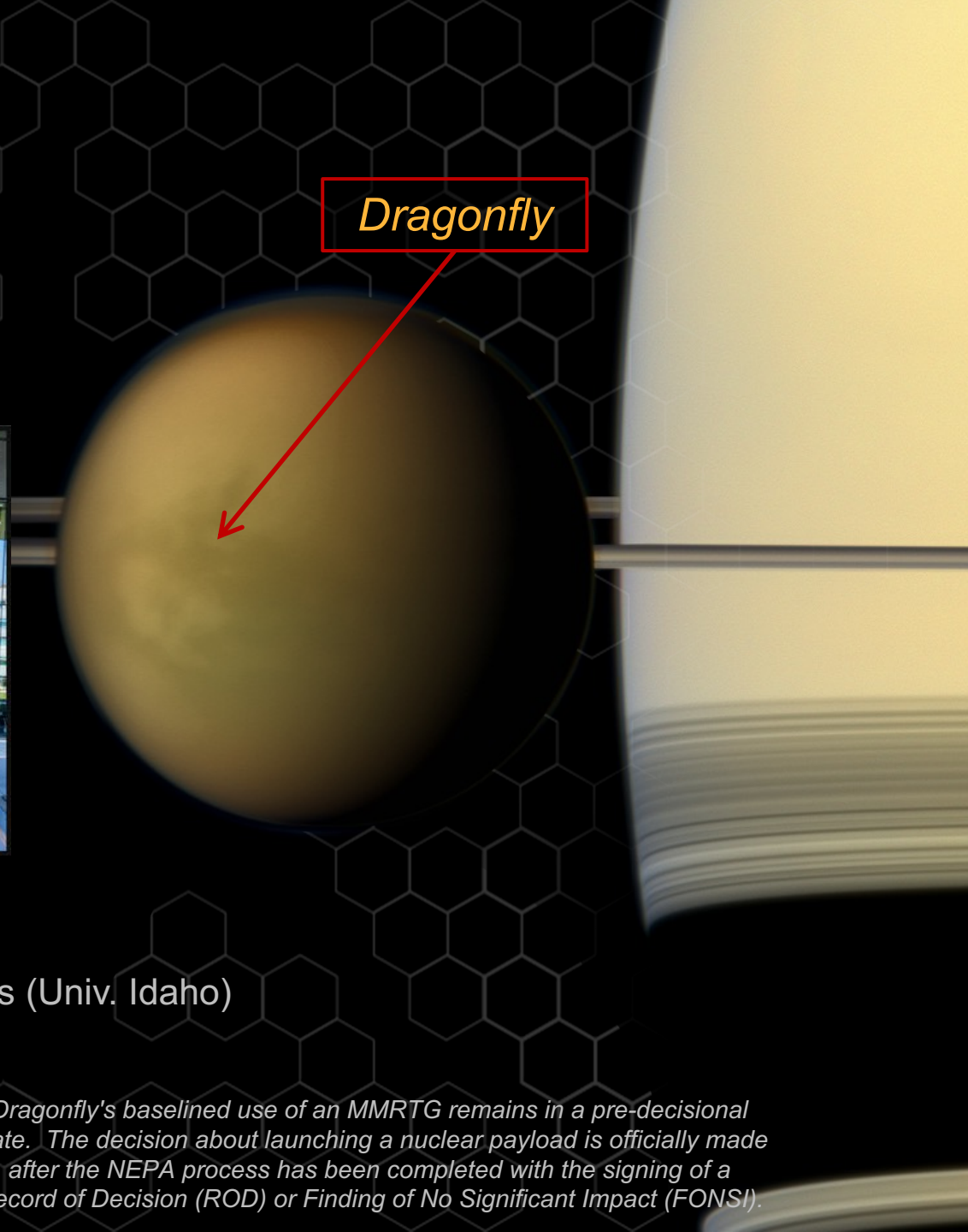
# DRAGONFLY

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





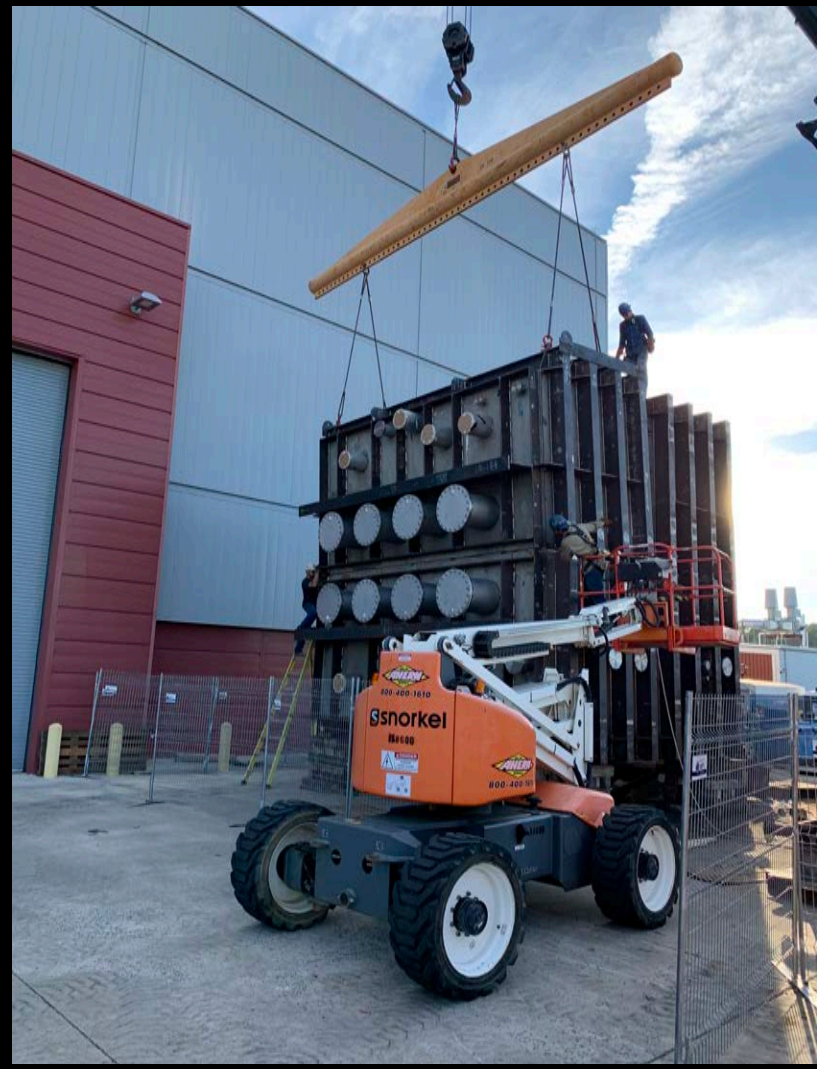

## Dragonfly Update to CAPS, 23 March 2022

Principal Investigator: E. Turtle (APL); DPIs M. Trainer (GSFC), J. Barnes (Univ. Idaho)
Project Manager: P. Bedini (APL); DPM R. Fitzgerald (APL)
Mission System Engineer: K. Hibbard (APL); DMSE S. Thibault (APL)

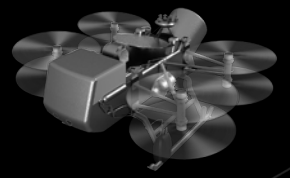
*Dragonfly's baselined use of an MMRTG remains in a pre-decisional state. The decision about launching a nuclear payload is officially made after the NEPA process has been completed with the signing of a Record of Decision (ROD) or Finding of No Significant Impact (FONSI).*

