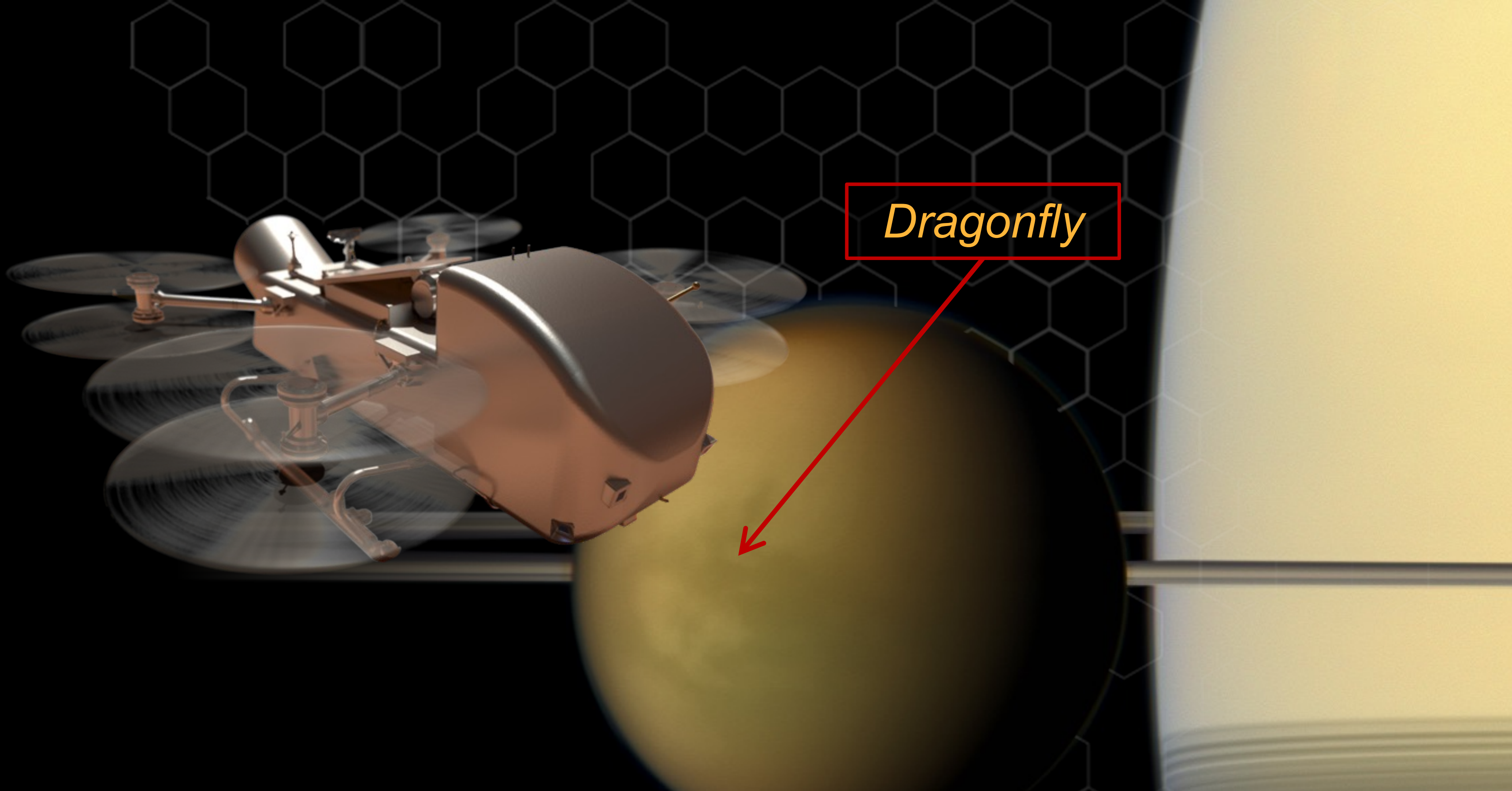
DRAGONFLY

A relocatable lander to explore Titan’s prebiotic chemistry and habitability



Dragonfly: Flights of Exploration on an Exotic Ocean World

18 May 2023

Melissa Trainer, Dragonfly Deputy Principal Investigator
NASA Goddard Space Flight Center

Mid-Atlantic Senior Physics Group (MASPG)

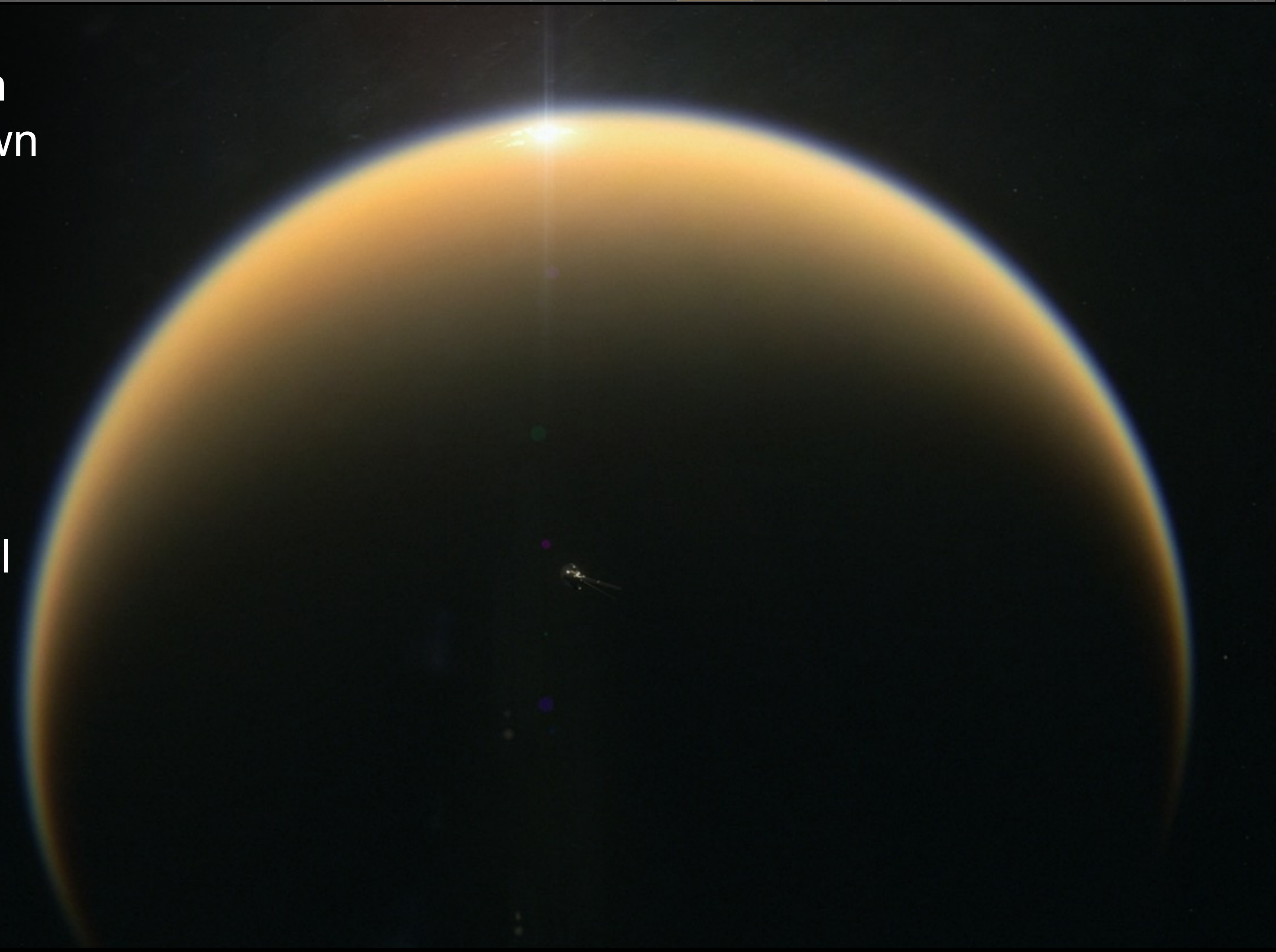
A little more about me …

Position and Institution	Research Scientist, Goddard Space Flight Center
Dragonfly Team Role	Deputy Principal Investigator, DraMS Instrument Lead
Education	• B.A., Chemistry, Franklin and Marshall College • Ph.D., Atmospheric Chemistry, University of Colorado at Boulder
Other activities	• Venus Mass Spectrometer on NASA's DAVINCI Mission • Science Team on NASA's Curiosity Rover • Hiking and camping with my family


DRAGONFLY
February 25, 2023

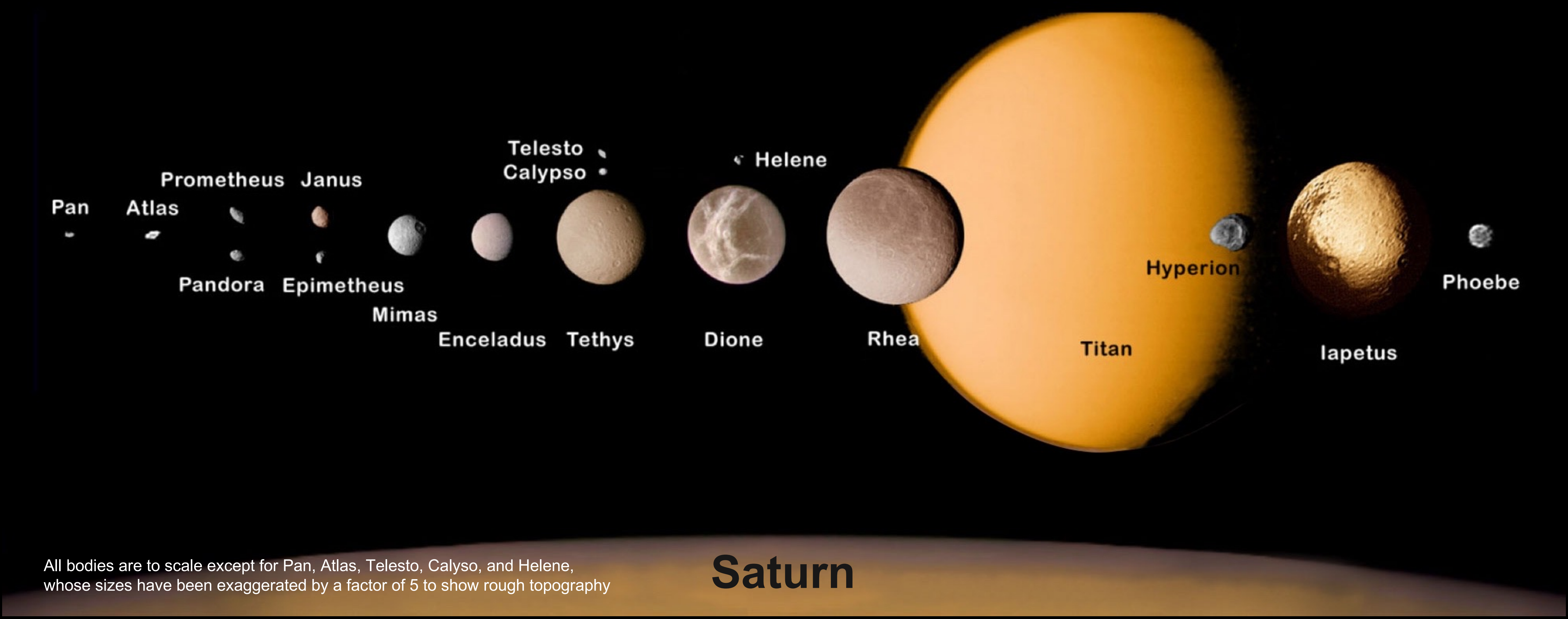
Unique and compelling science

- We do not know how life came to form on Earth and cannot go back to study our own prebiotic history
- Places elsewhere in our Solar System provide pieces to the puzzle of the chemical processes that led to life
- **Titan** is the most like the early Earth and holds keys to understanding our chemical origins



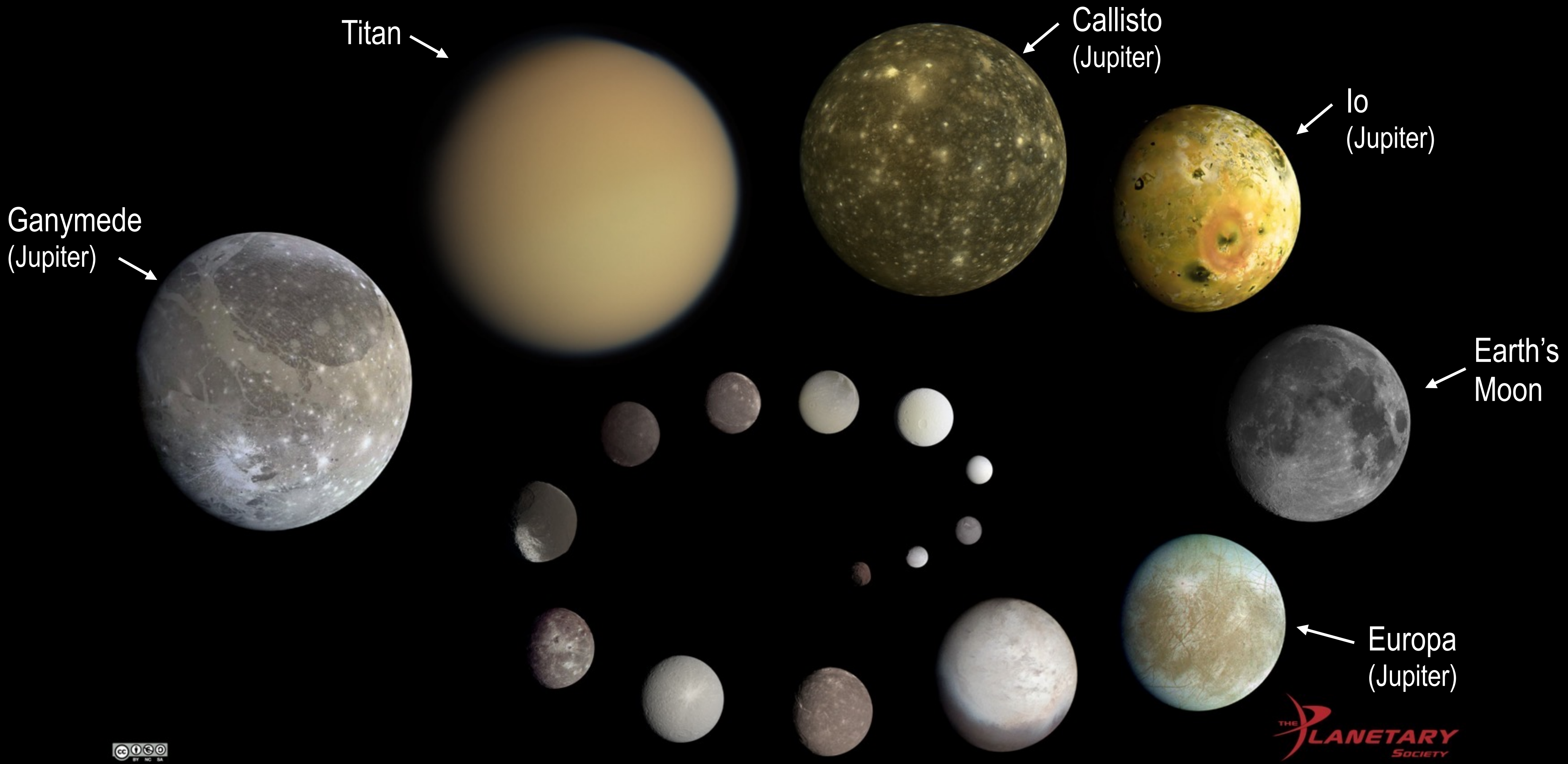
Unique and compelling science

The largest of Saturn’s 62 moons



All bodies are to scale except for Pan, Atlas, Telesto, Calyso, and Helene, whose sizes have been exaggerated by a factor of 5 to show rough topography

Titan's unique environment



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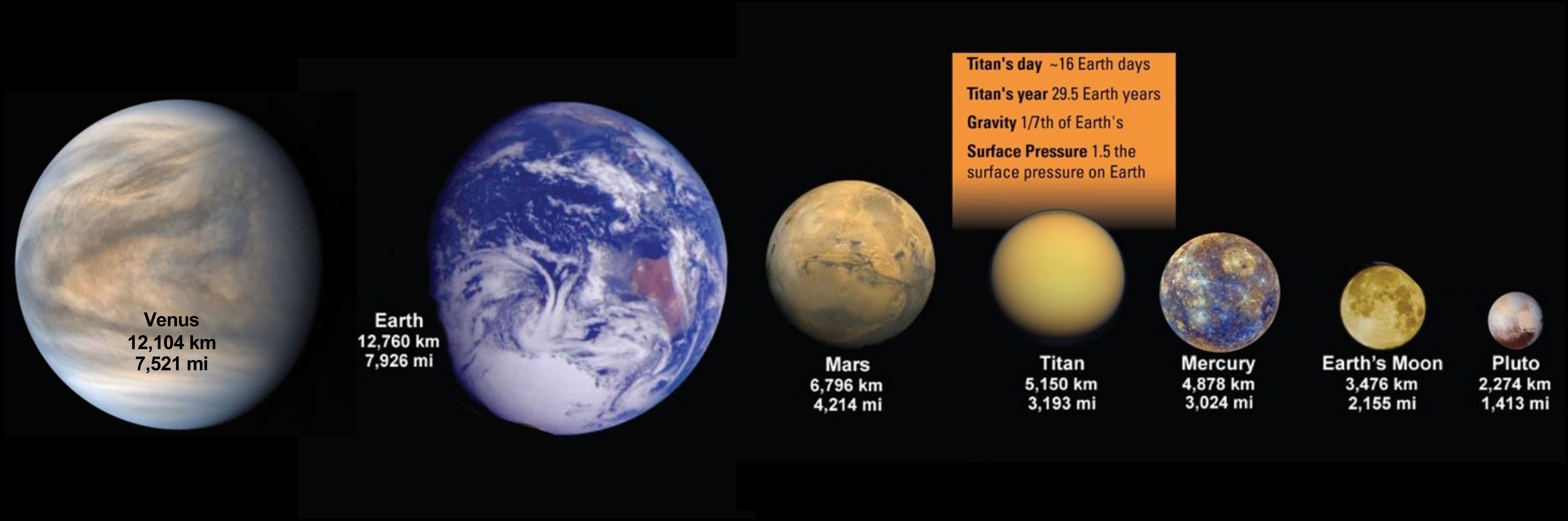

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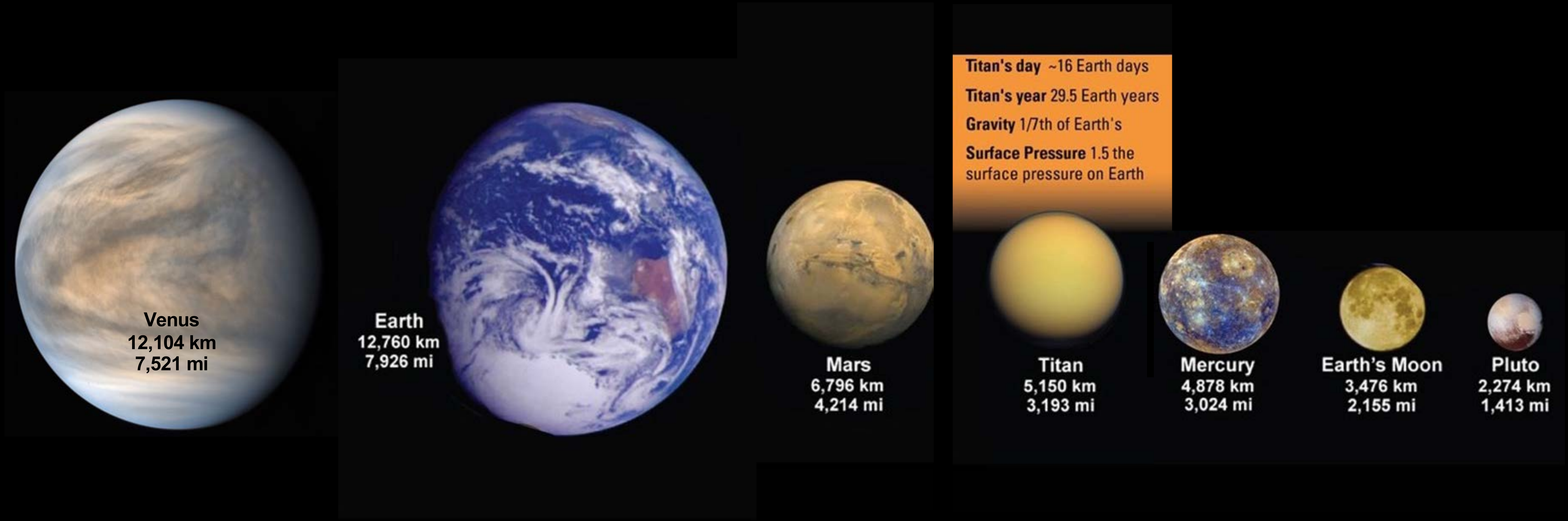
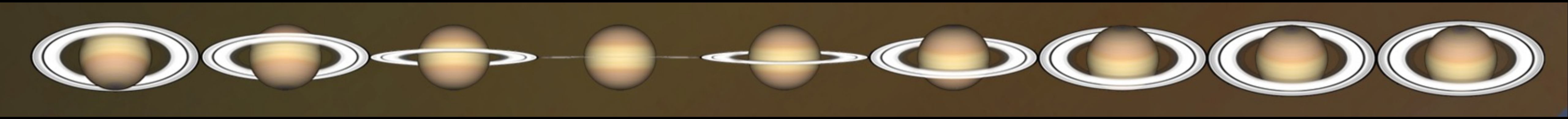


