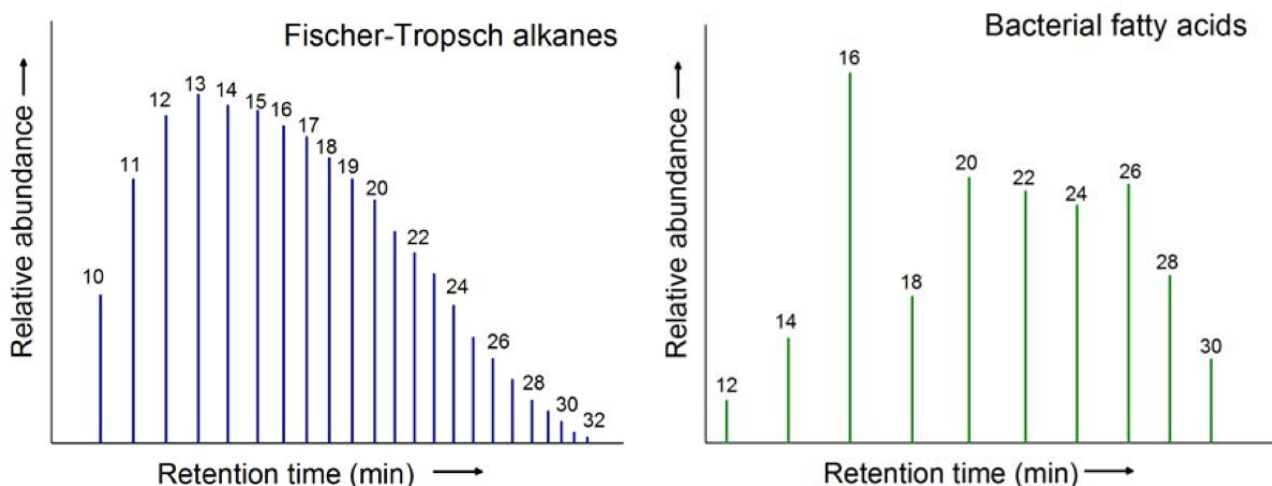


Figure 4.1.3. Left: Gas chromatogram of reaction products of Fischer-Tropsch synthesis, a non-biological process, showing the broad, non-specific production of organics. In contrast, the gas chromatogram on the right shows the specificity associated with biological processes, in particular the fatty acid fraction from a bacterial extract (Hartgers et al., 2000). Numbers above each line indicate total number of carbon atoms in the molecule associated with each peak. (Hand et al., 2017, Europa Lander SDT Report)

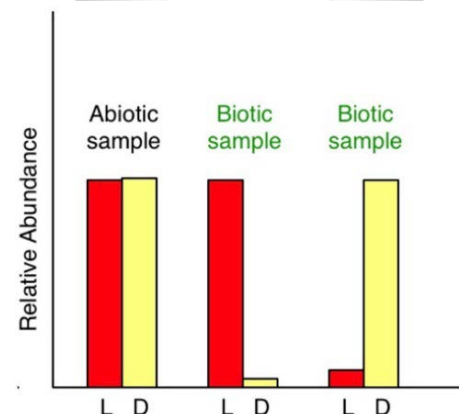
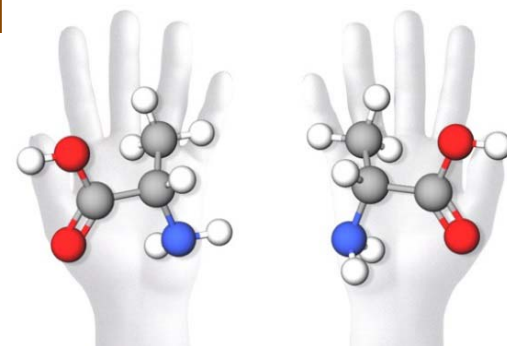
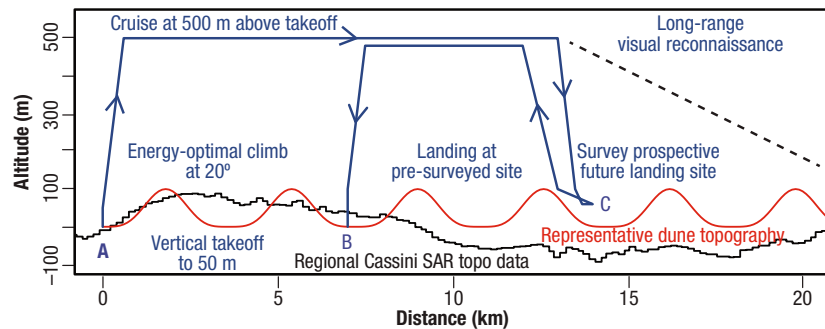
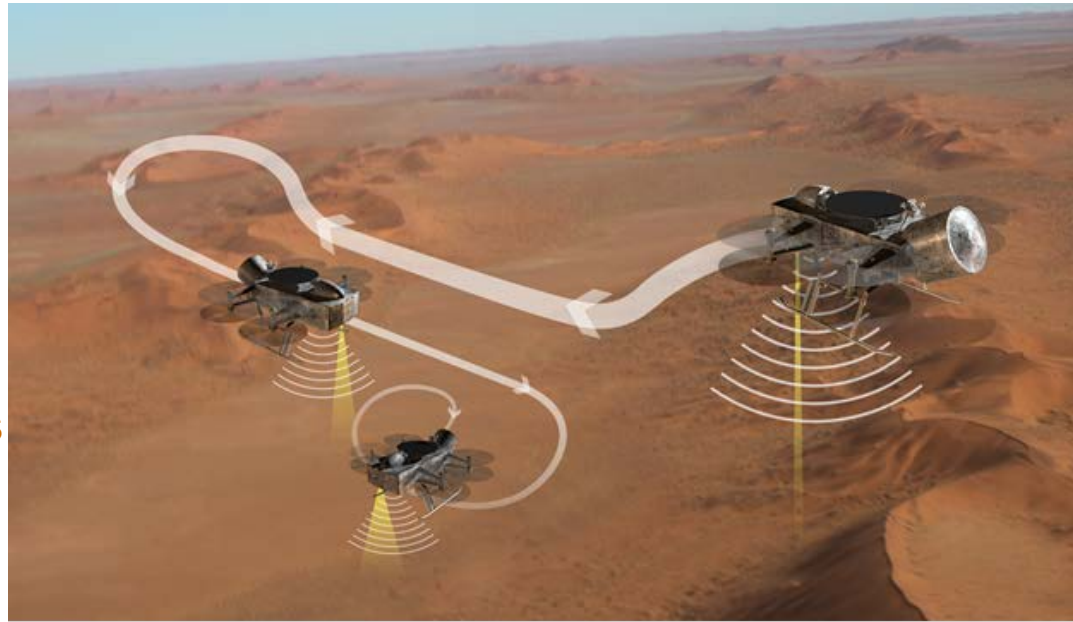