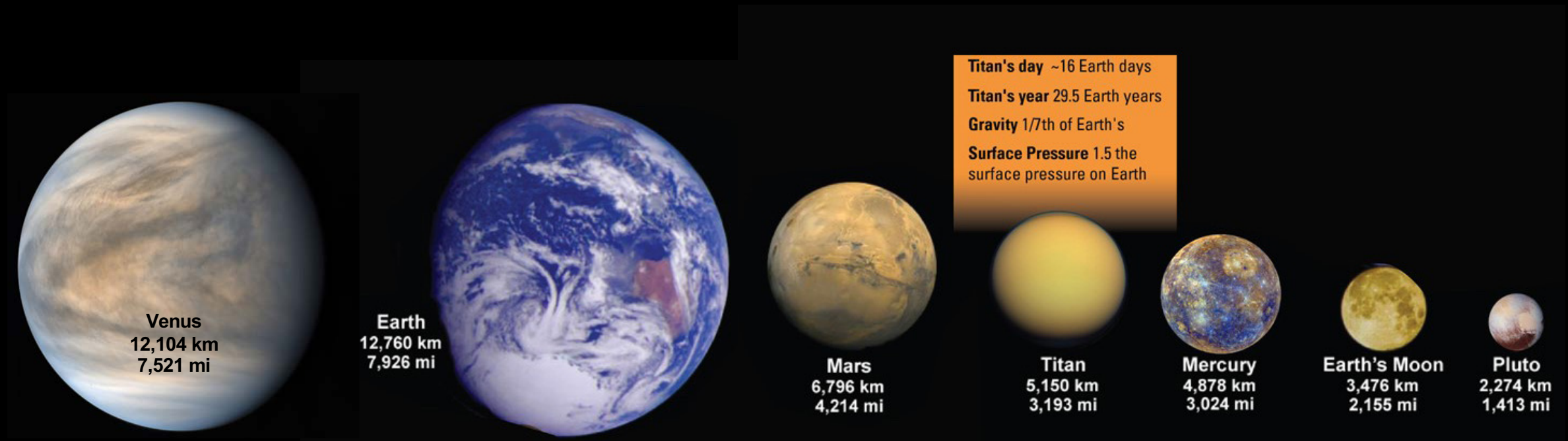
# Outline

- Mission overview
- Mission timeline
- Project status and activities

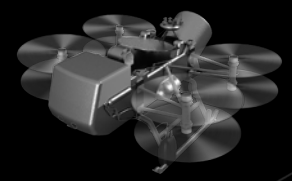




# Titan's unique environment



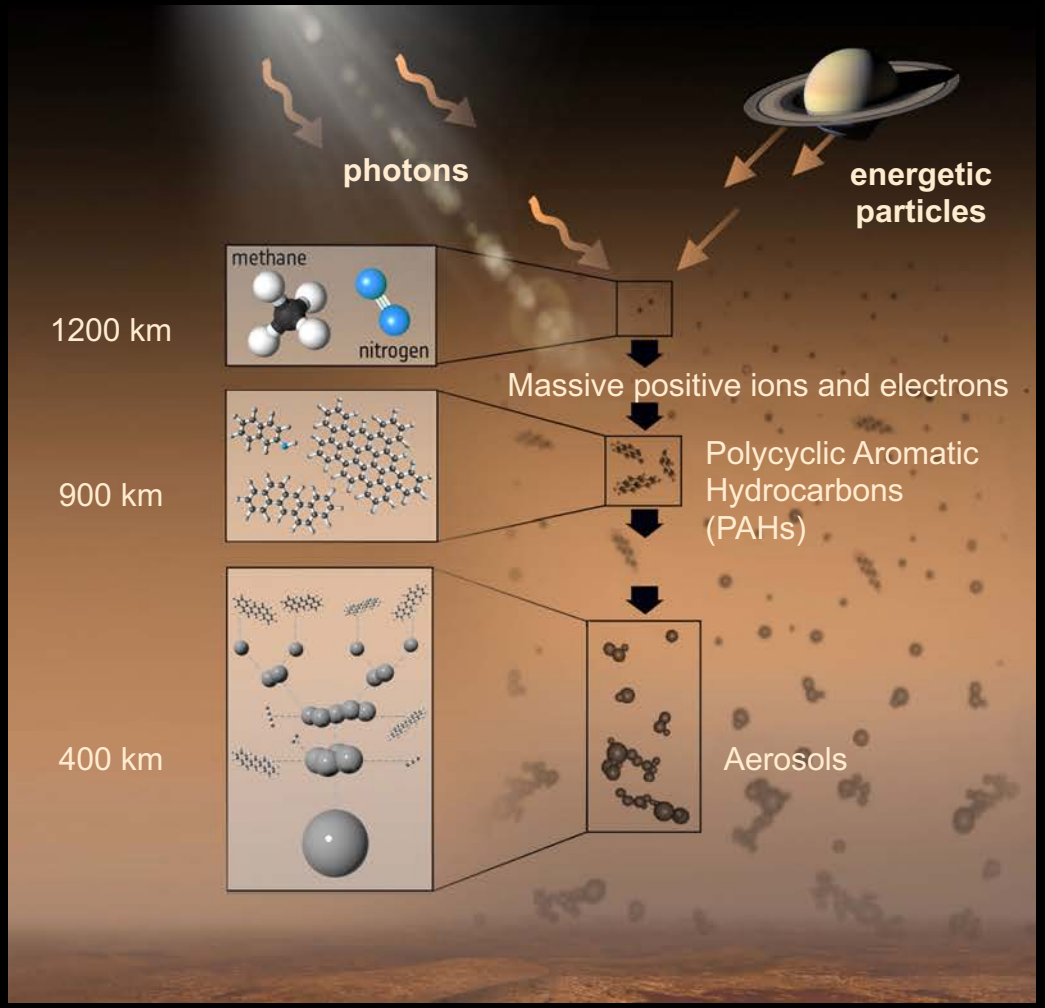


# Complex organic chemistry

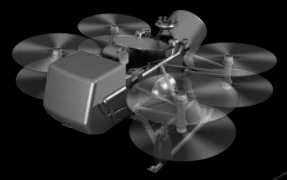


- Photochemistry in upper atmosphere produces complex carbon molecules