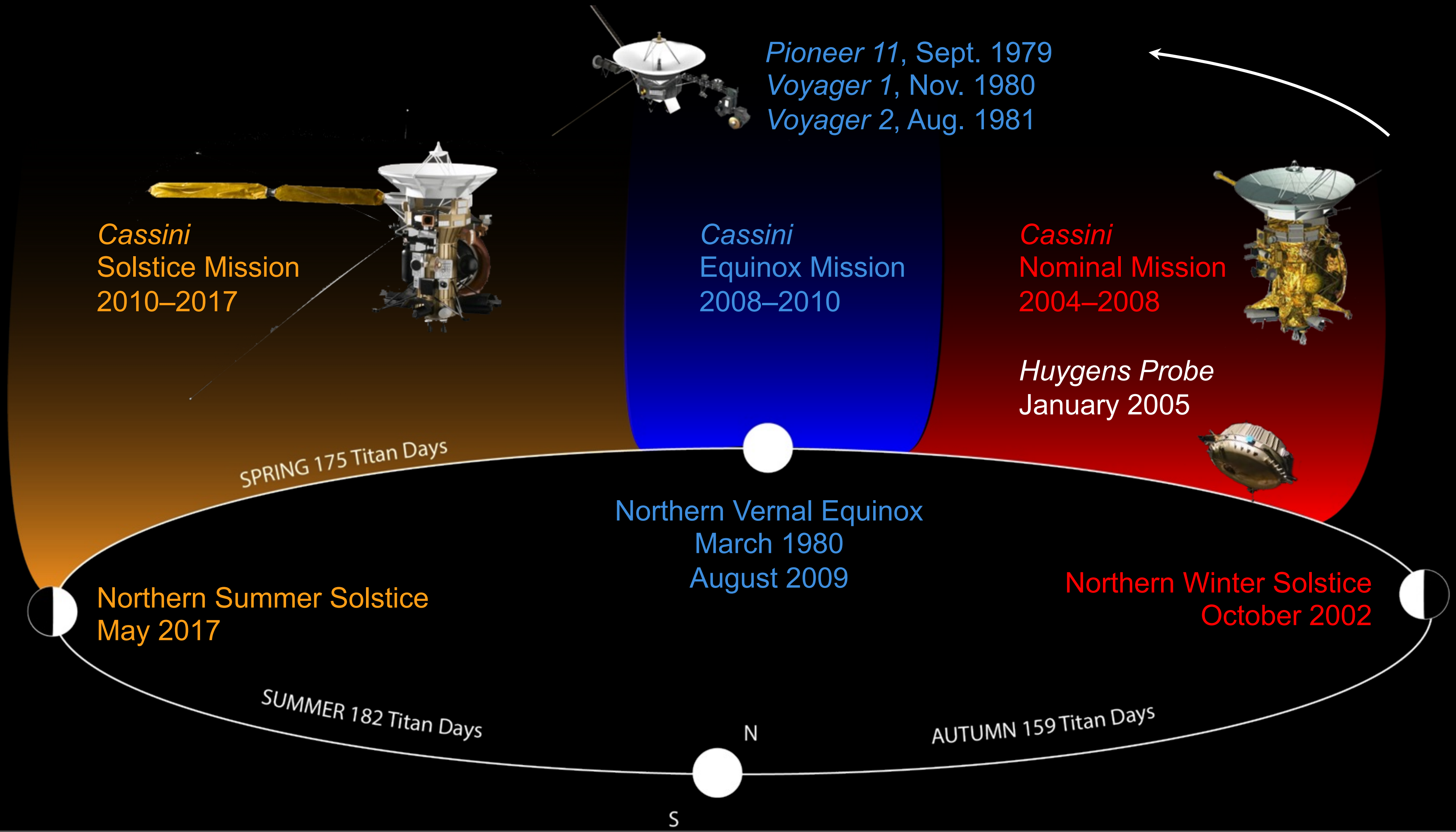
Seasons on Titan



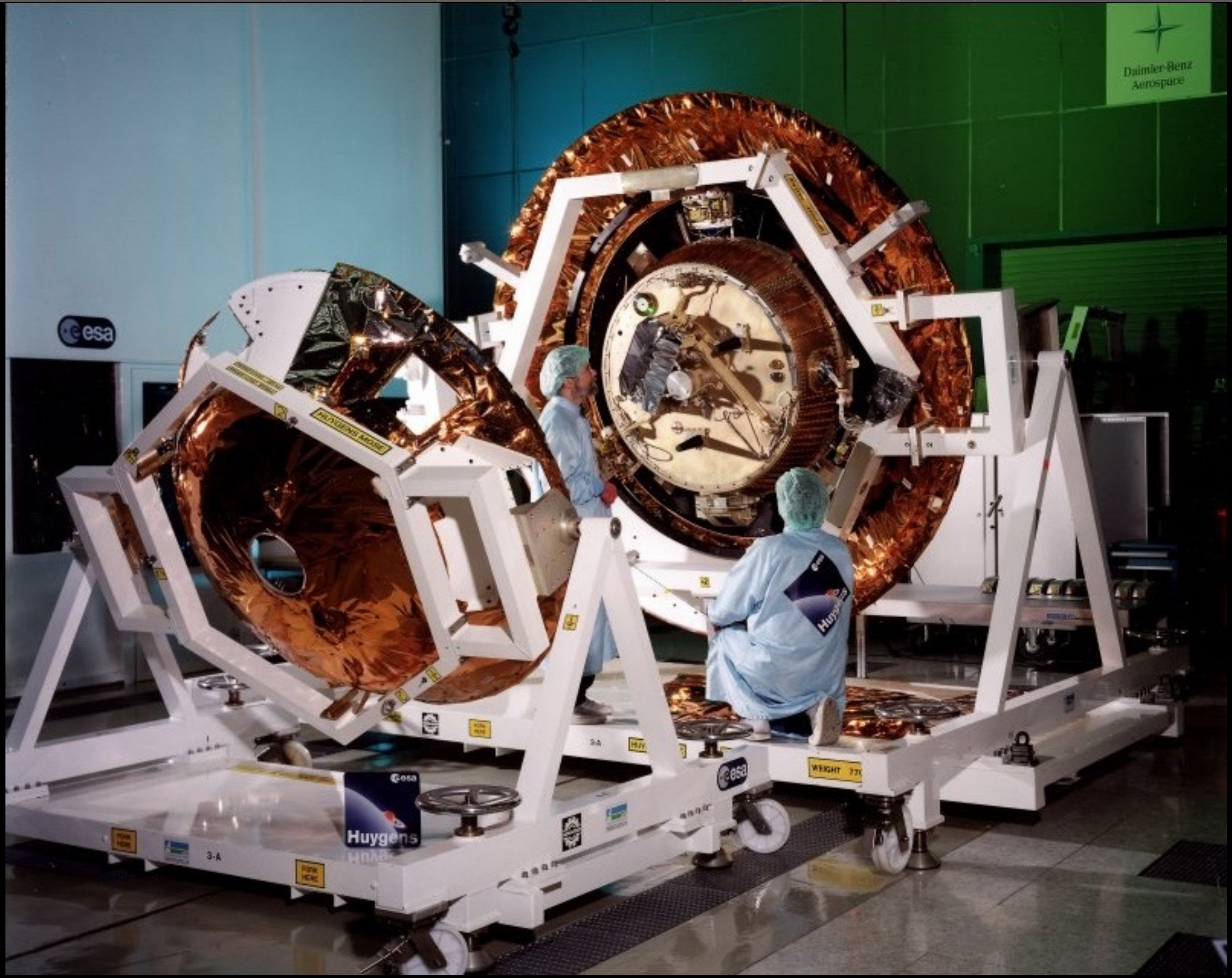
- Saturn and Titan's year = 29.5 Earth years
- Saturn's axial tilt = 26.7°
- Titan's day = 16 Earth days

Northern winter solstice	Oct 2002
Equinox	Aug 2009
Northern summer solstice	May 2017
Equinox	May 2025
Northern winter solstice	Apr 2032
Equinox	Jan 2039

Exploration of the Saturnian System

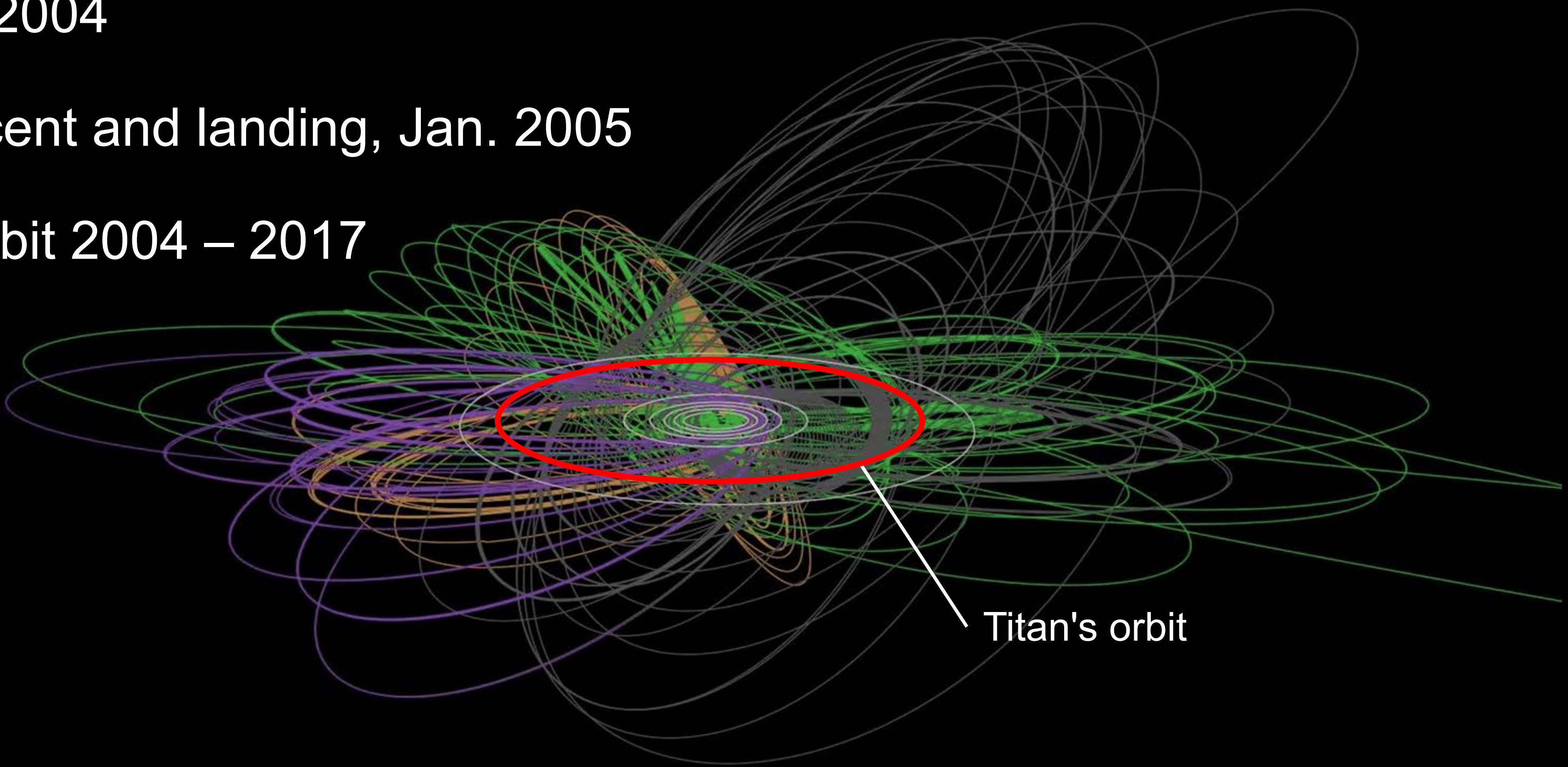


Cassini-Huygens spacecraft



Cassini-Huygens exploration

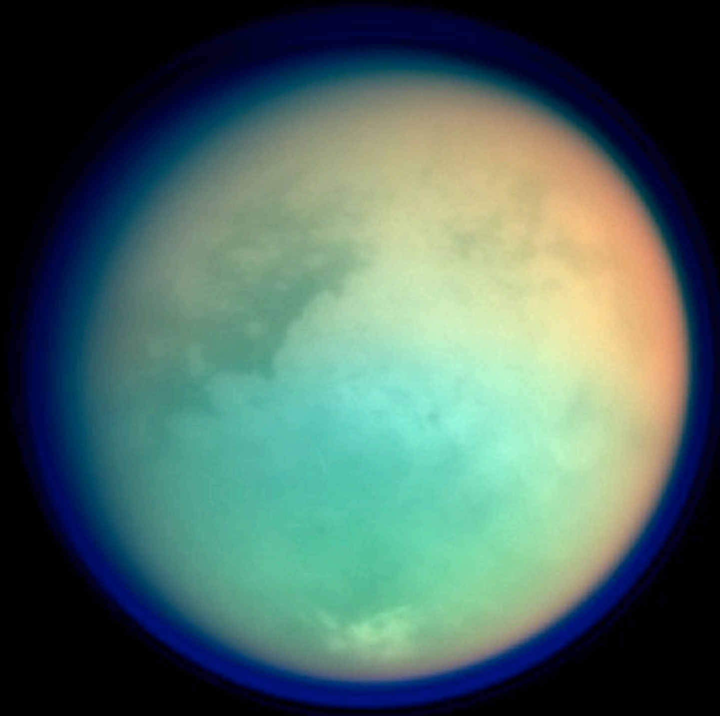
- Saturn arrival, July 2004
- *Huygens* Titan descent and landing, Jan. 2005
- *Cassini* in Saturn orbit 2004 – 2017
  - 126 close Titan flybys



Titan

- Diameter: 5,150 km (3,193 miles)
- Surface gravity: 1.35 m/s2 (0.14 g)
  - 14% of gravity at Earth's surface
  - 83% of gravity at Moon's surface
- Surface temperature: 94 K (–179°C, –290°F)
  - Bedrock composition: water ice
  - Atmospheric composition: nitrogen, few % methane
- Surface pressure: 1.5 bar
  - 1.5× pressure at Earth's surface

Voyager 2
23 August 1981



Cassini
26 October 2004

Titan

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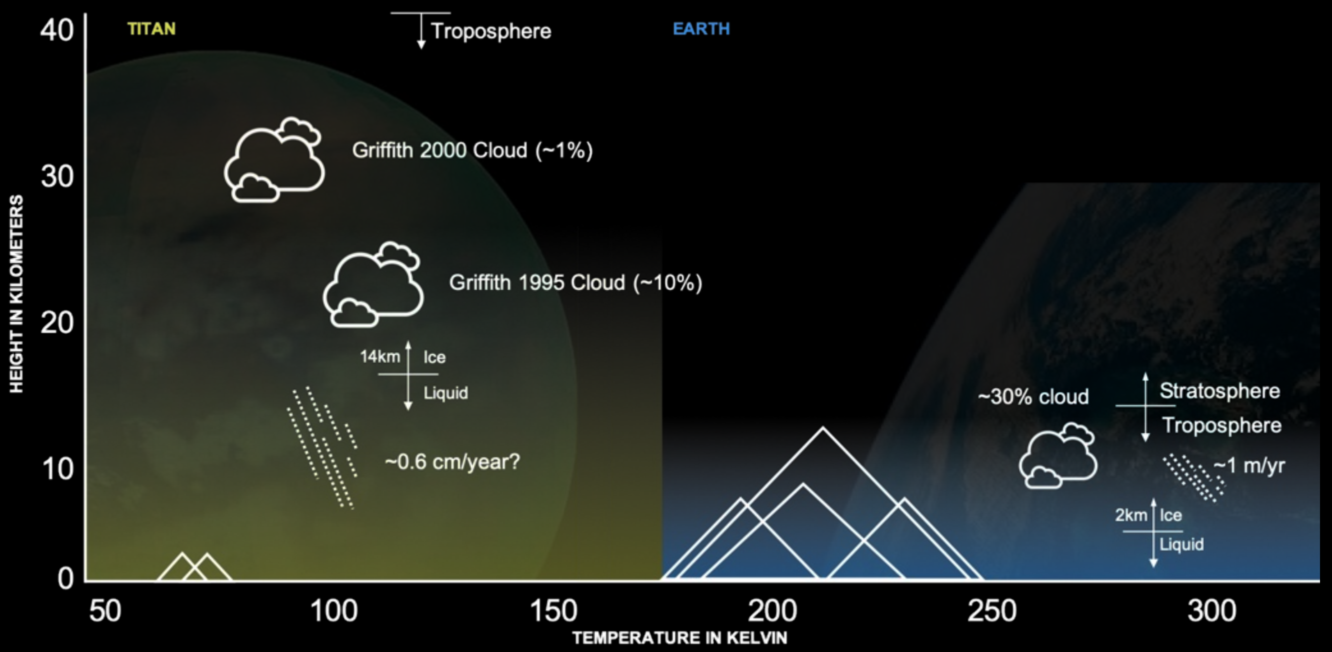

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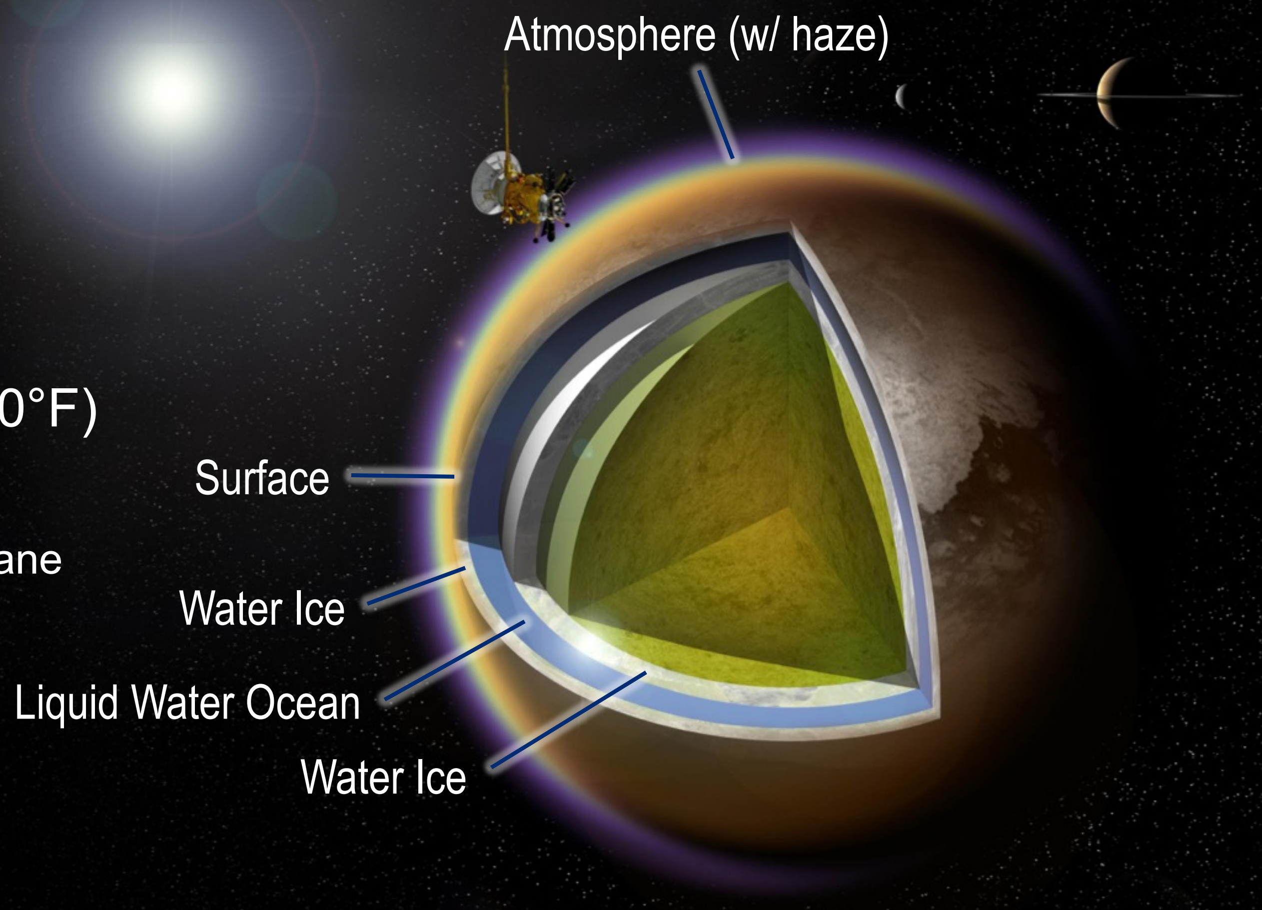
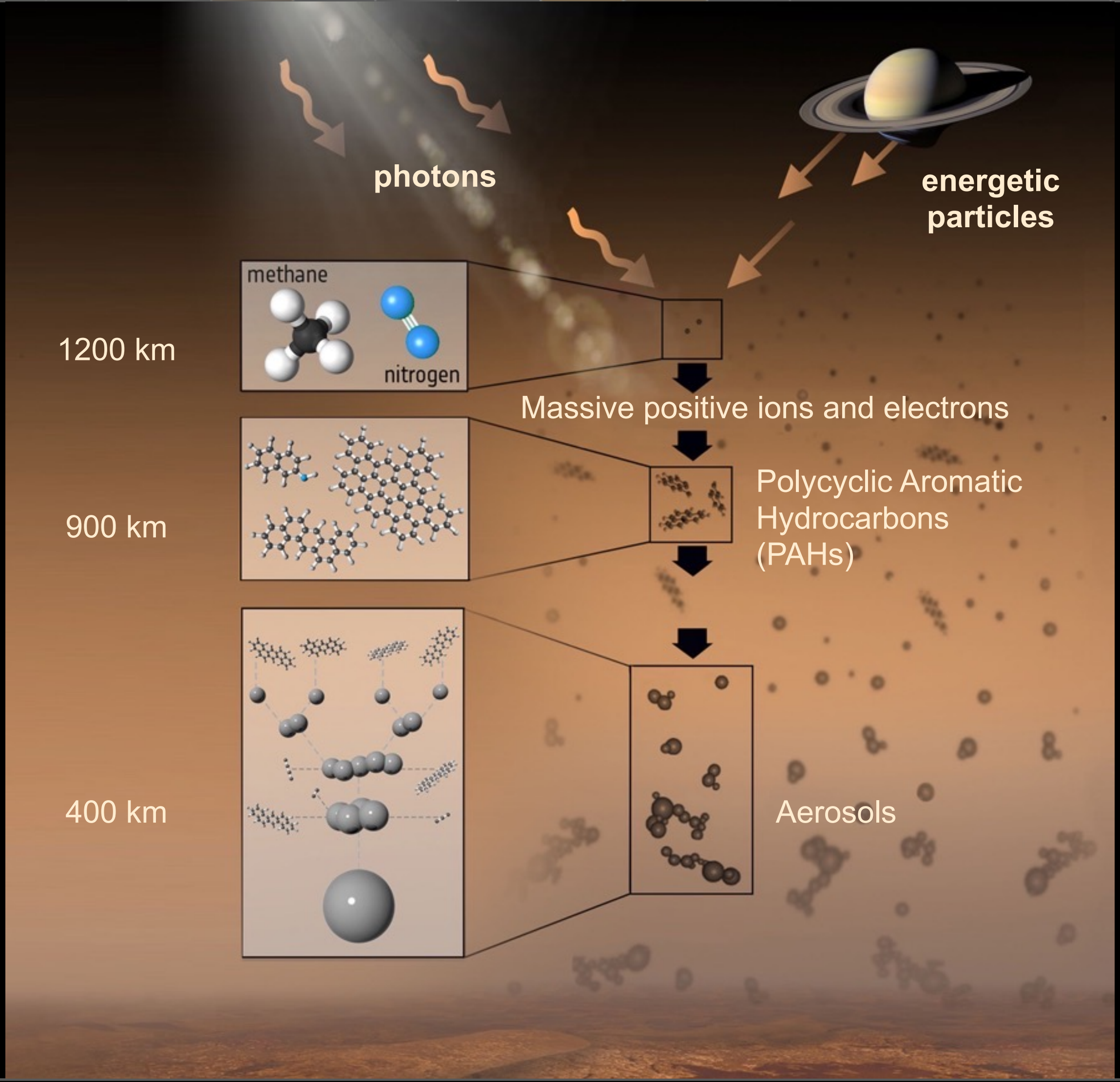
- Deep interior ocean of liquid water