Figure 4.1.6. Chirality of alanine, represented artistically as the left- (L) and right- (D) handed versions. Biological use of predominantly one form of chiral molecules, i.e., one enantiomer (L or D), may provide a highly diagnostic biosignature.

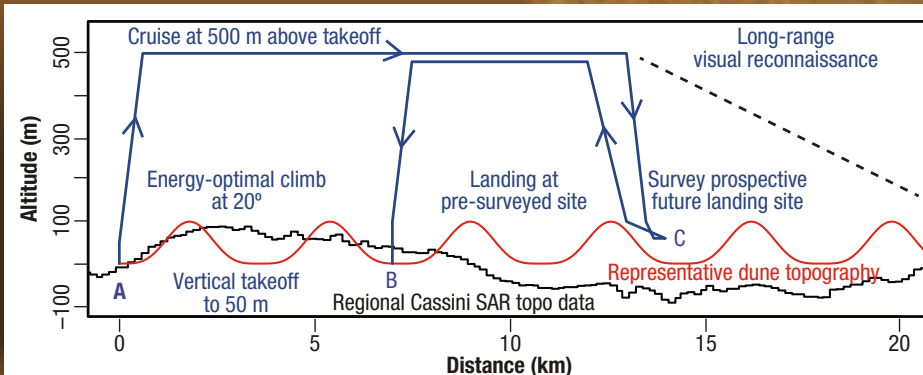
- Launch in 2025
- Titan arrival in 2034
 - landing in equatorial interdunes
 - ~100-m-high, several-km spacing
 - well characterized by *Cassini*
 - similar latitude and time of year as descent of *Huygens* probe
- Over 2 years of exploration, covering variety of terrain over 10s – 100s of km





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

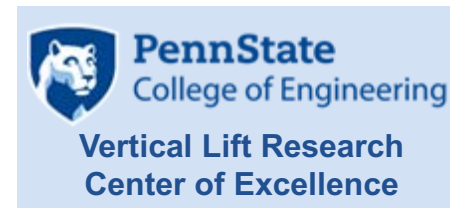
- Downlink of data and uplink of direction from science team
- Weather measurements as part of pre-flight checklist
- Flight profile and landing-site assessment:
 - Take off from site A, survey landing zone B (e.g., imaging, lidar for terrain roughness), return to site A, downlink data for science-team analysis and selection of landing site B
 - Take off from A, survey landing zone C, land at site B
- Downlink of flight data and aerial images of the landing site
- Thermal and electrical measurements using DraGMet landing-skid sensors estimate physical character of surface material
- DraGNS measurement of bulk composition discriminates among basic surface types (e.g., organic dune sand, solid H₂O ice, frozen NH₃-hydrate)
- DragonCam imaging of surroundings; DraGMet atmospheric monitoring
- Sampling and DraMS analysis
- Downlink of data and uplink of direction from science team
- Overnight recharge of battery by MMRTG
- Sampling & DraMS analysis (if deferred to night when excess energy is available)
- DraGMet seismic and meteorological monitoring
- DragonCam imaging using LED illuminators (cf. Phoenix and Curiosity) for better color discrimination of Titan surface materials; UV to identify organic material via fluorescence (e.g., dune sand polycyclic aromatic hydrocarbons)