- Rich organic material covers the surface
- Potential for organic compounds to have mixed with liquid water for extended periods of time at the surface

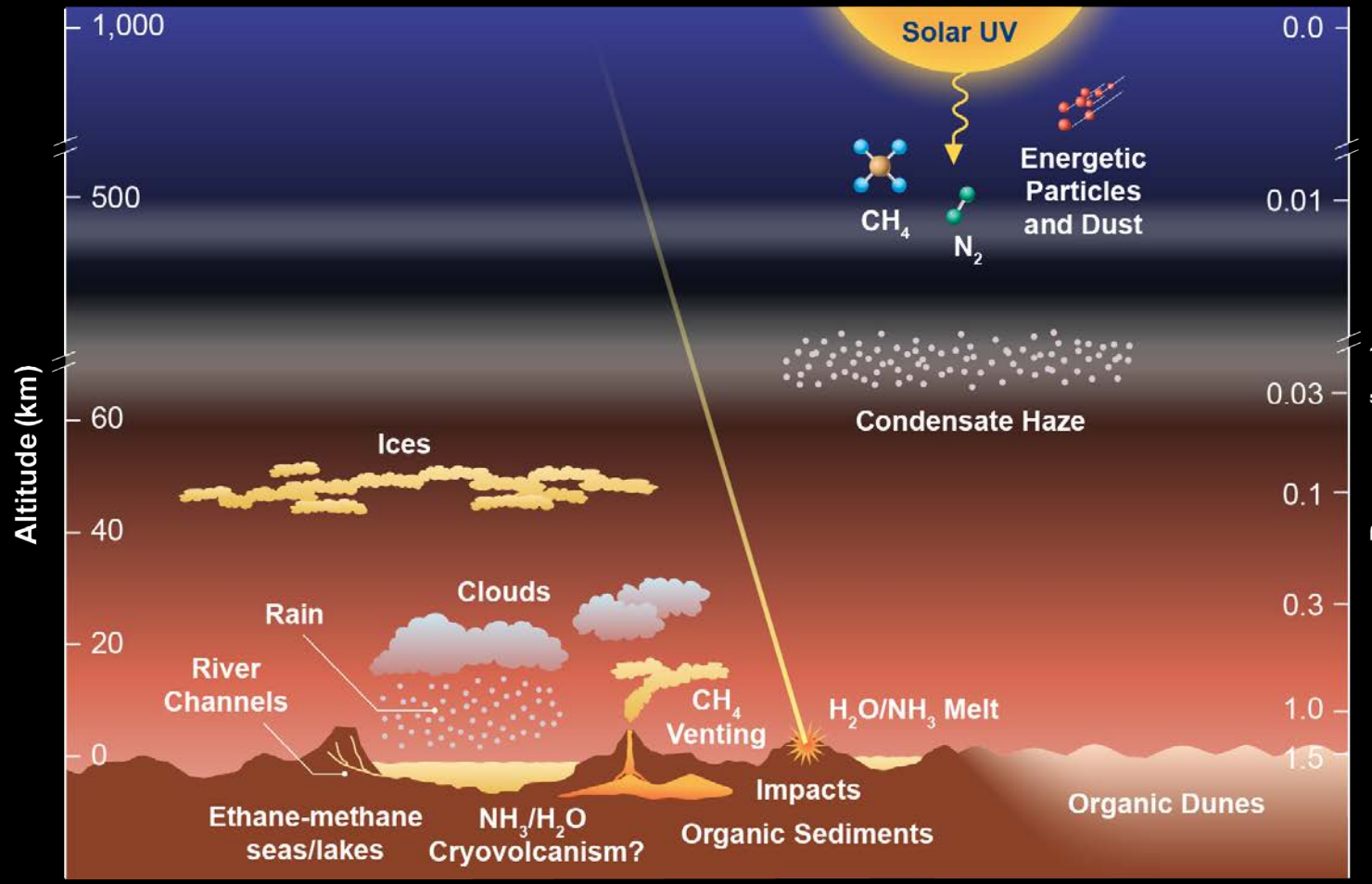
**Titan is a singular destination for understanding the chemical processes on our own planet that supported the development of life**