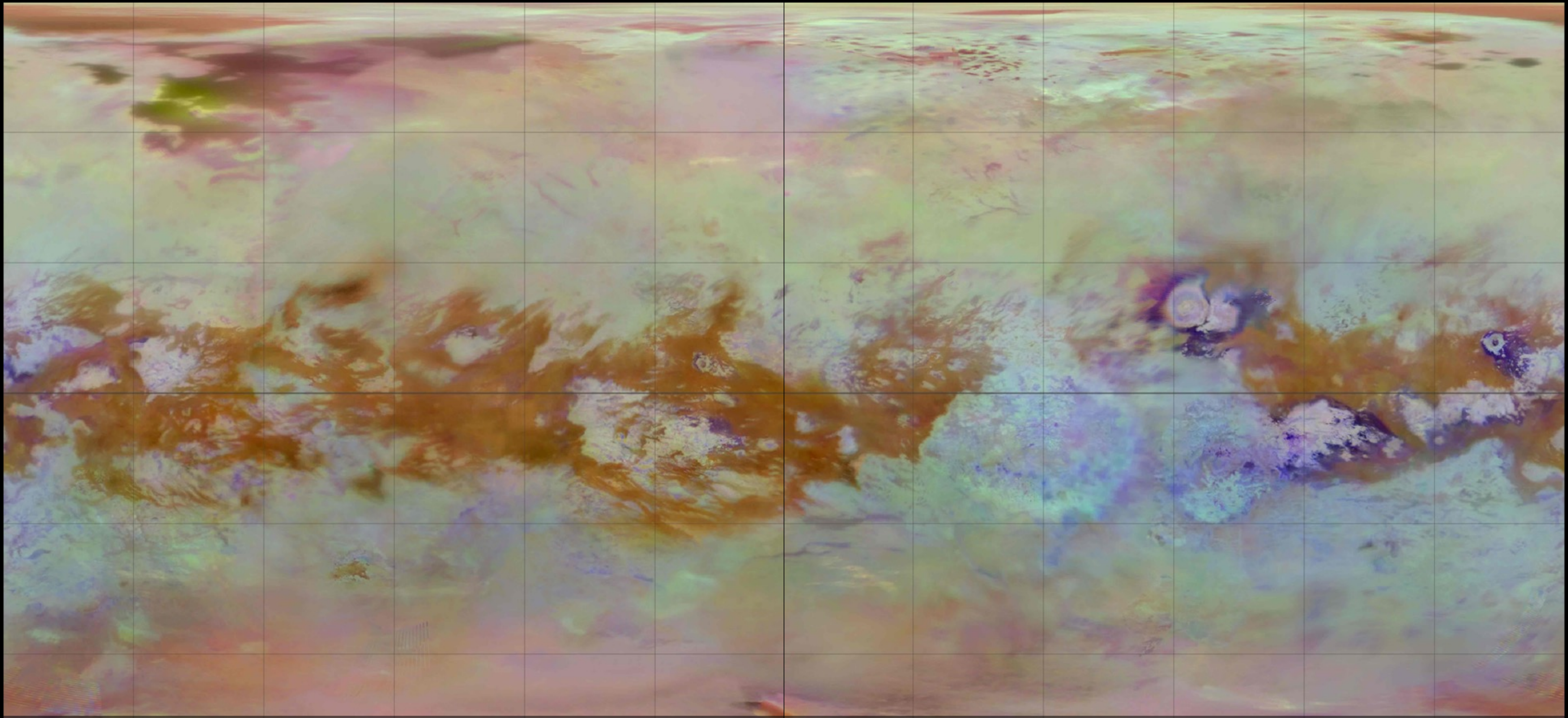


Q: Why does Titan look hazy?
A: Complex organic chemistry!

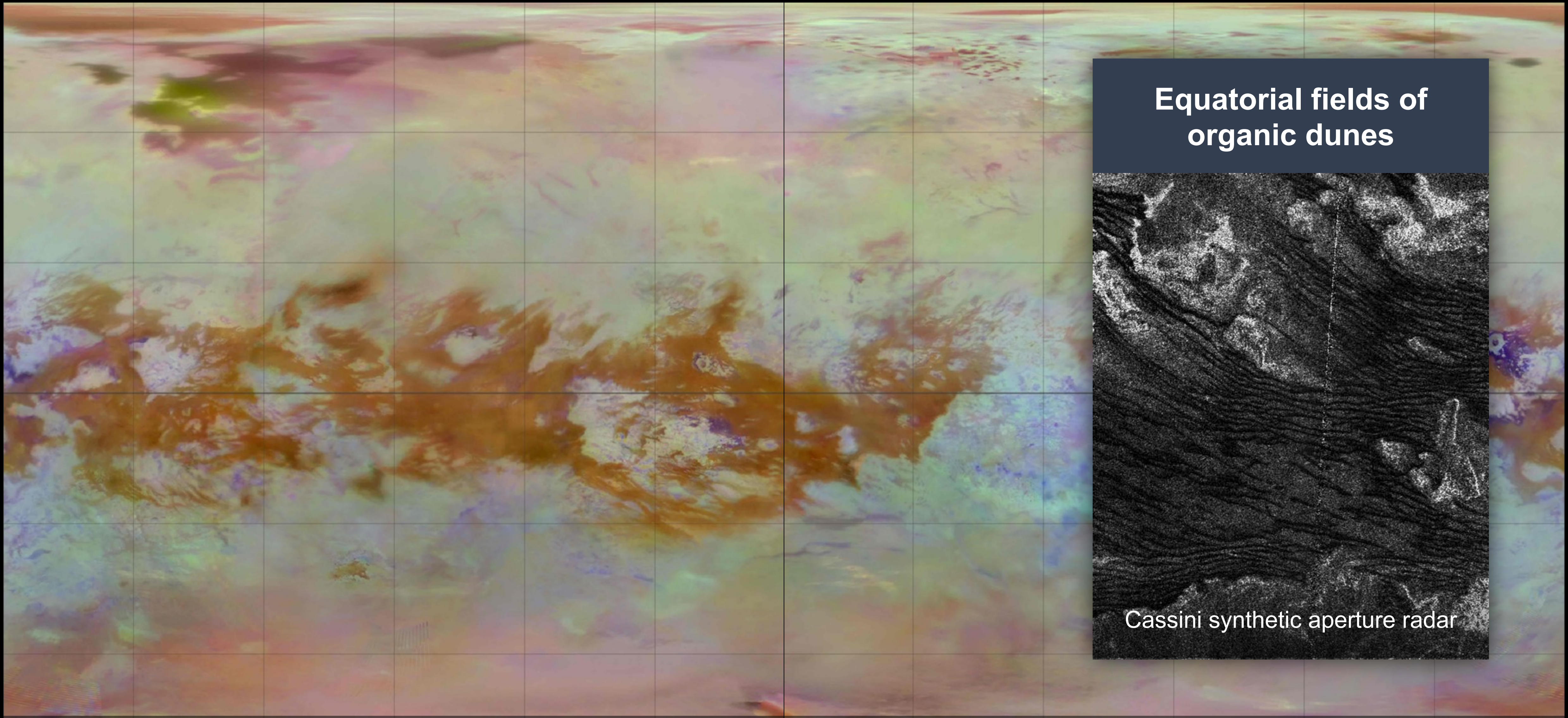
- Photochemistry in upper atmosphere produces complex carbon molecules
- Rich organic material covers the surface
- Potential for organic compounds to have mixed with liquid water for extended periods of time at the surface

Titan is a singular destination for understanding the chemical processes on our own planet that supported the development of life





Cassini enhanced-color map of Titan's surface at near-infrared and infrared wavelengths (Seignovert et al. 2019)

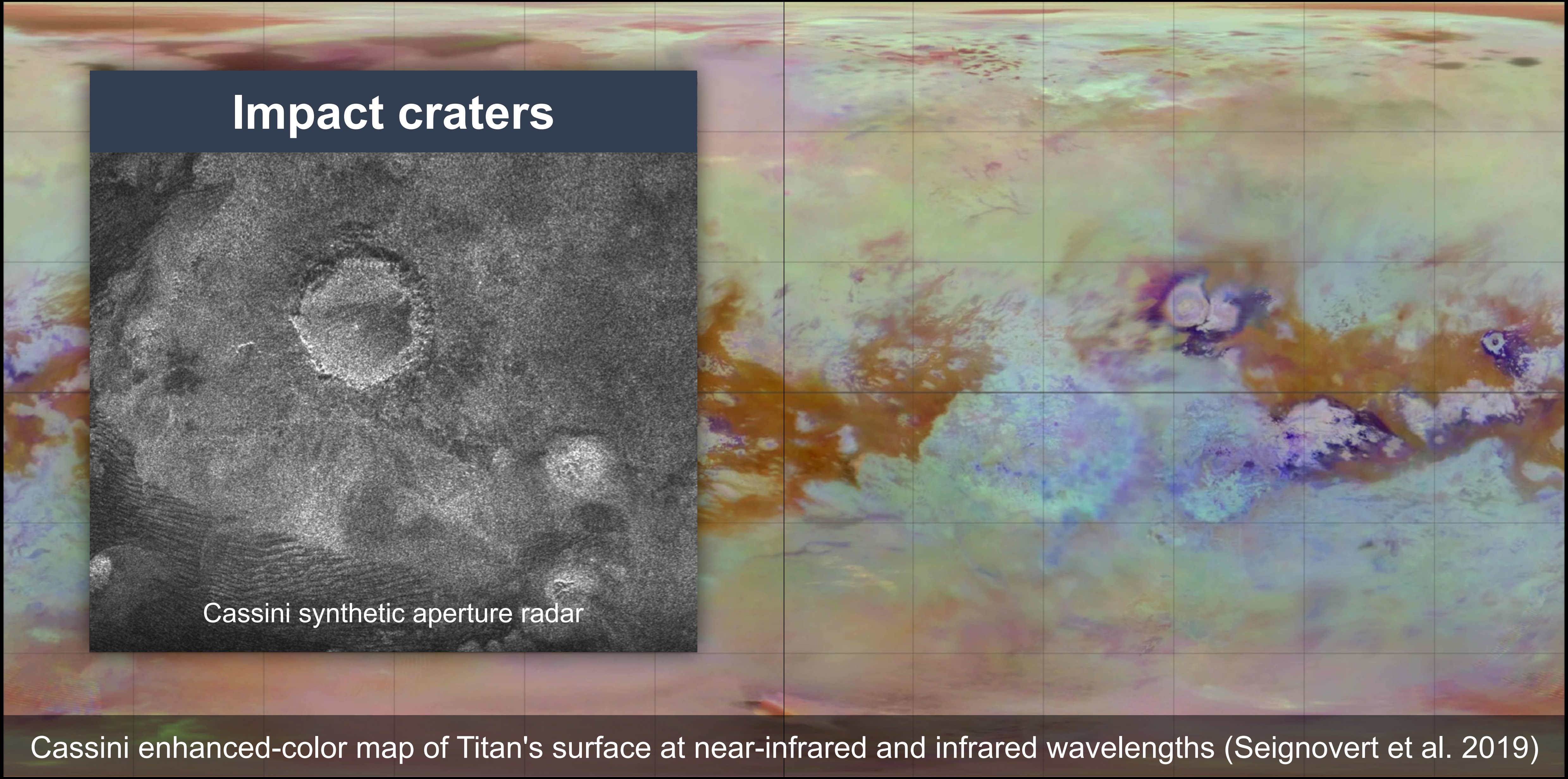


Equatorial fields of organic dunes

Cassini synthetic aperture radar

Cassini enhanced-color map of Titan's surface at near-infrared and infrared wavelengths (Seignovert et al. 2019)

Impact craters



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Tectonic structures

Cassini synthetic aperture radar

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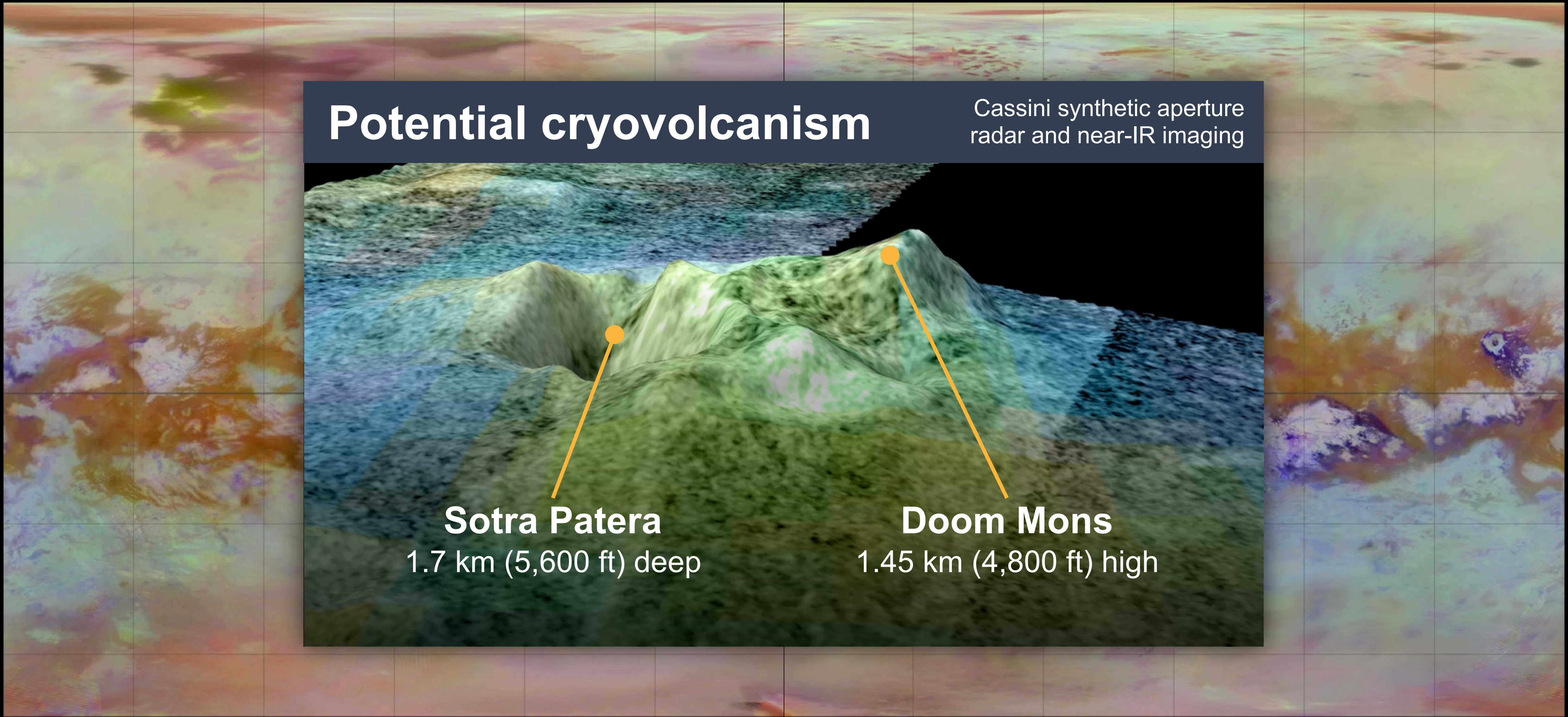
Potential cryovolcanism

Cassini synthetic aperture radar and near-IR imaging



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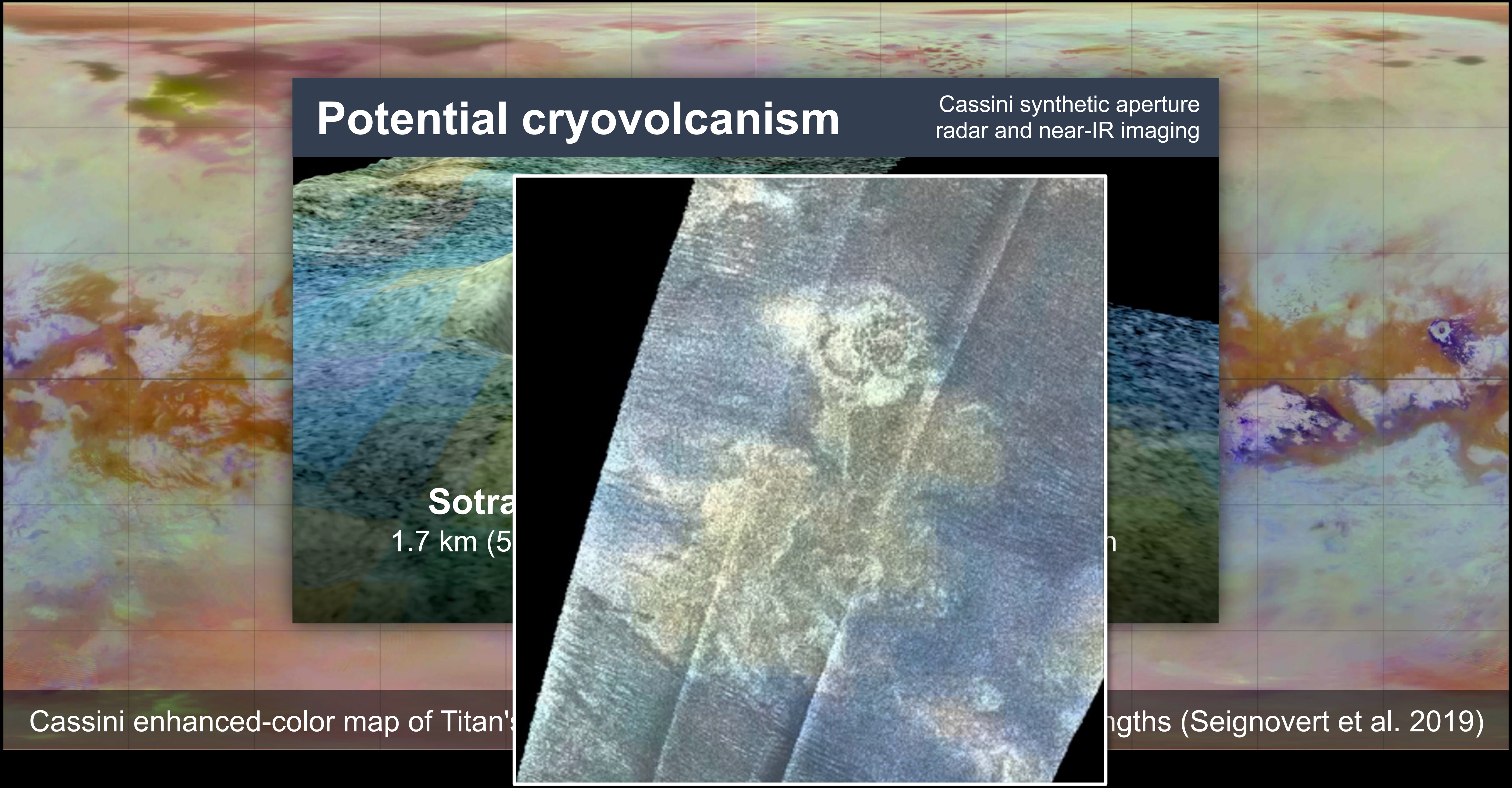