The Dragonfly team reflects broad science and technical expertise

- Broad scientific and technical expertise and flight experience – both spaceflight and atmospheric flight
 - Spacecraft development, flight hardware, instrumentation, measurement techniques
 - Building on autonomous rotorcraft flight development
 - In situ operations – landed experience on Titan and Mars
 - Titan environment – surface and atmosphere
- Mentoring early career scientists and engineers
- NASA Participating Scientist Program



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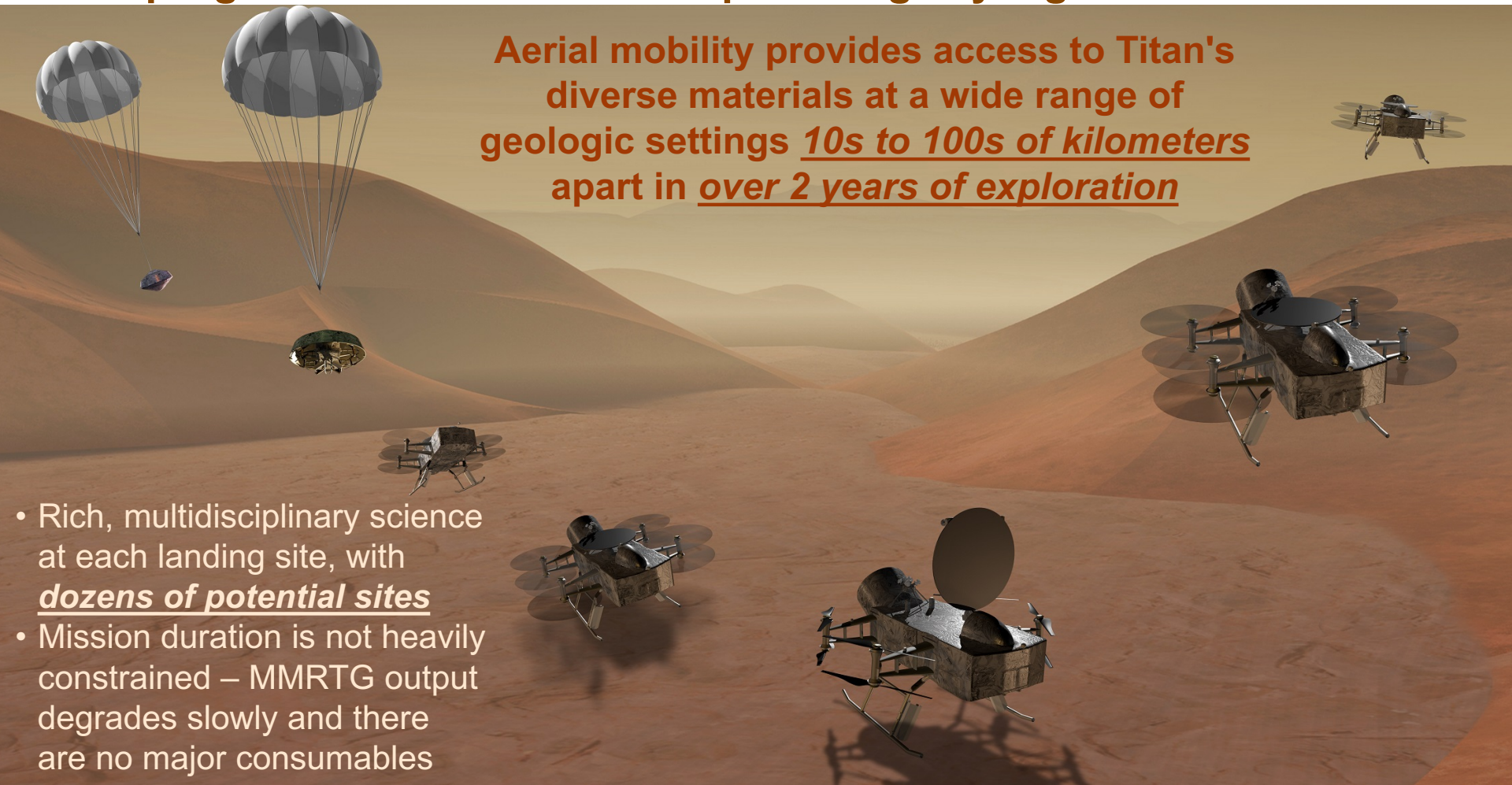




A rotorcraft lander for in situ investigation of Titan's prebiotic chemistry and habitability

New Frontiers mission concept study to perform in situ 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 10s to 100s of kilometers apart in over 2 years of exploration



- 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



DRAGONFLY