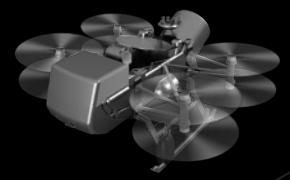
# Key ingredients necessary for life



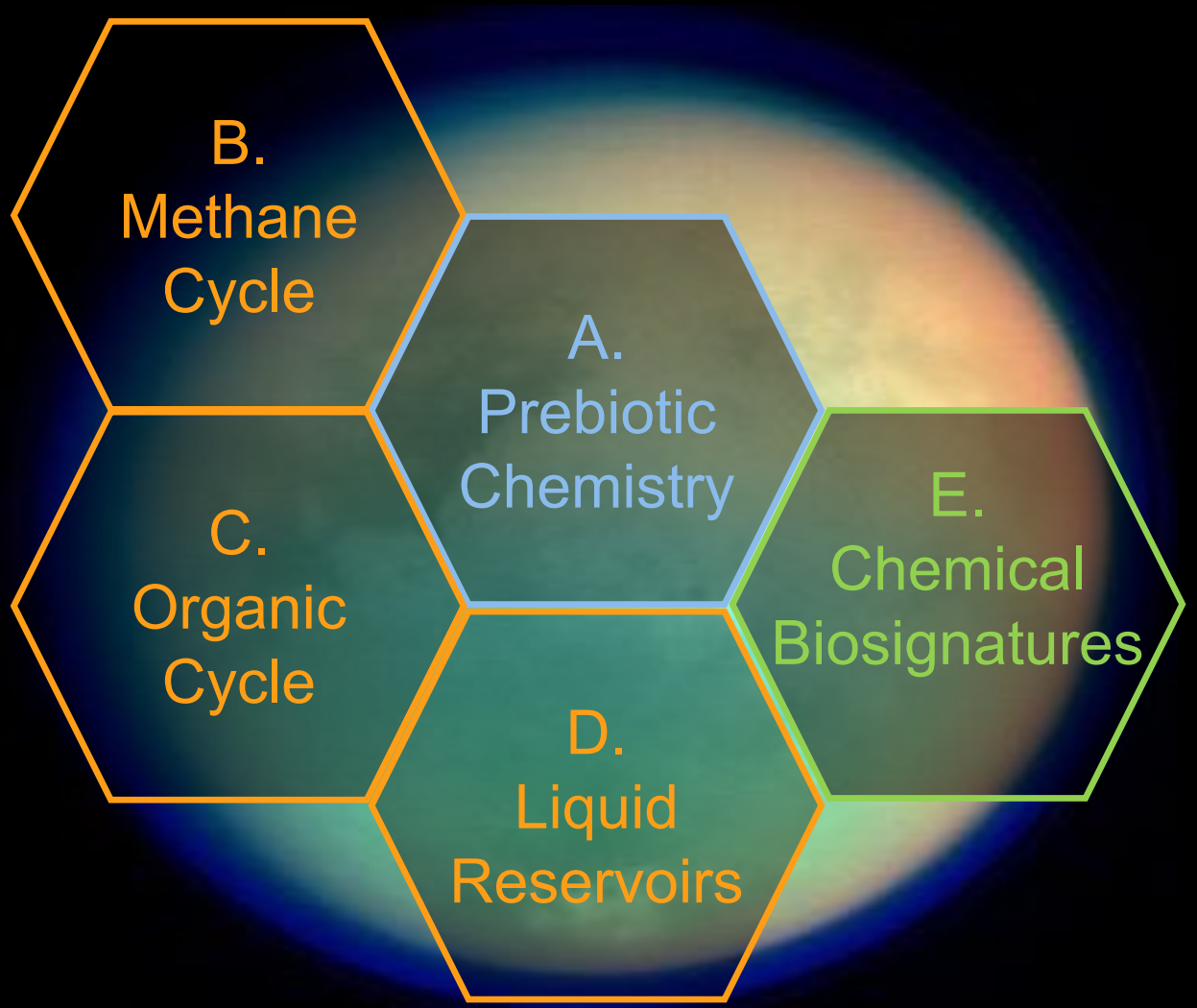
- Energy
  - Sunlight, photochemistry
- Organic material
  - Abundant complex organics
- Two liquids
  - Water
    - available at the surface in Titan's past
    - interior ocean
  - Methane
    - active methane cycle like Earth's water cycle
    - liquid methane could support development of alternate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