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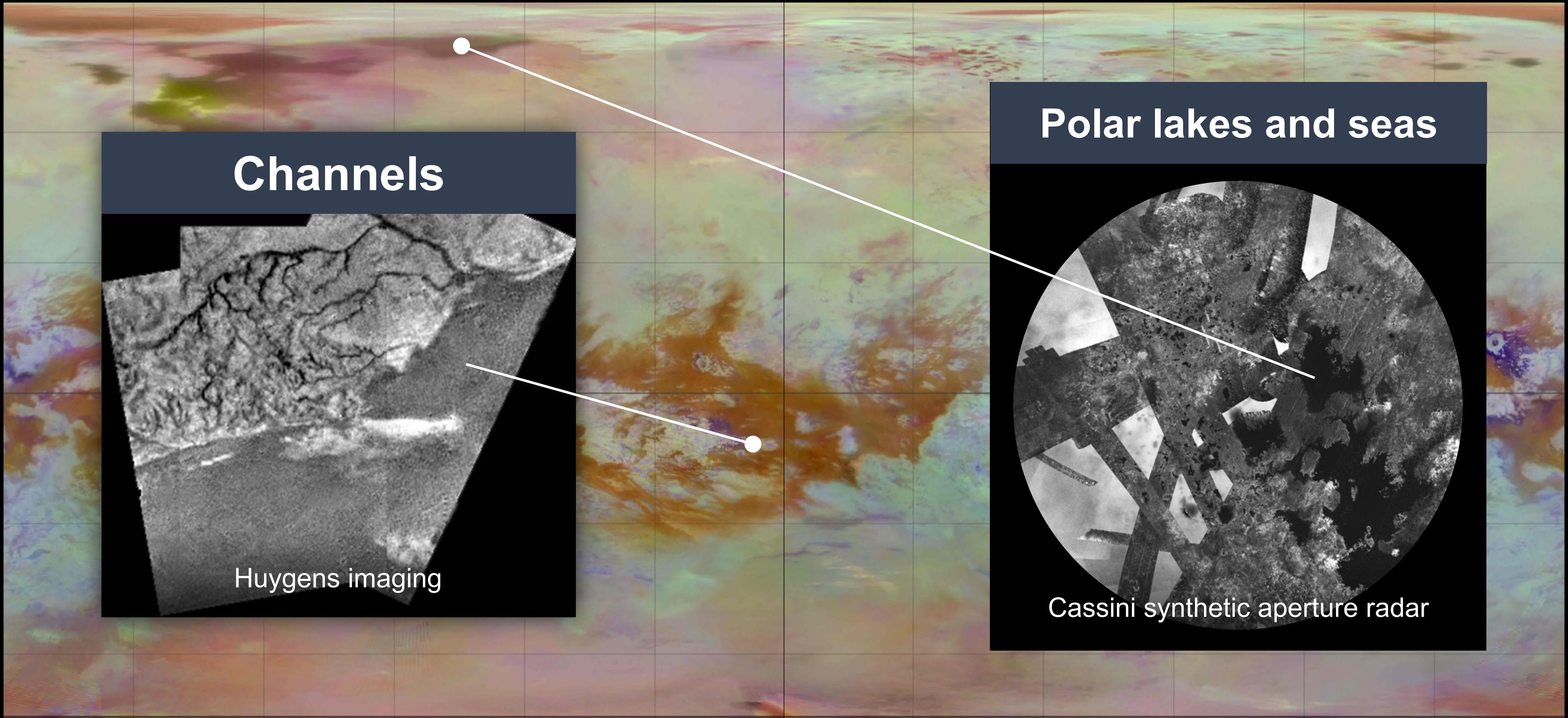

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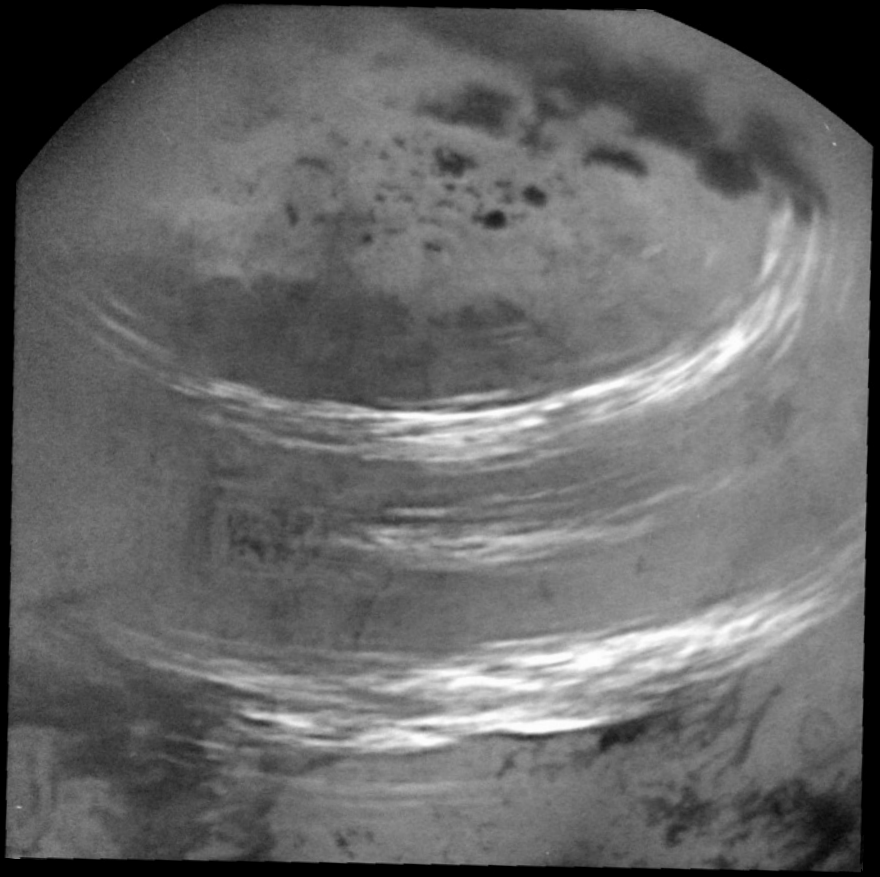
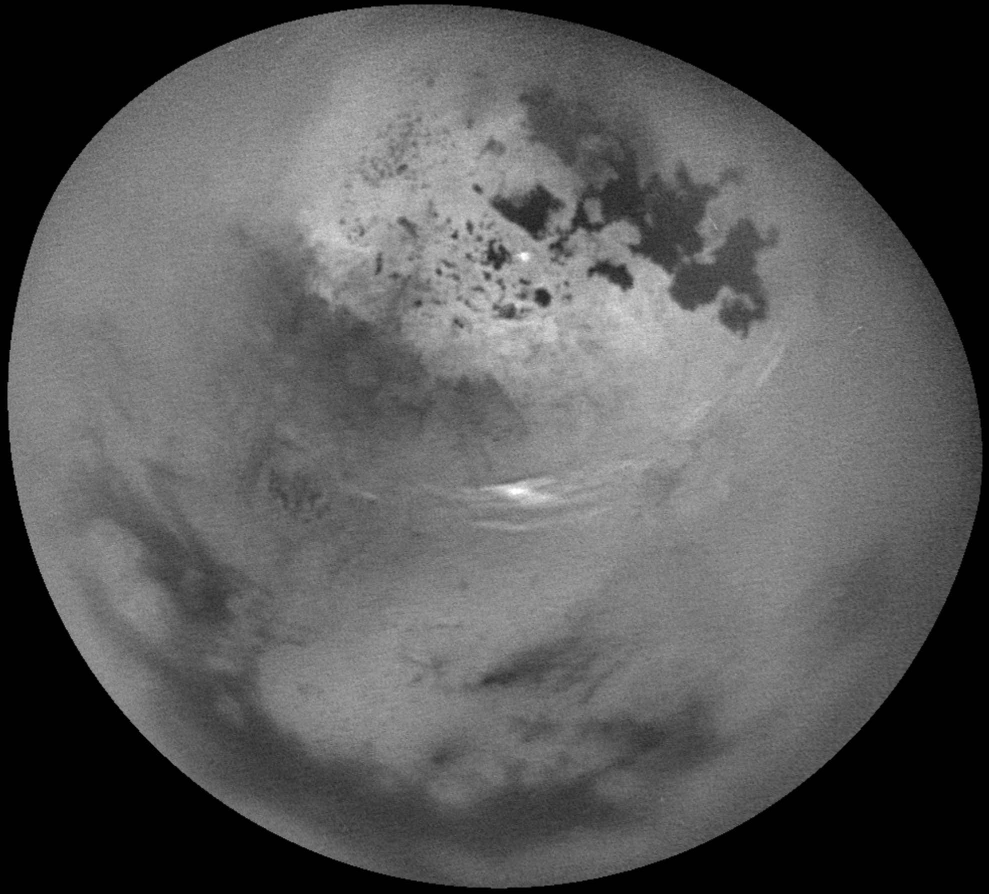
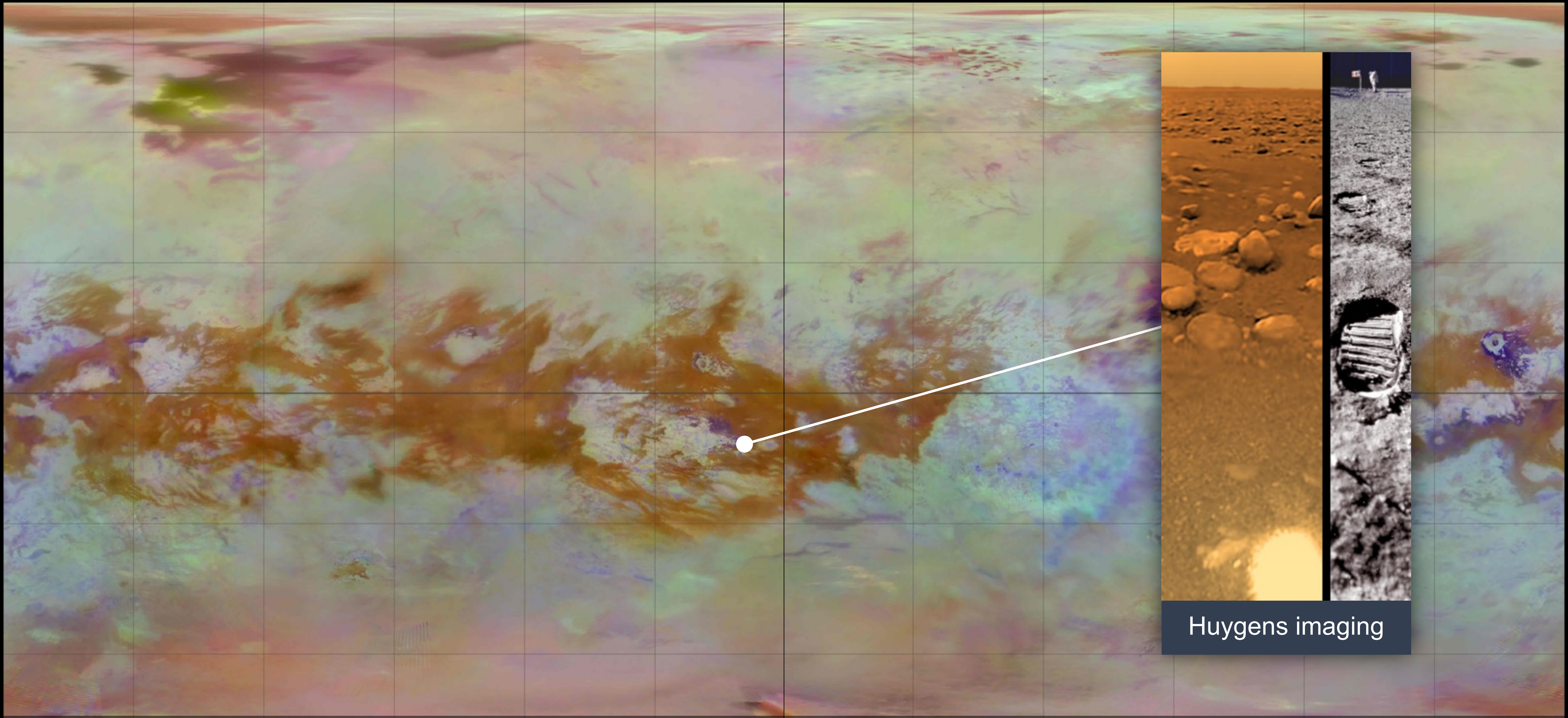
Clouds and weather patterns

Methane cycle is similar to Earth's water cycle







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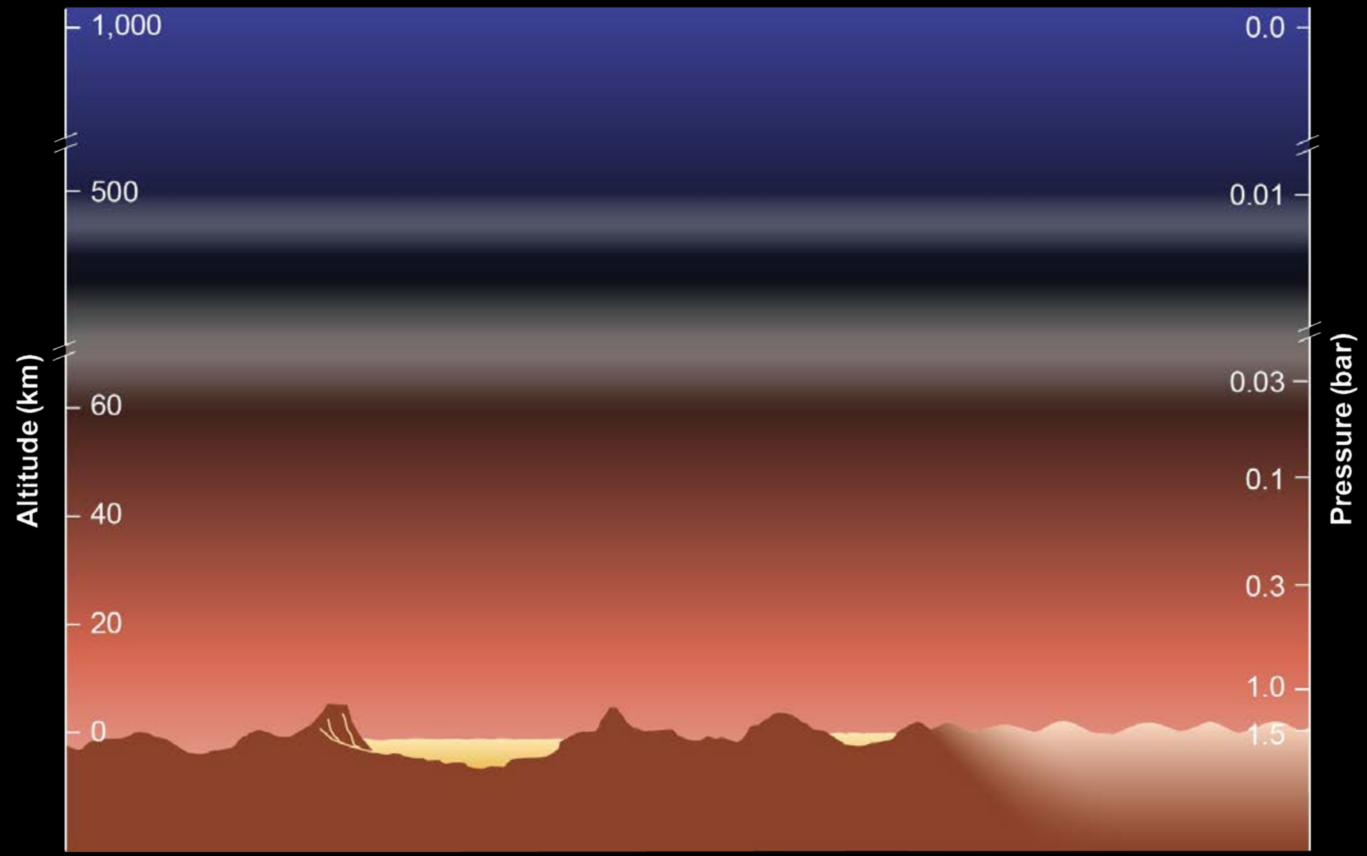
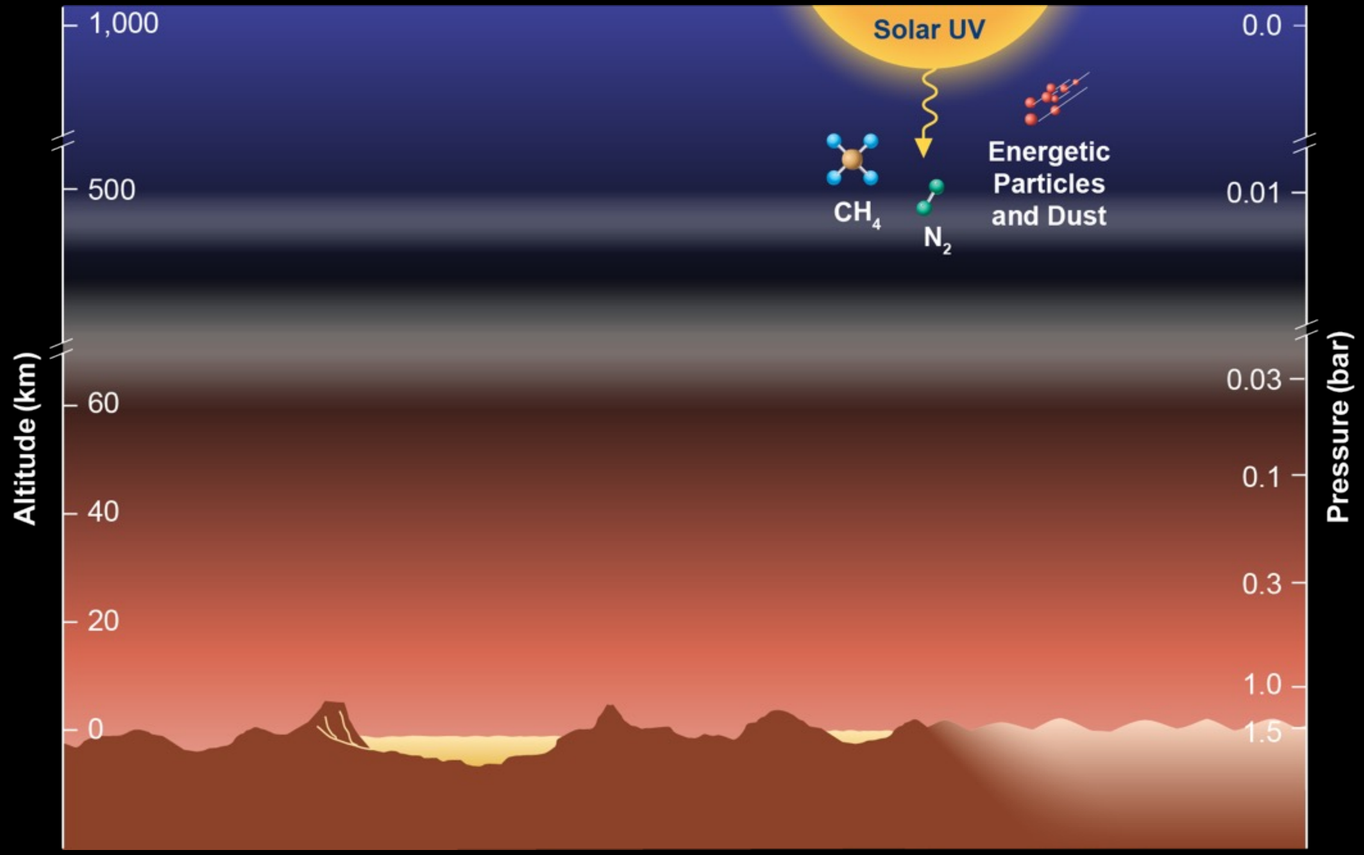
Key ingredients necessary for life