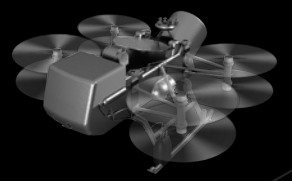
# Dragonfly mission science



- 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



# Dragonfly mission science



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https://doi.org/10.3847/PSJ/abfdcf

The Planetary Science Journal, 2:130 (18pp), 2021 August https://doi.org/10.3847/PSJ/abfdcf


**Science Goals and Objectives for the Dragonfly Titan Rotorcraft Relocatable Lander**

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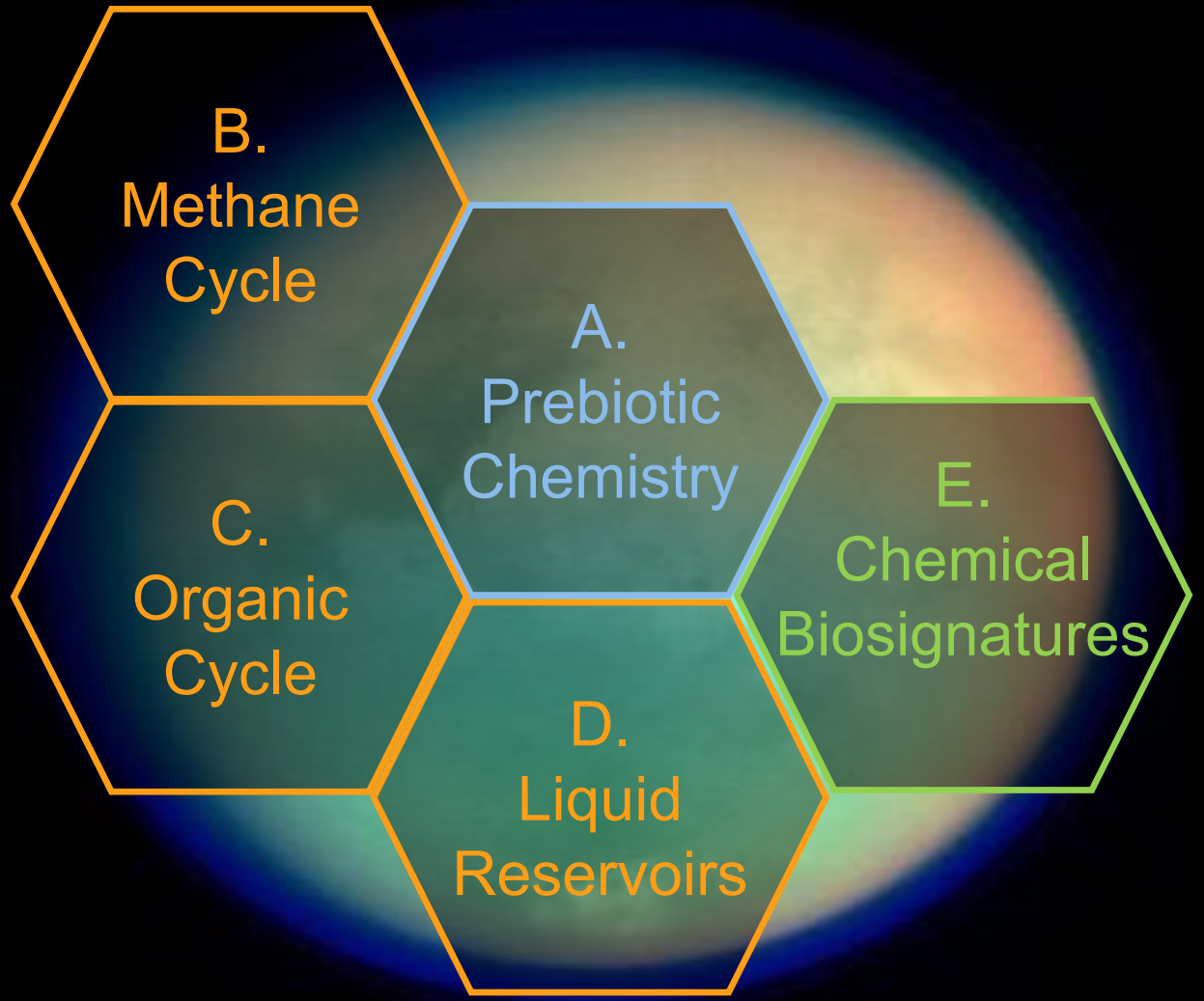
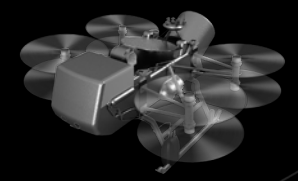
**Abstract**