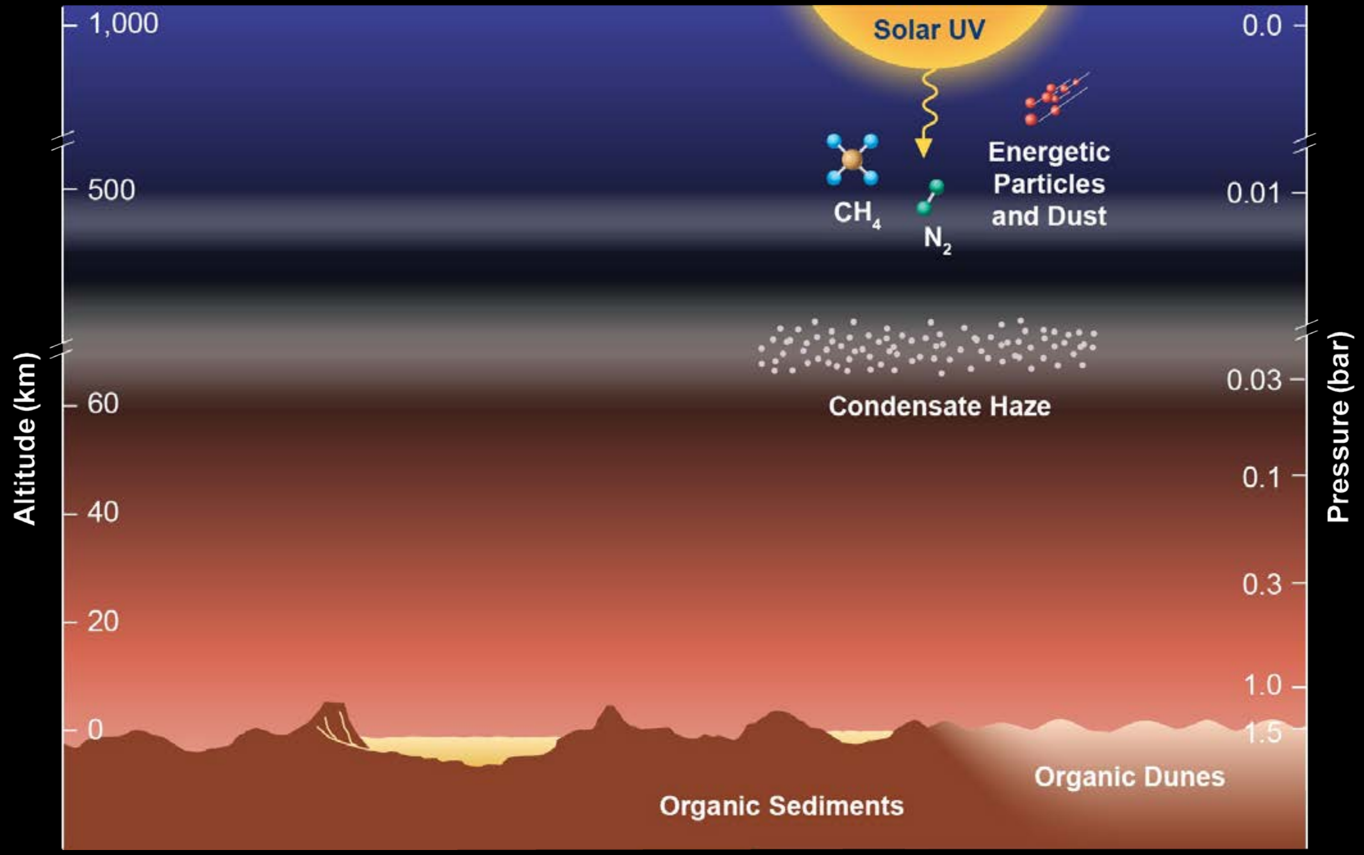
Key ingredients necessary for life

- Energy
  - Sunlight, photochemistry



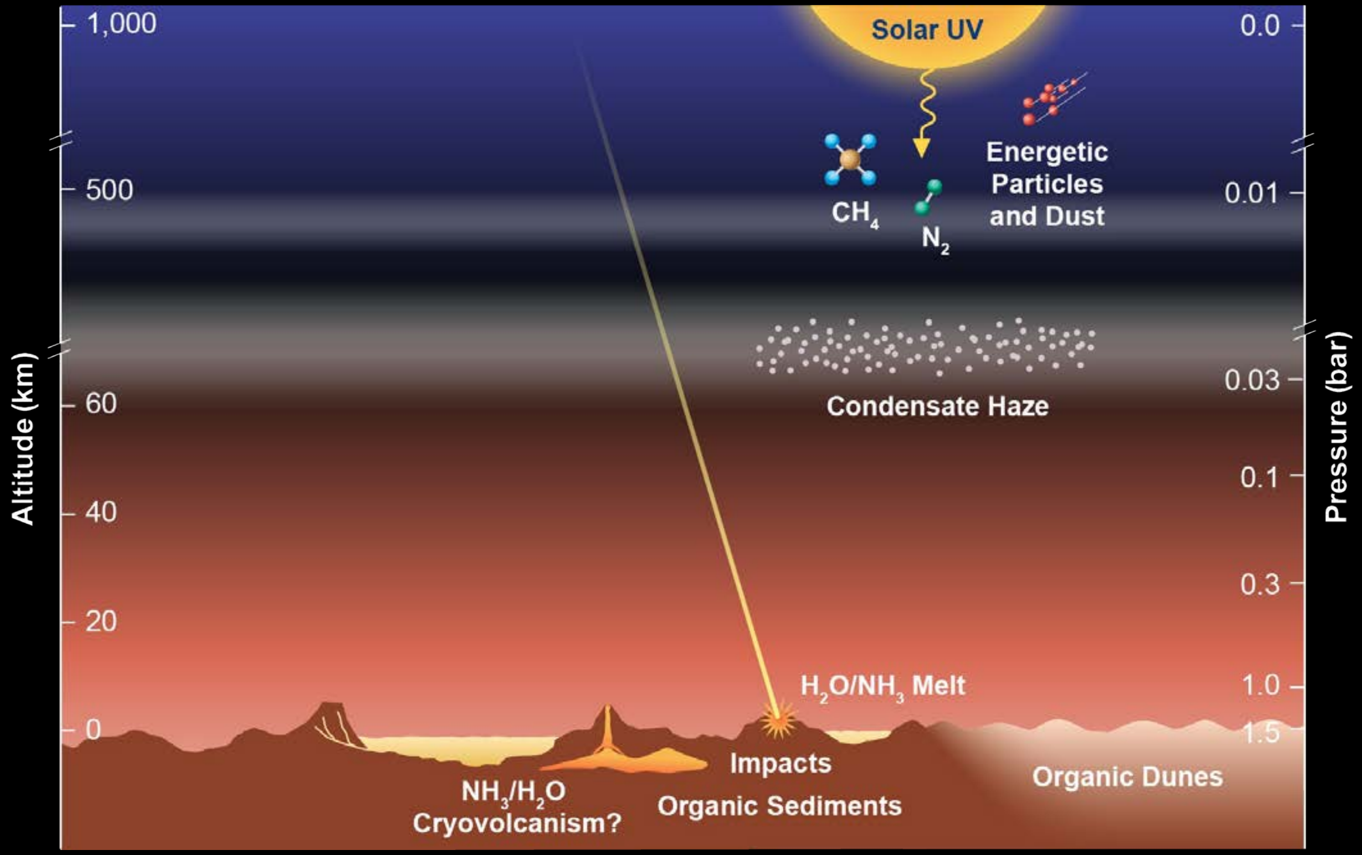
Key ingredients necessary for life

- Energy
  - Sunlight, photochemistry
- Organic material
  - Abundant complex organics



Key ingredients necessary for life

- Energy
  - Sunlight, photochemistry
- Organic material
  - Abundant complex organics
- Liquid
  - Water
    - available at the surface in Titan's past
    - interior ocean



Key ingredients necessary for life

- Energy
  - Sunlight, photochemistry
- Organic material
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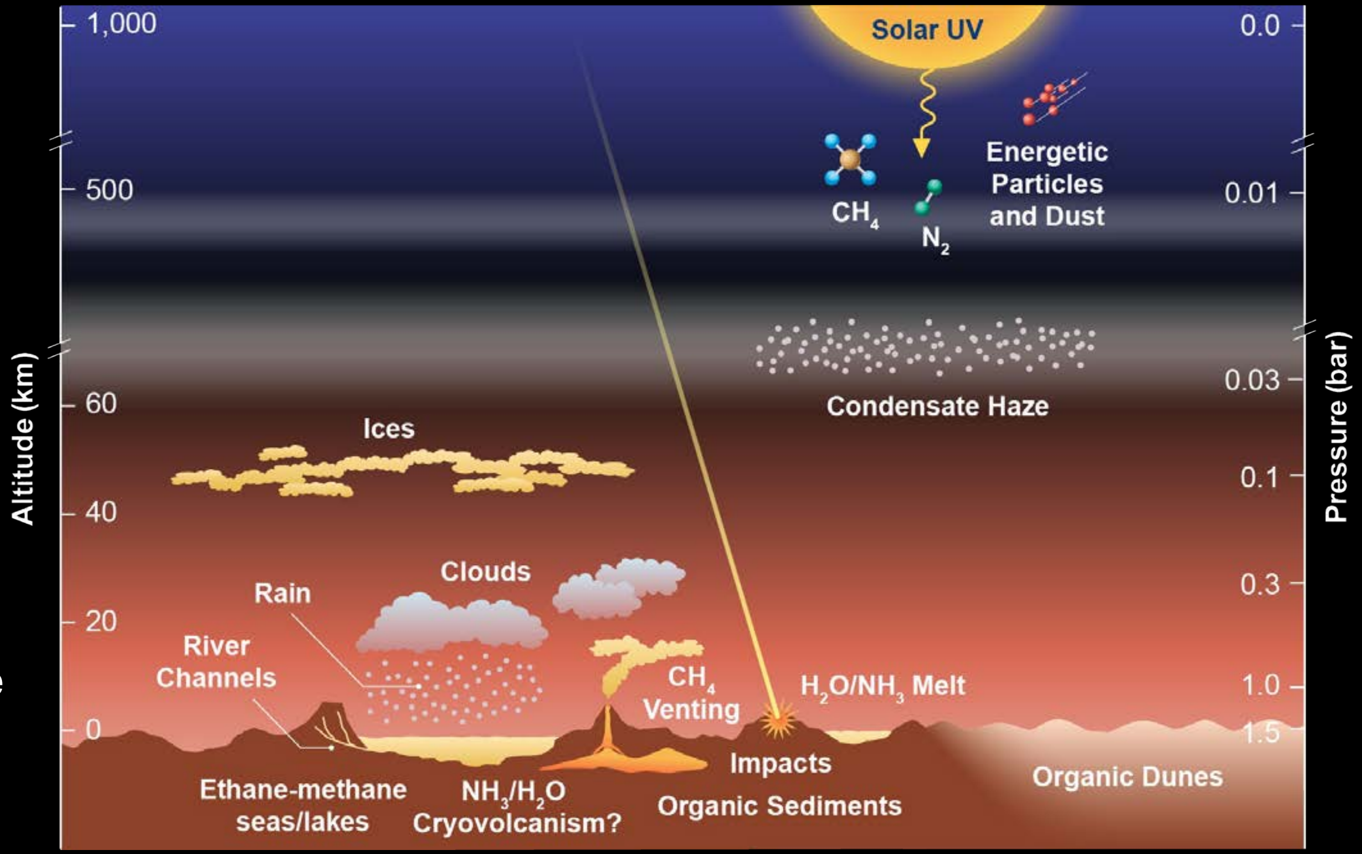
- *Two* liquids
  - Water
    - available at the surface in Titan's past
    - interior ocean
  - Methane
    - active methane cycle like Earth's water cycle
    - liquid methane could support development of alternate biological systems



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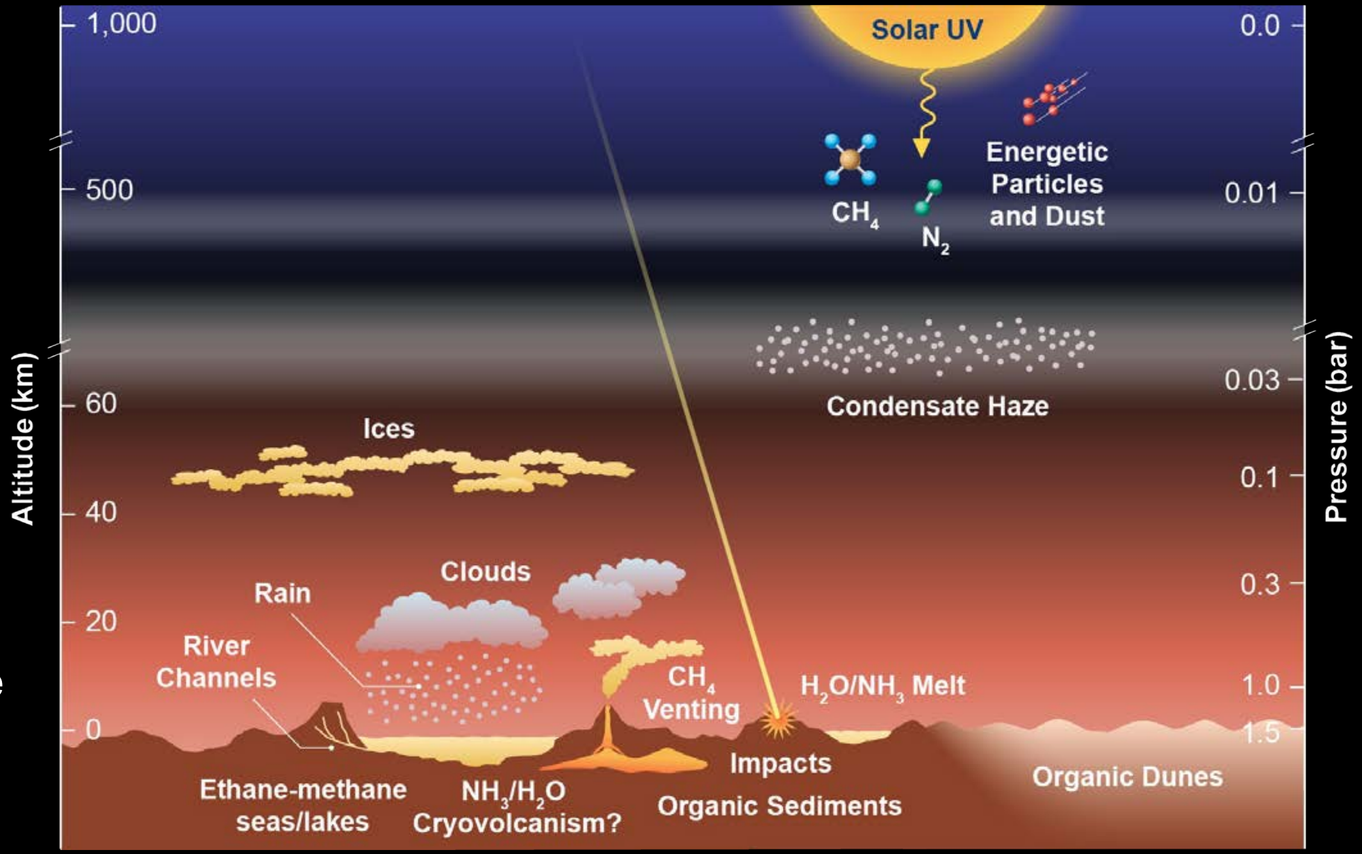
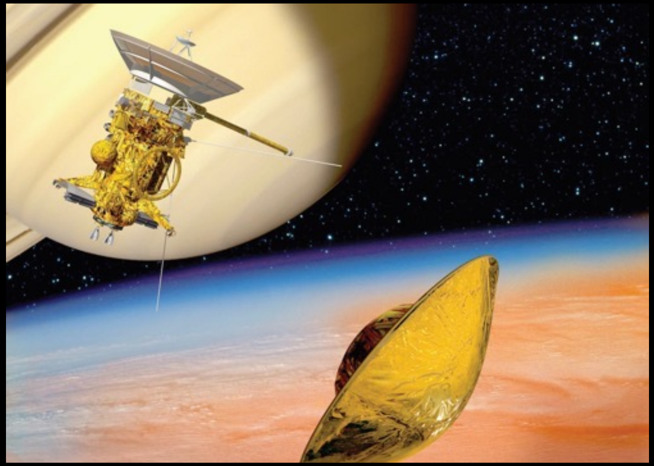
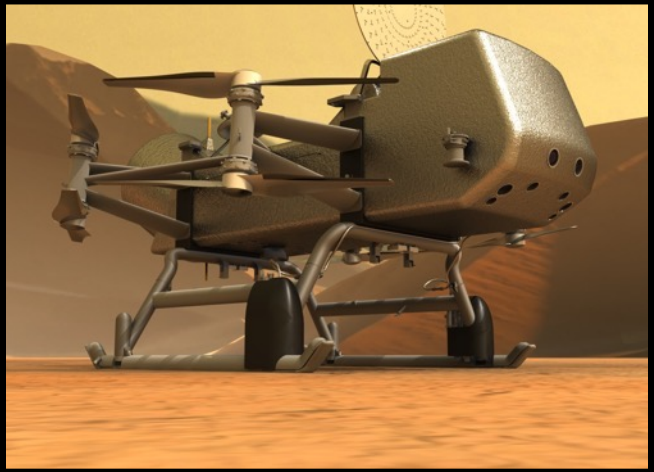


On Titan alone, can we study prebiotic chemistry in the full context of a planetary environment and Earth-like surface processes.

Titan offers the next step to answer fundamental questions

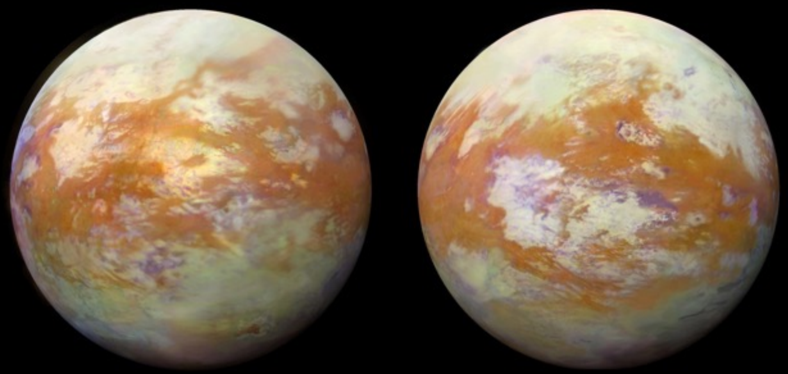
- What makes a planet or moon habitable?
- What chemical processes led to the development of life?
- Has life developed elsewhere in our solar system?





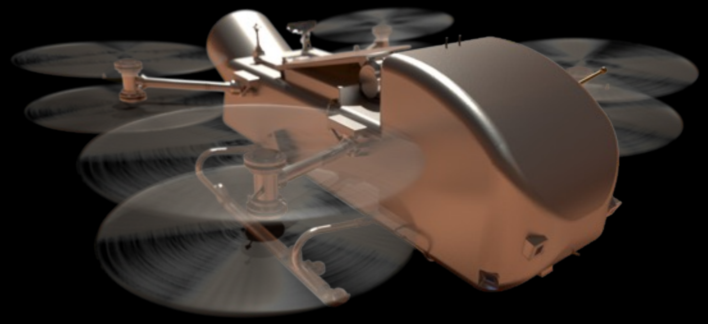
Lander with aerial mobility enables wide-ranging in situ exploration – key for science measurements

Cassini revealed where to look for answers



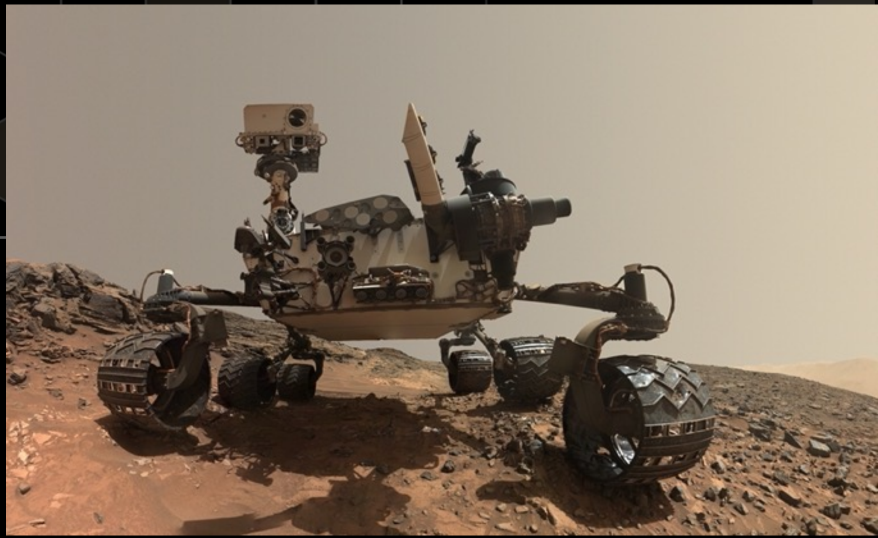
- Diverse surface materials and environments
- Earth-like variety of geologic processes
- Science challenge is to get instruments to multiple sites to sample materials and measure composition

Heavier-than-air mobility highly efficient at Titan



- Atmospheric density 4x higher than Earth's reduces wing/rotor area required for lift
- Gravity 1/7th of Earth's → reduces power required

Diversity of surface materials =
scientific priority to sample diverse locations



- On Mars, the paradigm is to *ROVE*

[1]Lorenz 2000; Langelaan et al. 2017

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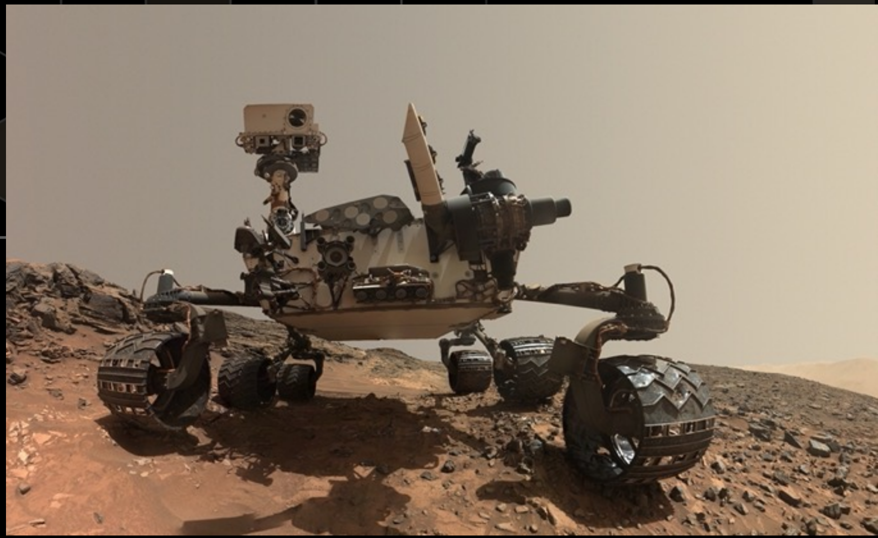

- On Mars, the paradigm is to *ROVE*
- Titan has a huge advantage over Mars:
  - Titan's atmosphere 4x denser than Earth's
    ➔all forms of aviation are easier (lighter- and heavier-than-air)[1]

    ➔reduces wing/rotor area required to generate lift
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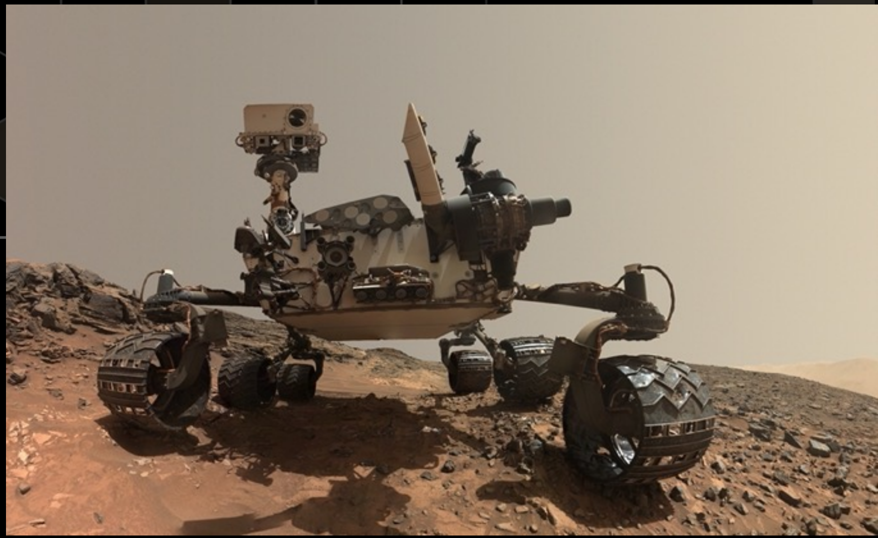

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XKCD.com: https://what-if.xkcd.com/30/

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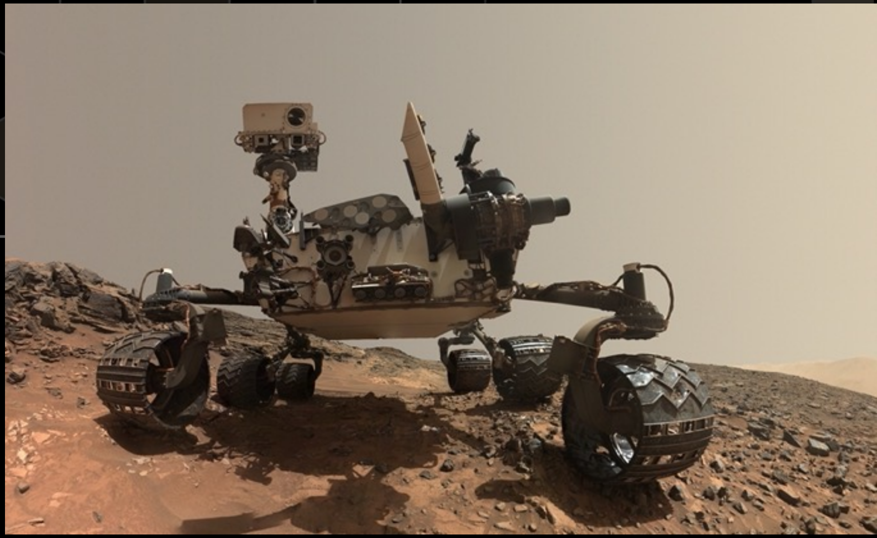
    ➔all forms of aviation are easier (lighter- and heavier-than-air)[1]
    ➔reduces wing/rotor area required to generate lift
  - Titan's gravity 1/7th Earth's reduces the power for required lift
- On Titan, we can *FLY*
  - Provides the means to access different geologic terrains 10s to 100s of kilometers apart
  - Does not require high resolution images of surface to navigate



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Dragonfly rotorcraft lander features

POWER

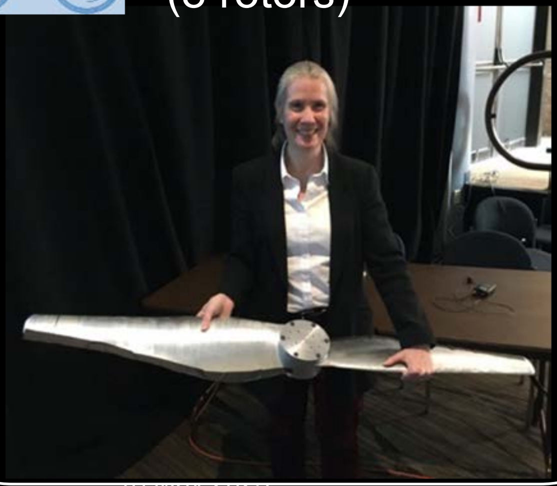
Designed for MMRTG
(like Curiosity + Perseverance)

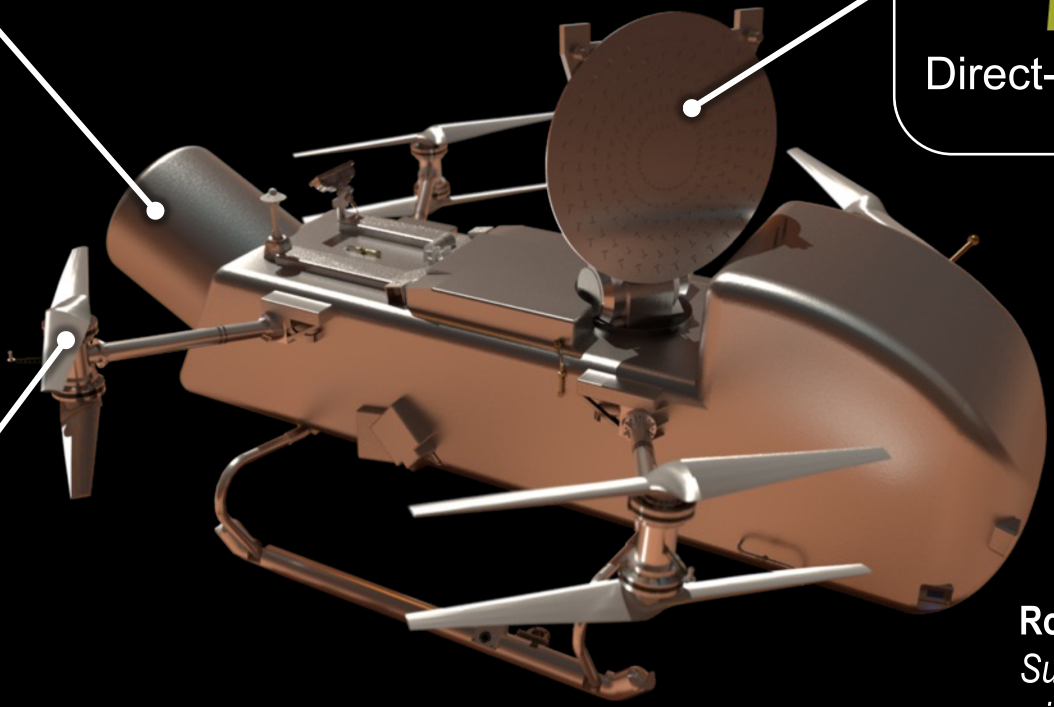
COMM

Direct-to-Earth Communication

FLIGHT

Dual Quadcopter
(8 rotors)

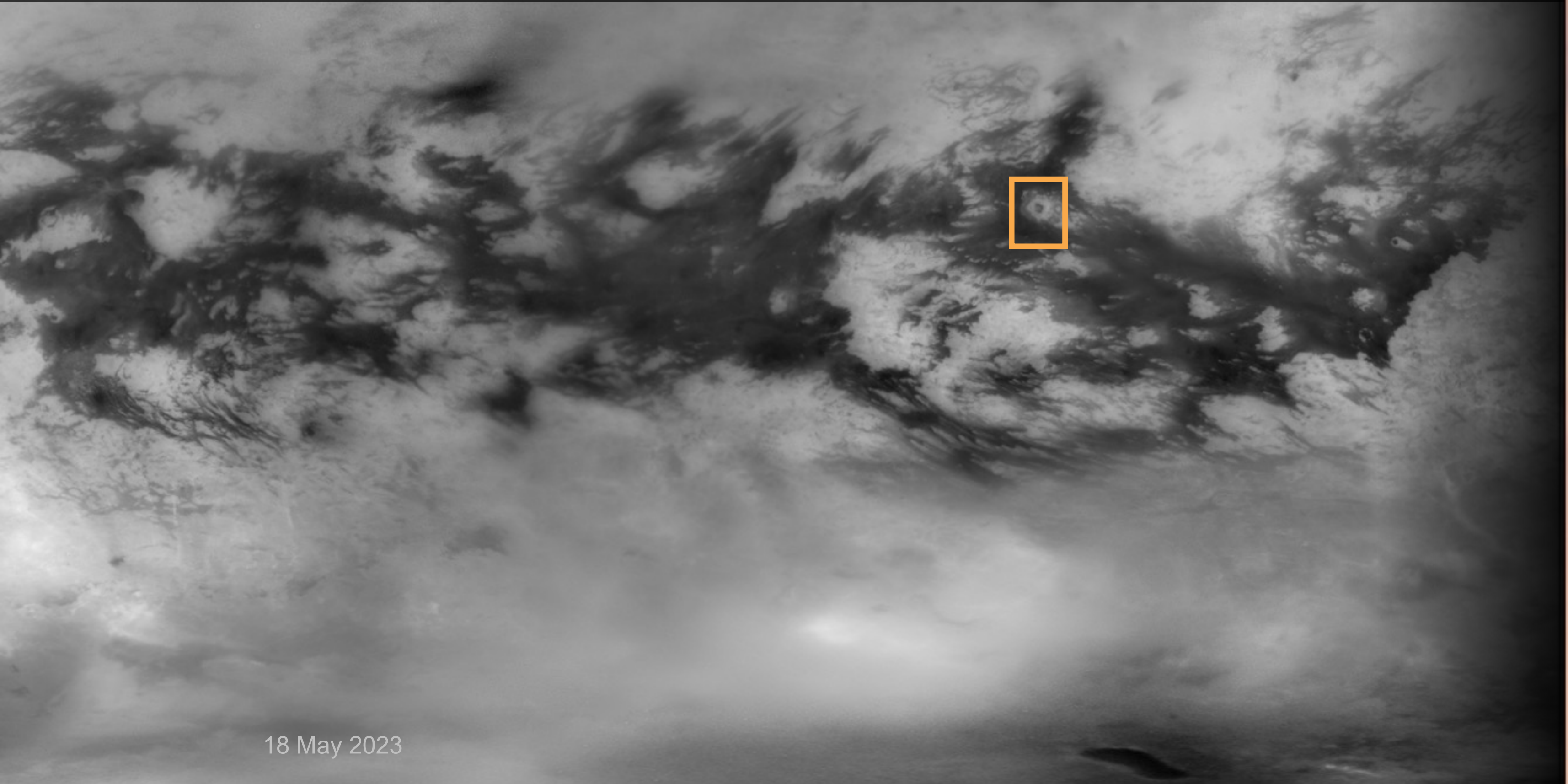




Rotorcraft Lander
Surface configuration with HGA deployed

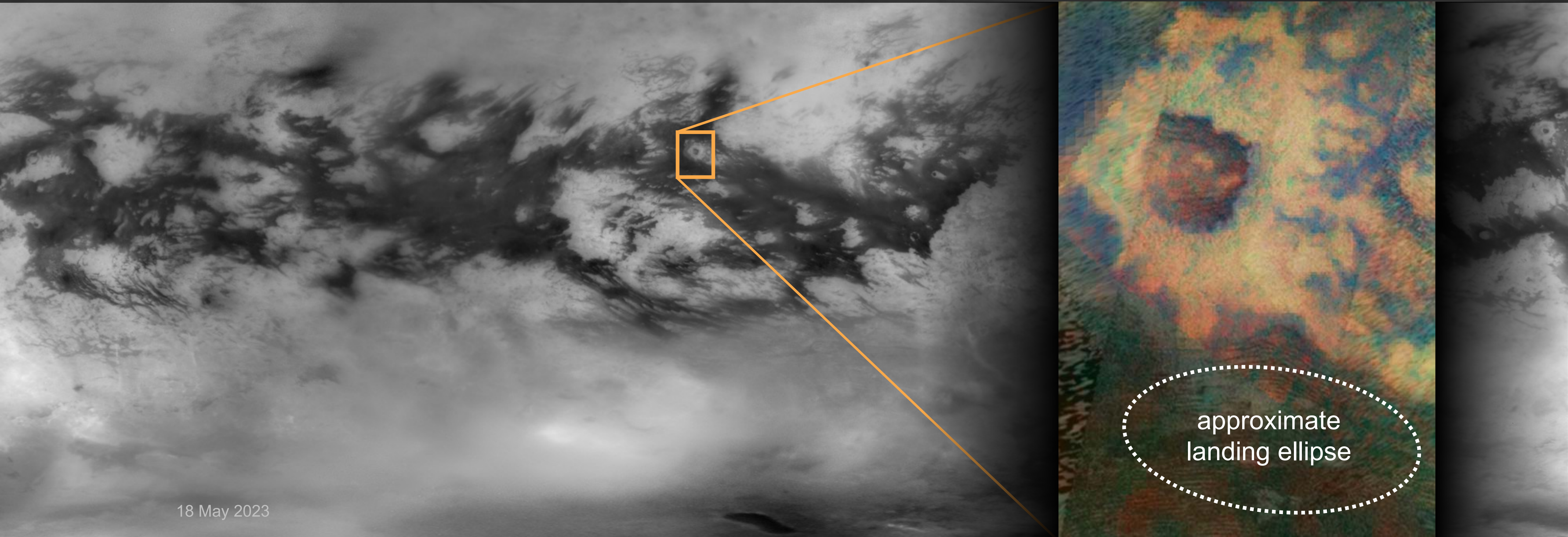
Dragonfly mission timeline

- Launch NET June 2027, and Titan arrival by 2034
  - Direct atmospheric entry
  - Similar latitude and same time of year as descent of Huygens probe



Dragonfly landing site and region of exploration

- Initial landing site provides access to a variety of materials
  - Sand dunes: organic sediments
  - Interdune areas: materials with a water-ice component
  - Selk impact crater: materials where organics may have mixed with liquid water impact melt



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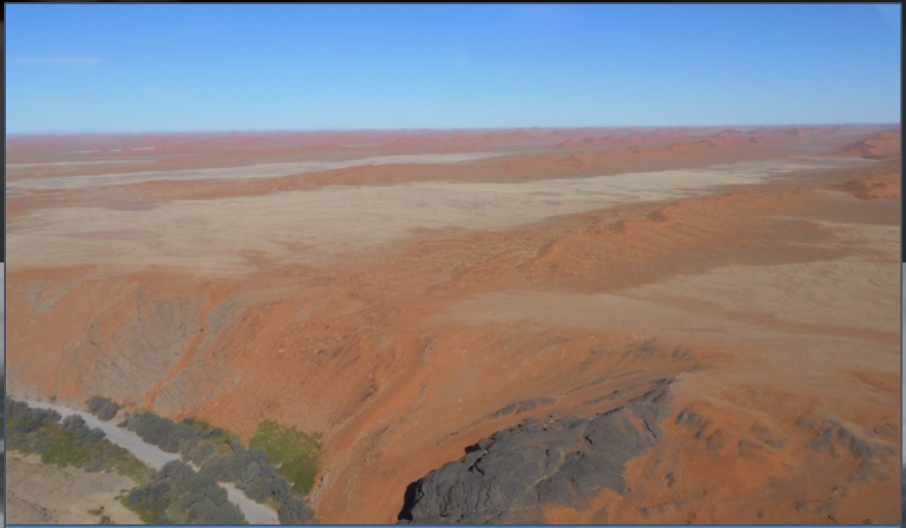
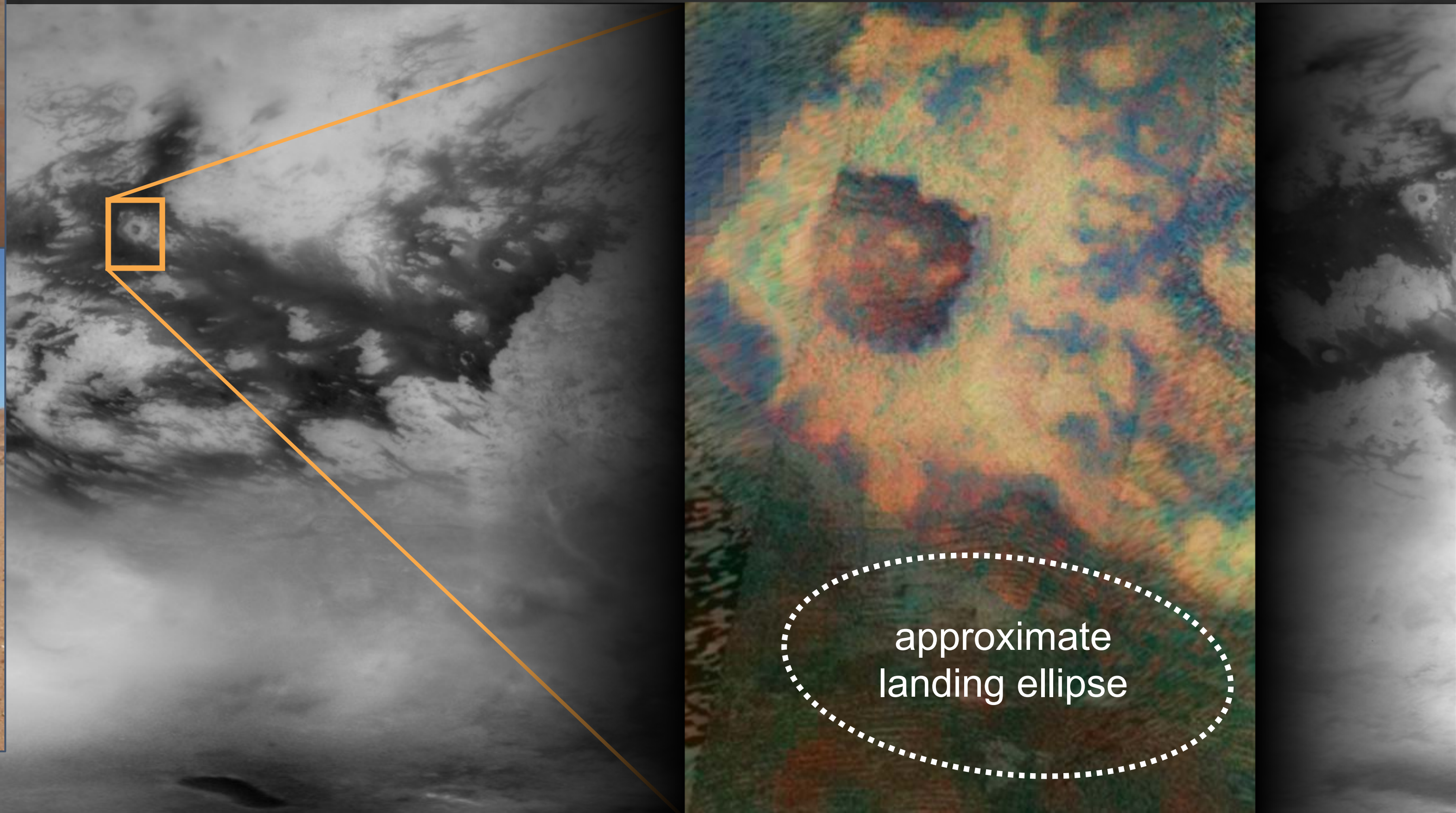
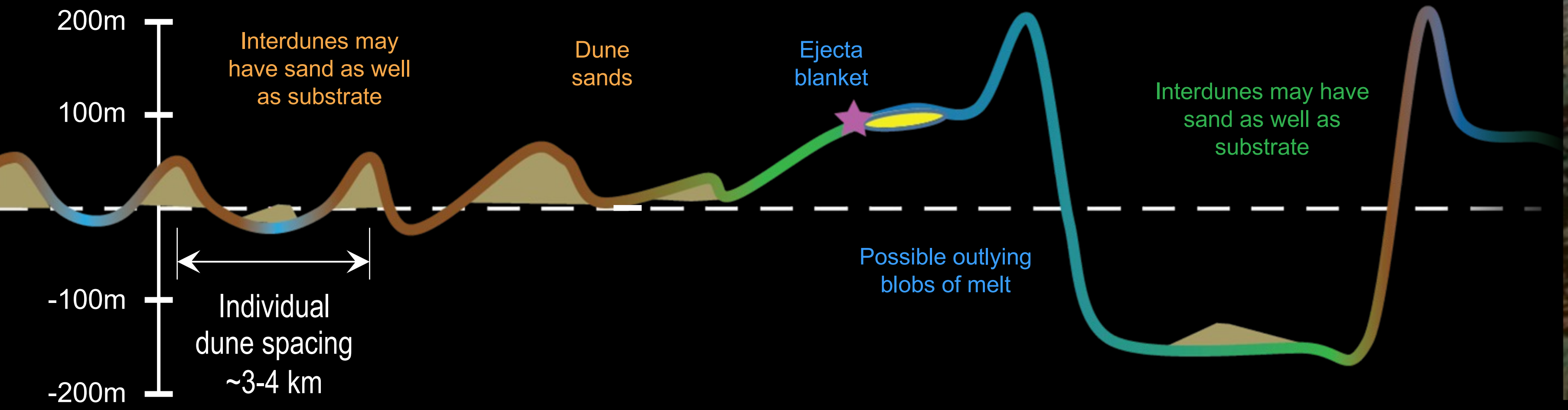
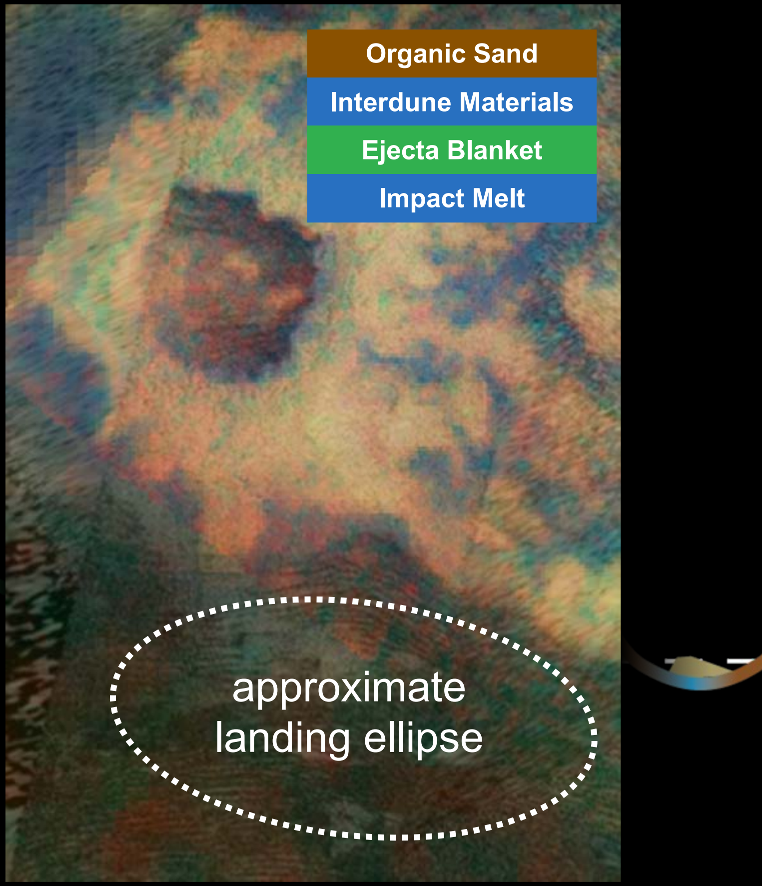




Dragonfly exploration strategy

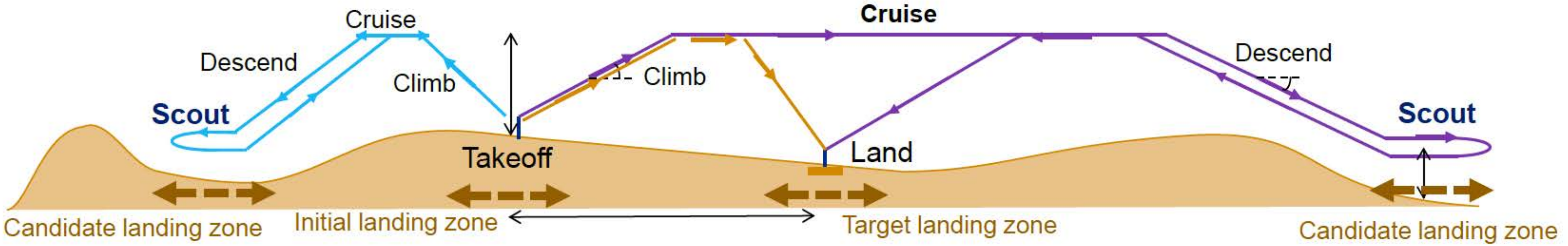
- **~3.3 years, ~74 Tsols (Titan days) of science operations**
  - Traverse distance up to ~100 km
  - Exploration of ~25-30 unique sites





Flight on Titan

- 3 types aerial flights used in traverse; imaging provides context, scouting of future landing sites*
  - Jump flights with or without preceding Scout flight are used to exit sand sea
  - A Leapfrog flies over previously scouted landing area, scouts next landing zone, descends to landing area

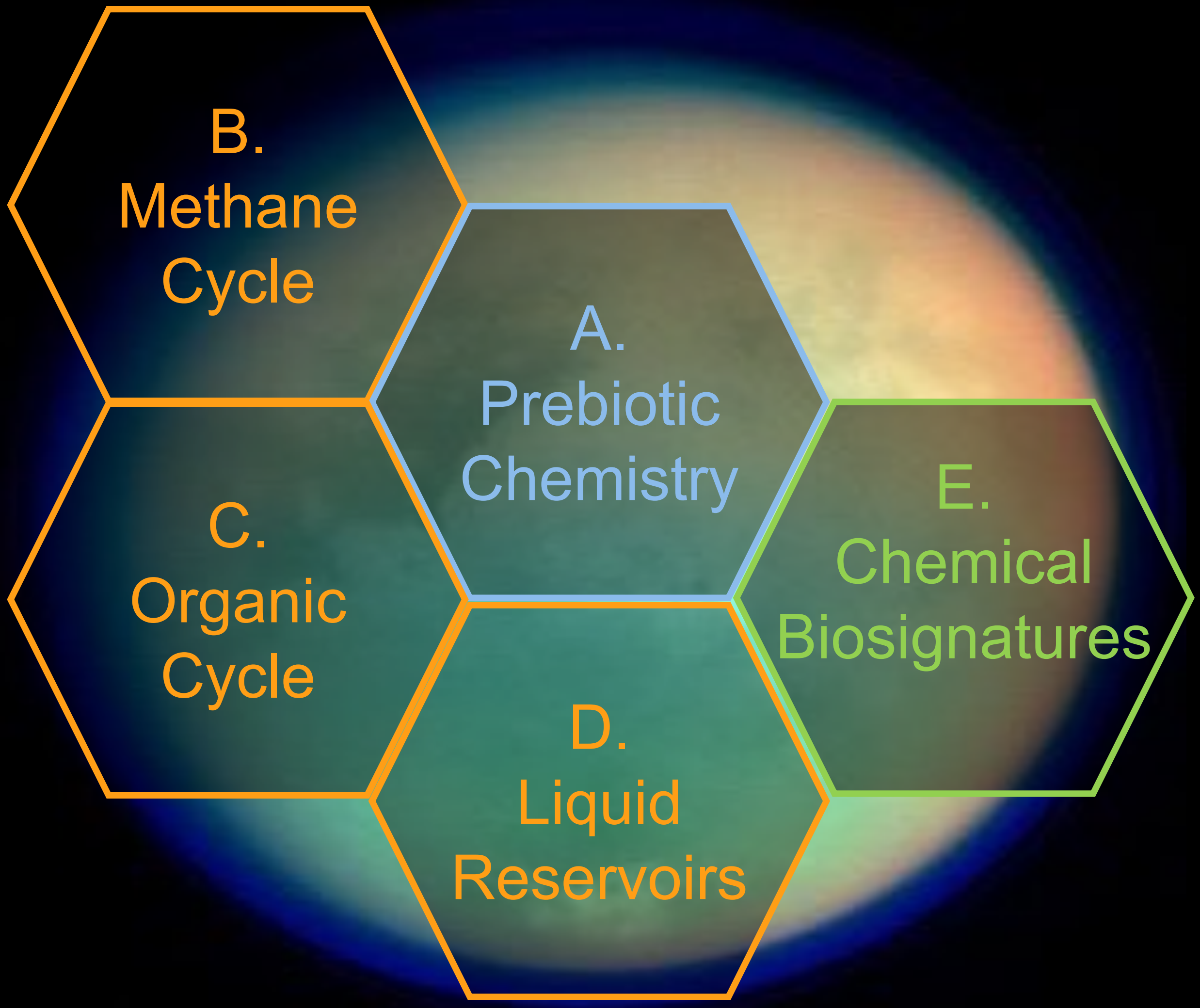


- Max range speed ~ 10 m/s (22 mph). Typical flight duration ~ 20-30 minutes.
- ‘Leapfrog’ strategy to allow off-line assessment of terrain hazards by science team on Earth prior to planning landing at new location

DRAGONFLY

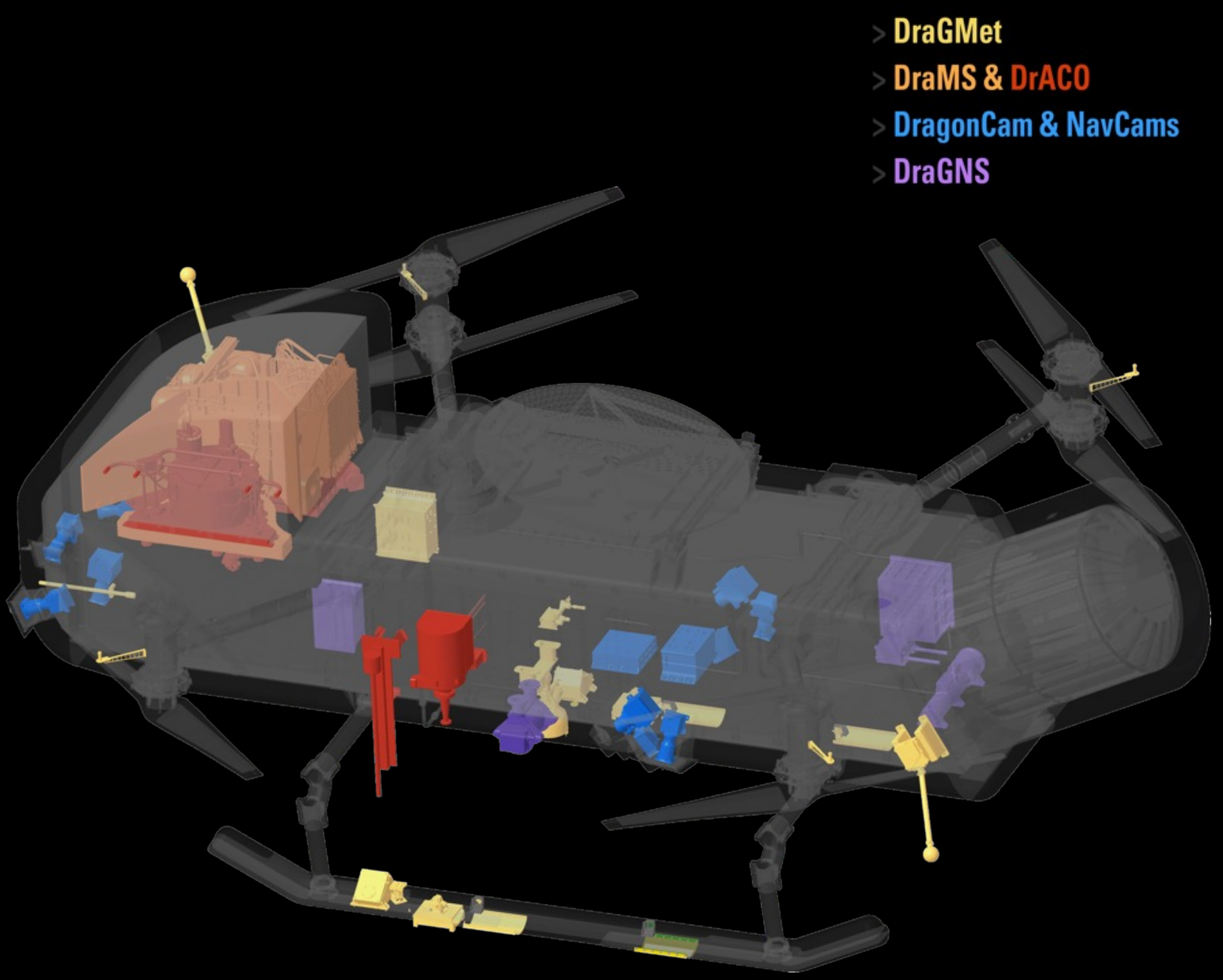
Multidisciplinary science measurements

- **Prebiotic chemistry**
  - Analyze chemical components and processes at work that produce biologically relevant compounds
- **Habitable environments**
  - 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 biosignatures**
  - Search for chemical evidence of water- or hydrocarbon-based life



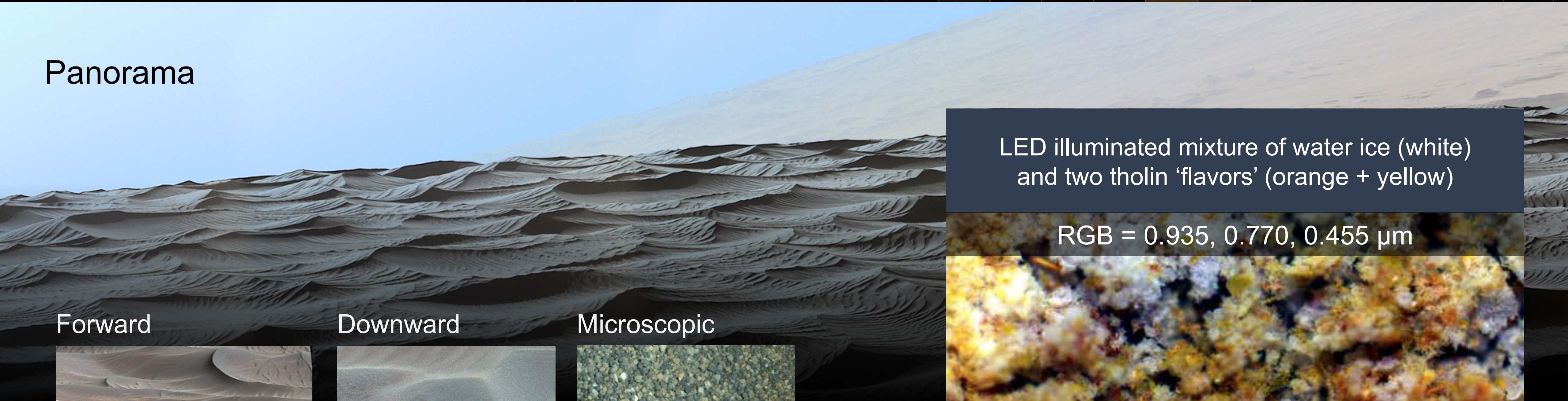
Multidisciplinary science measurements

- **DraMS**: Mass Spectrometer
  - GSFC, CNES – MSL SAM, ExoMars MOMA
- **DrACO**: Drill for Acquisition of Complex Organics
  - Honeybee Robotics
- **DraGNS**: Gamma-ray and Neutron Spectrometer
  - APL, LLNL – *MESSENGER* GRNS, *Psyche* GRNS
  - GSFC, Schlumberger – Pulsed Neutron Generator
- **DraGMet**: Geophysics & Meteorology Package
  - APL sensor suite + JAXA *Lunar-A* seismometer
- **DragonCam**: Camera Suite
  - MSSS – *OSIRIS-REx* ECAM, *MSL* Mastcam, *Mars 2020* descent camera

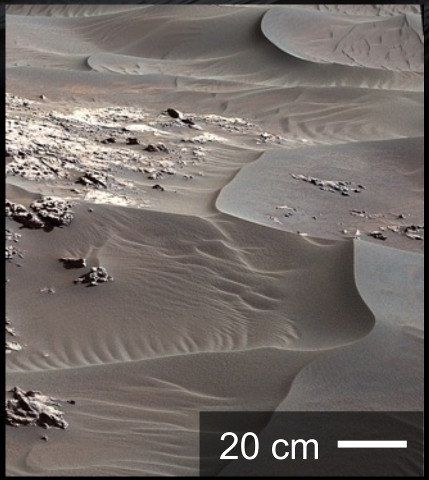


Characterization of landforms and surface processes in multiple geologic settings

DragonCam



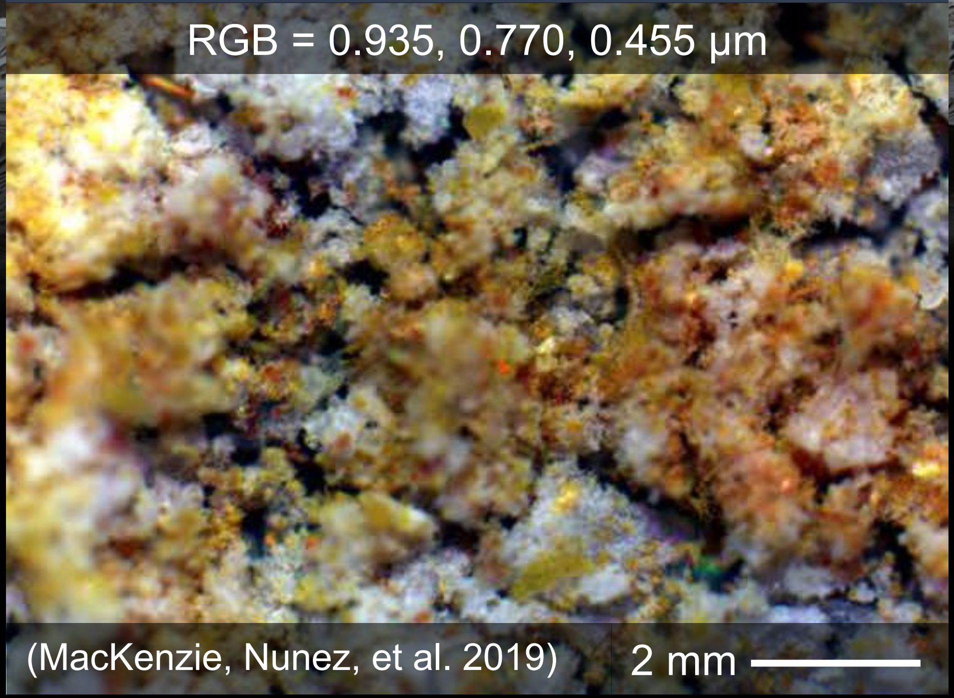
Forward



Downward

Microscopic

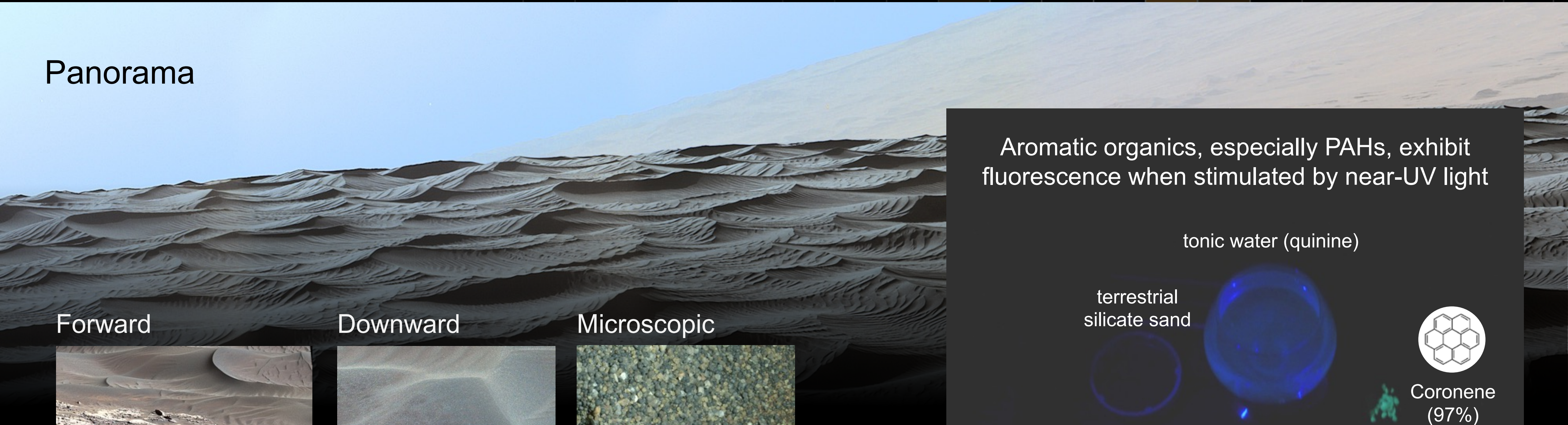
LED illuminated mixture of water ice (white) and two tholin 'flavors' (orange + yellow)



(MacKenzie, Nunez, et al. 2019)

Characterization of landforms and surface processes in multiple geologic settings

Panorama



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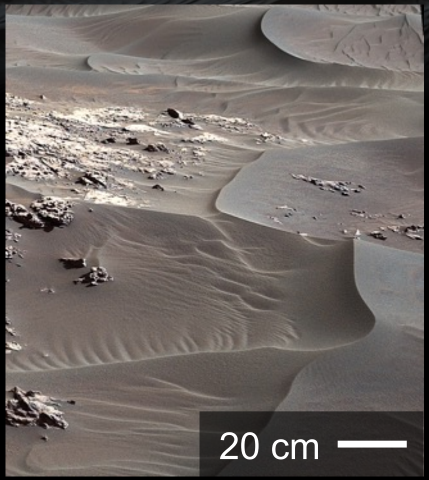
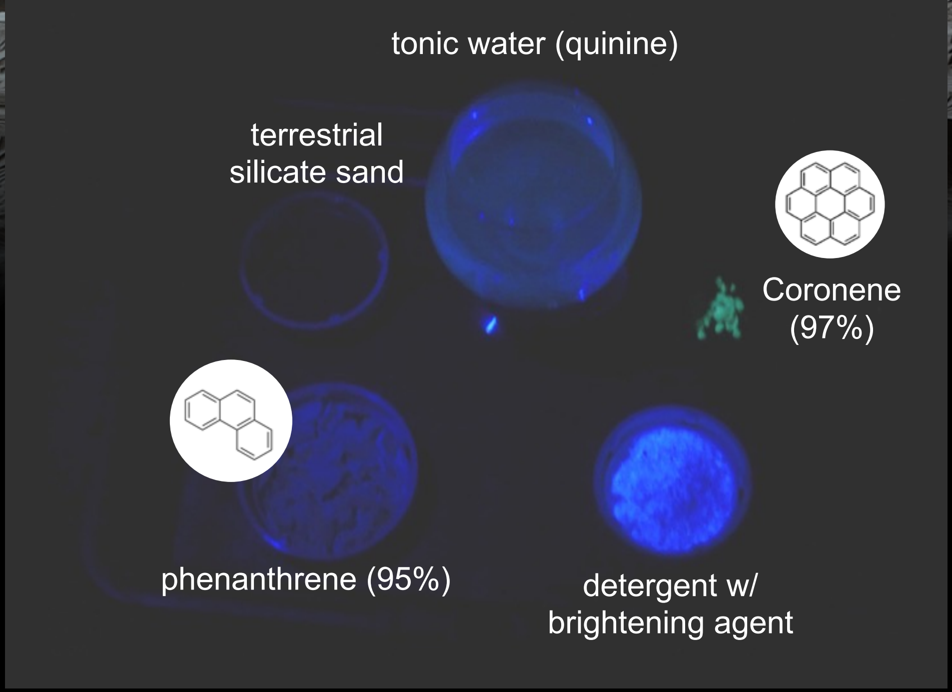


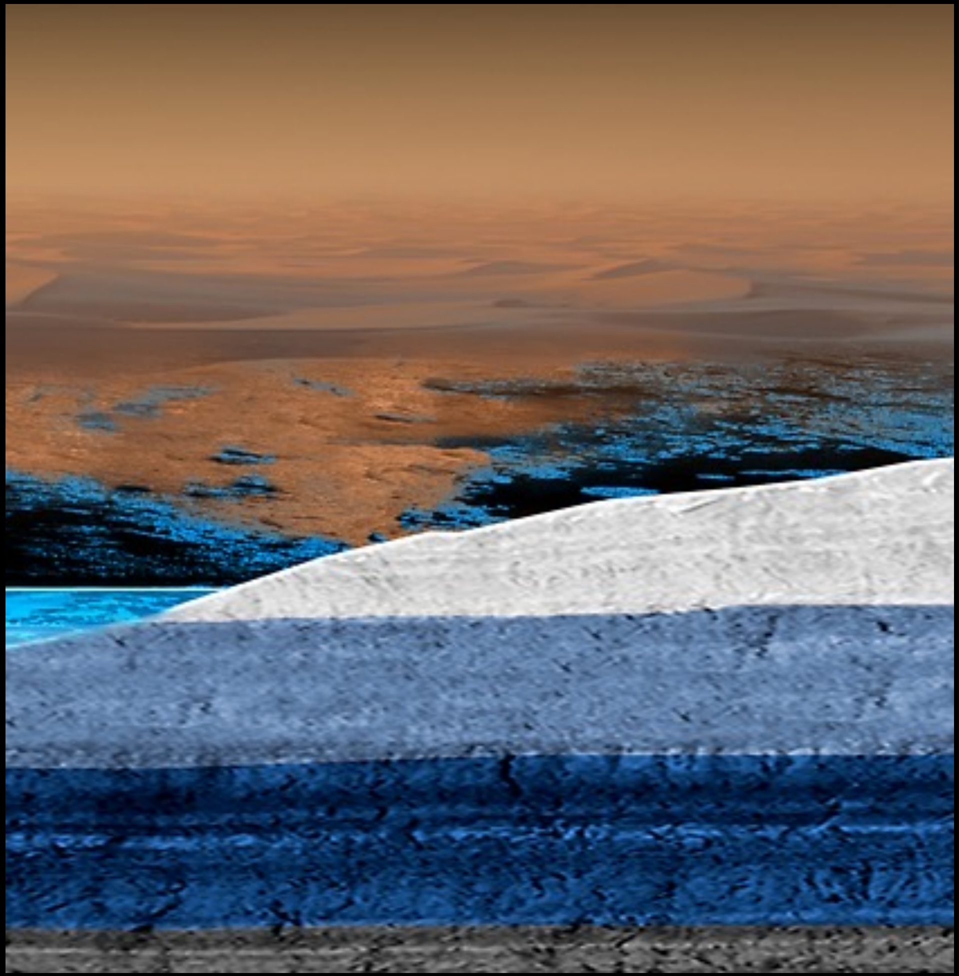
Downward

Microscopic

Aromatic organics, especially PAHs, exhibit fluorescence when stimulated by near-UV light



Meteorological and geophysical monitoring of Titan as an interconnected system



Monitor atmospheric conditions, identify CH_4 reservoirs, and determine transport rates

- Temperature, pressure, CH_4, H_2, wind speed & direction
- Diurnal and spatial variations; atmospheric profiles

Constrain regolith properties (e.g., porosity)

- Thermal response (dampness), dielectric constant

Constrain processes that mix organics with past surface liquid water or subsurface ocean

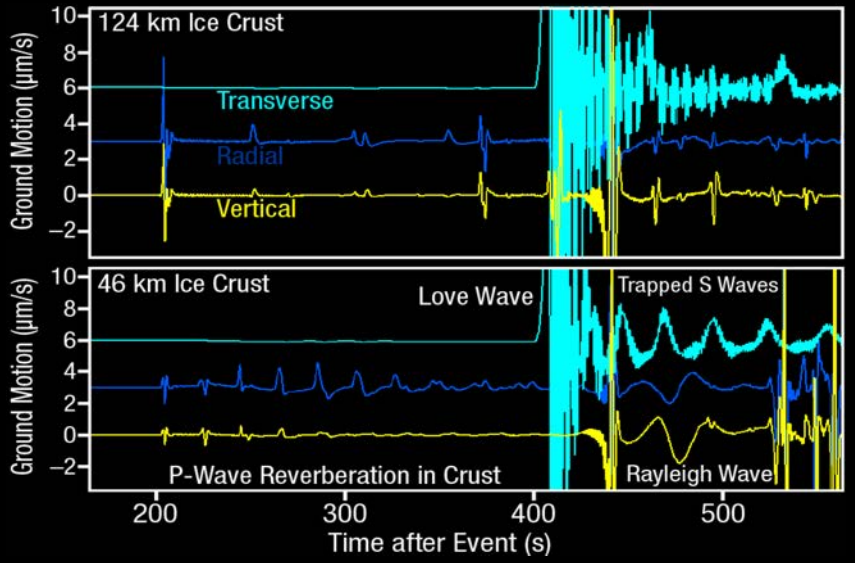
- E-Field (Schumann resonance), seismic activity

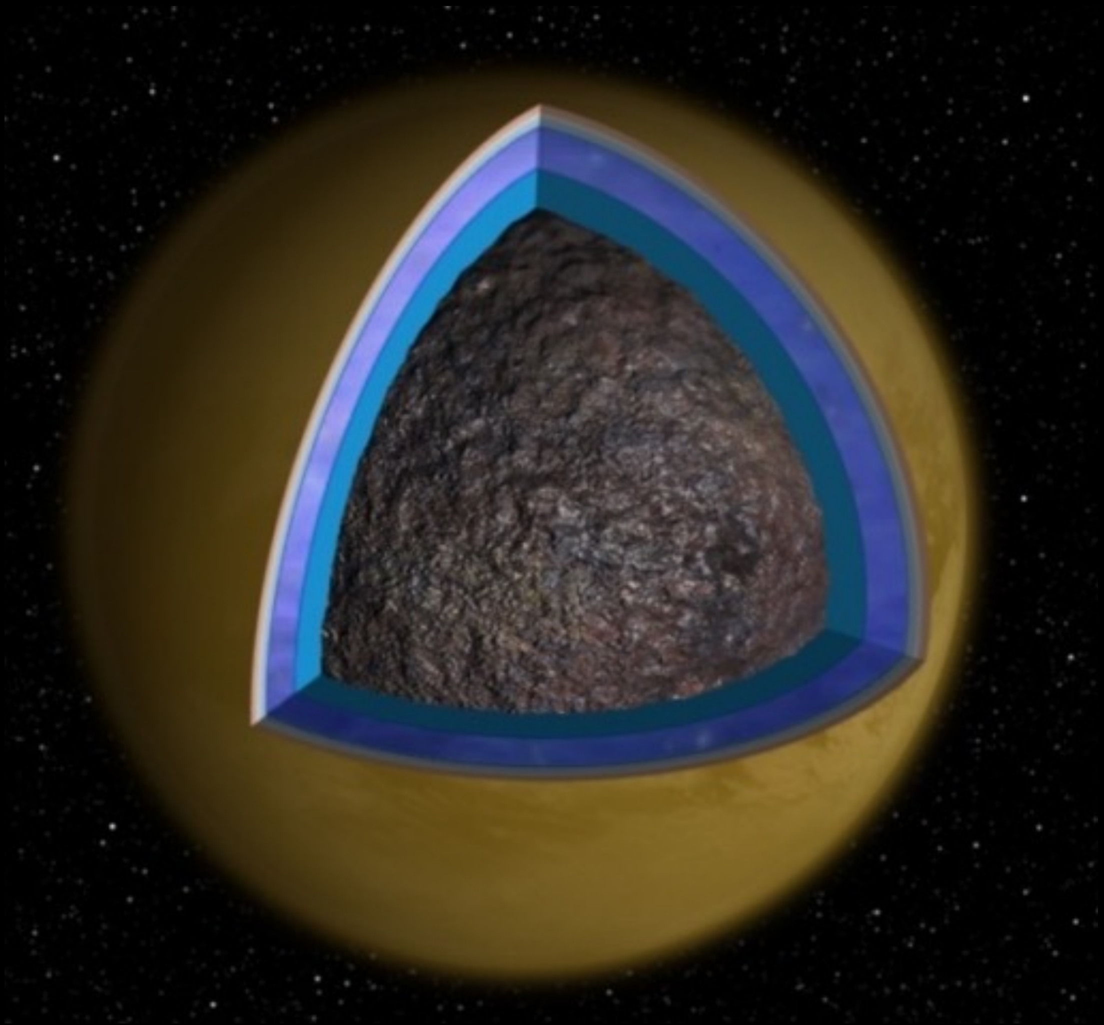
Seismological monitoring of an ocean world

DraGMet

- Detection and characterization of level of seismic activity

- Variation with orbital phase

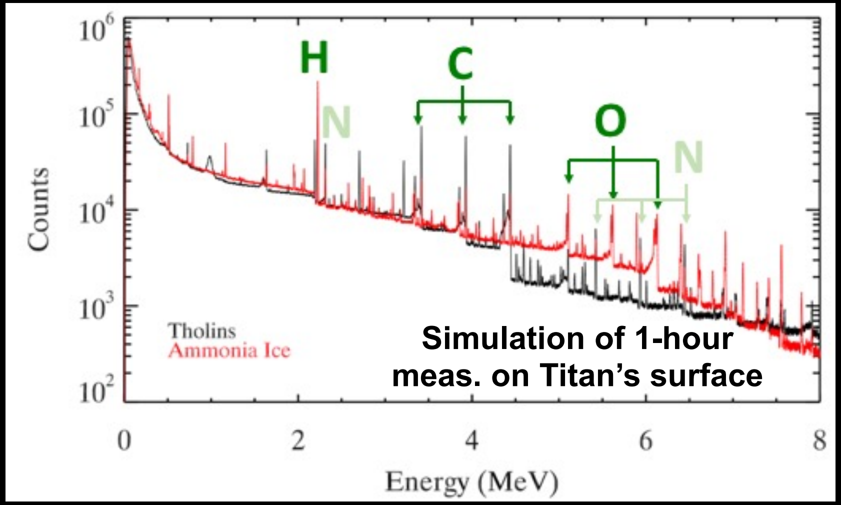


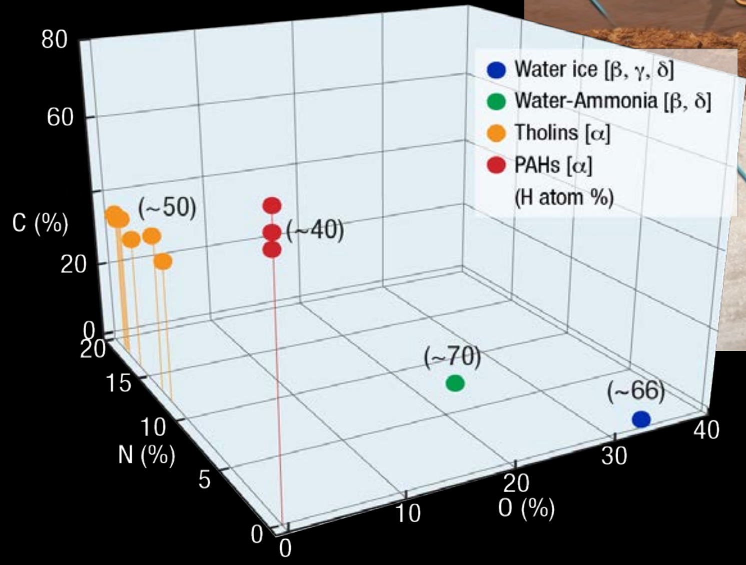


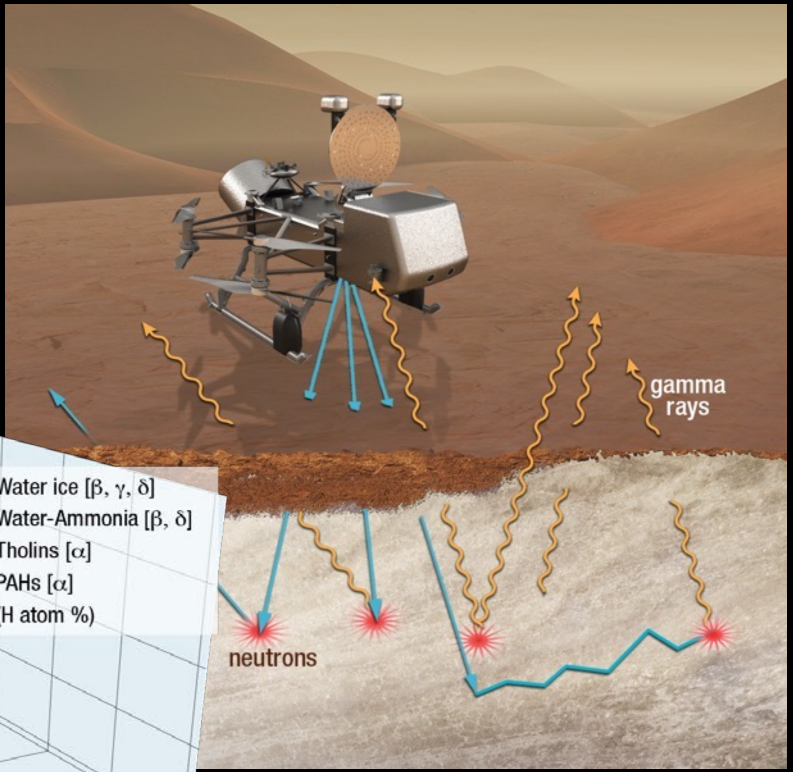
Classification of surface materials at every site

DraGNS

- Measure bulk elemental surface composition
  - Classify surface material
  - Detect minor inorganic elements
  - Reveal near-surface stratigraphy



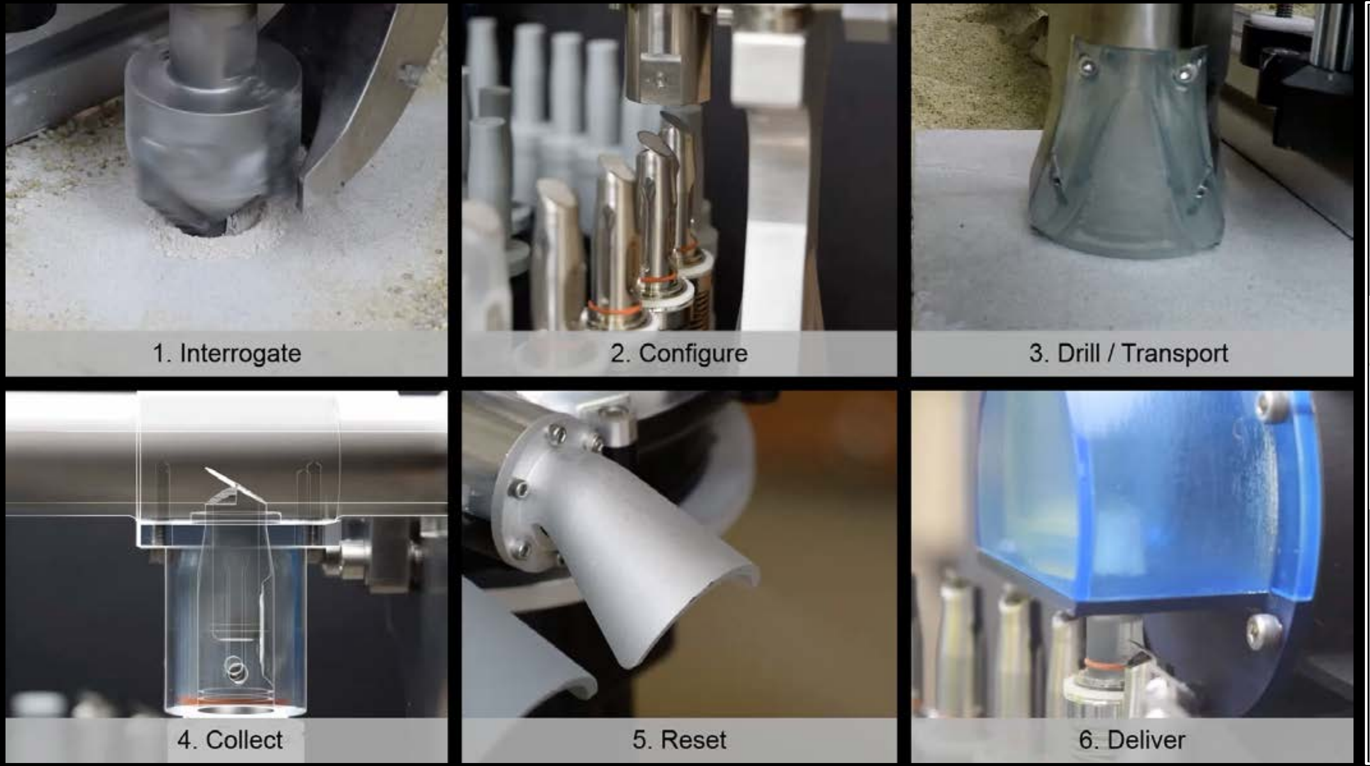




Acquisition of Titan's solid surface materials in a cryogenic environment

DrACO

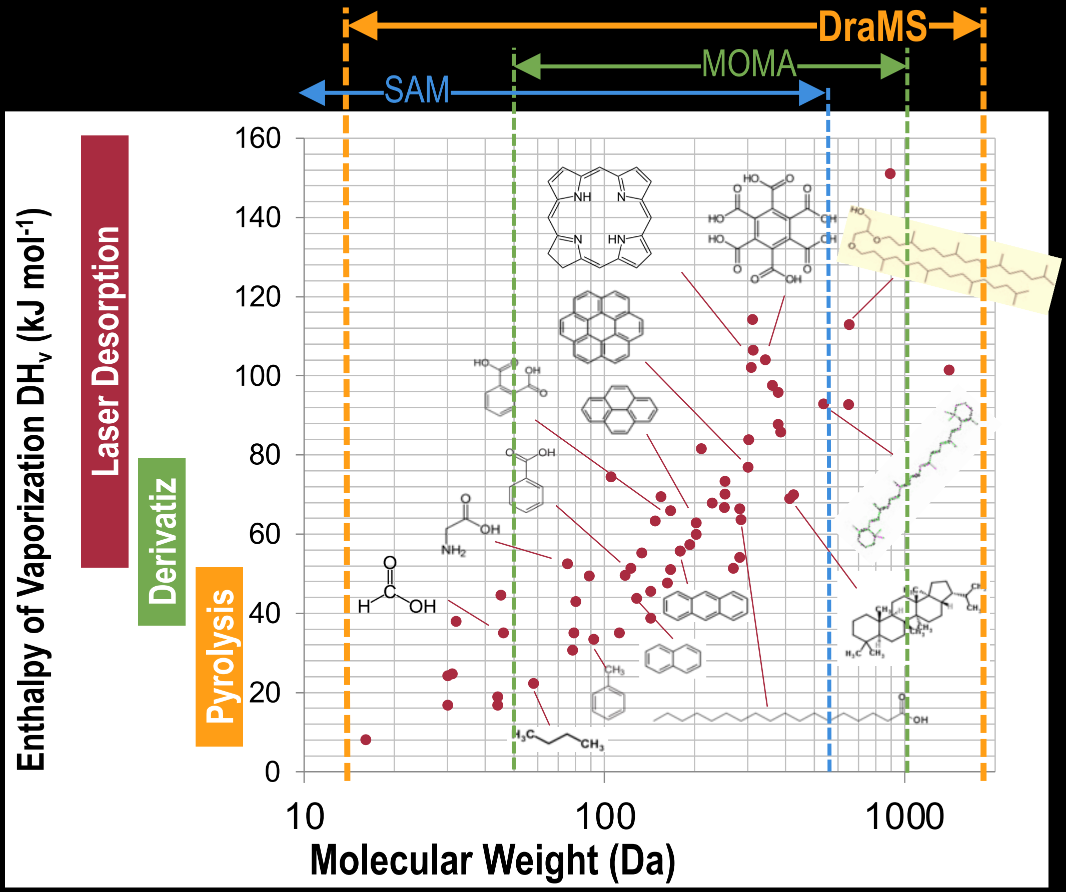
- DrACO: Sample surface materials for detailed chemical analyses with DraMS



Comprehensive study of the chemical complexity and diversity of Titan's solid surface

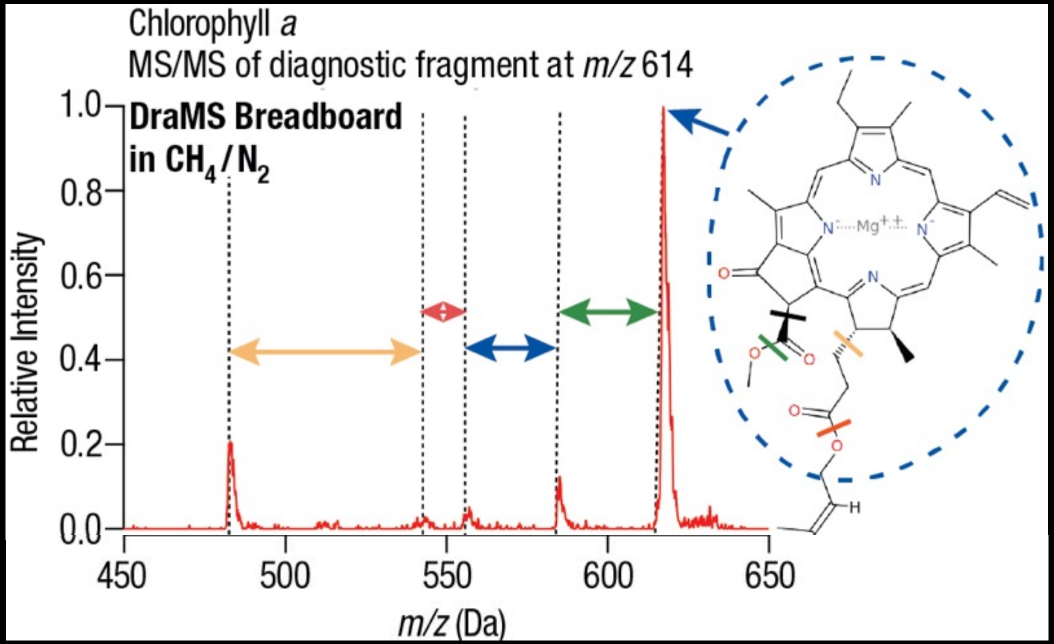
DraMS *fed by* DrACO

- Analyze chemical components and processes that produce biologically relevant compounds
- Complementary sample analysis modes:
  - LDMS = Laser Desorption Mass Spectrometry
  - GCMS = Gas Chromatography Mass Spectrometry



(Trainer et al., 2017)

DraMS Molecular Analysis of Surface Materials



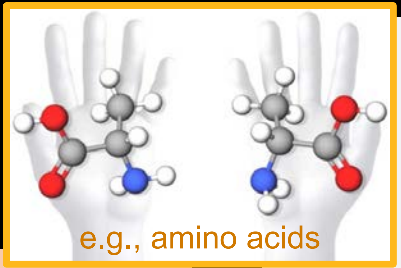
Broad Survey Mass Spectrometry

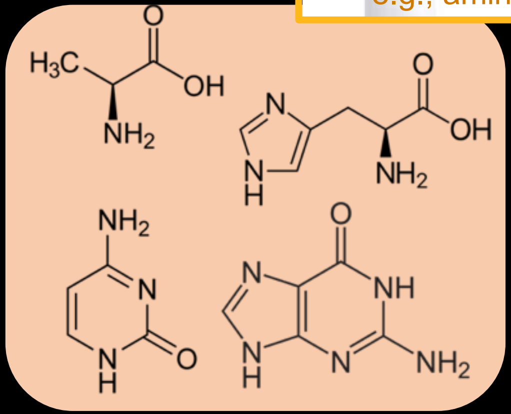
Organic inventory of high molecular weight organics

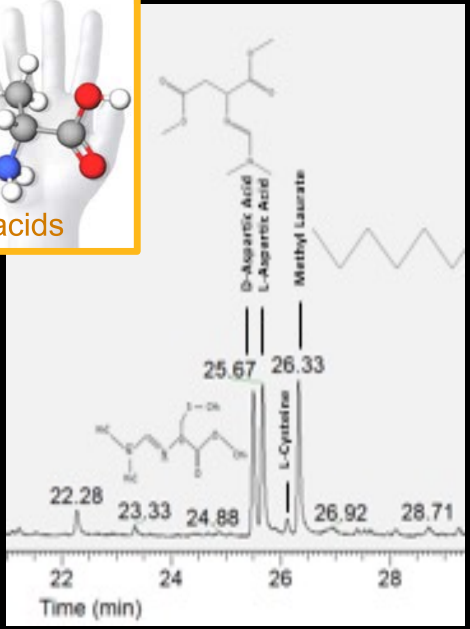
Preferential patterns and structural elucidation

Minimal sample processing

LDMS Mode







Sensitive and Selective MS

Gas chromatography targeting potential biomolecules

Search for enantiomeric excess

Derivatization options provide flexibility

GCMS Mode


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

Dragonfly in the Desert

Watch *Dragonfly* Movies!

- https://svs.gsfc.nasa.gov/13562
- https://www.youtube.com/watch?v=XbgIDa3rzBk

And more at https://dragonfly.jhuapl.edu/

DRAGONFLY

http://dragonfly.jhuapl.edu