NASA's Dragonfly mission will send a rotorcraft lander to the surface of Titan in the mid-2030s. Dragonfly's science themes include investigation of Titan's prebiotic chemistry, habitability, and potential chemical biosignatures from both water-based "life as we know it" (as might occur in the interior mantle ocean, potential cryovolcanic flows, and/or impact melt deposits) and potential "life, but not as we know it" that might use liquid hydrocarbons as a solvent (within Titan's lakes, seas, and/or aquifers). Consideration of both of these solvents simultaneously led to our initial landing site in Titan's equatorial dunes and interdunes to sample organic sediments and water ice, respectively. Ultimately, Dragonfly's traverse target is the 80 km diameter Selk Crater, at 7° N, where we seek previously liquid water that has mixed with surface organics. Our science goals include determining how far prebiotic chemistry has progressed on Titan and what molecules and elements might be available for such chemistry. We will also determine the role of Titan's tropical deserts in the global methane cycle. We will investigate the processes and processing rates that modify Titan's surface geology and constrain how and where organics and liquid water can mix on and within Titan. Importantly, we will search for chemical biosignatures indicative of past or extant biological processes. As such, Dragonfly, along with Perseverance, is the first NASA mission to explicitly incorporate the search for signs of life into its mission goals since the Viking landers in 1976.

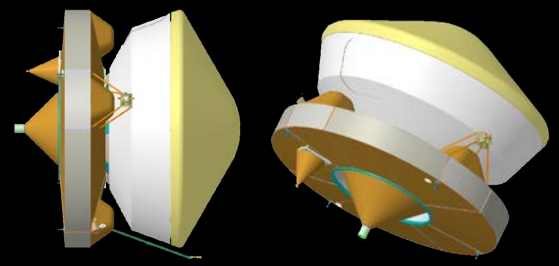
*Unified Astronomy Thesaurus concepts:* Titan (2186); Pre-biotic astrochemistry (2079); Astrobiology (74); Planetary atmospheres (1244); Planetary surfaces (2113)



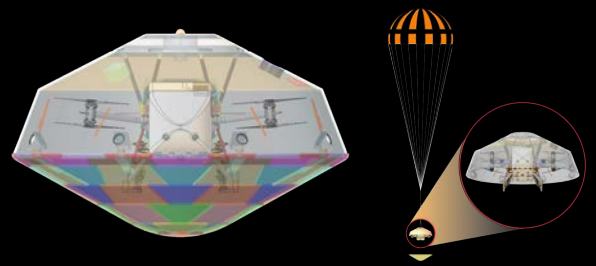
# Dragonfly mission elements



**Spacecraft =** Cruise Stage + Entry Vehicle



**Entry Vehicle =** EDL Assembly (heatshield and backshell) + Lander



## Carry entire payload from place to place

- Measurements on surface and in flight, including aerial imaging and atmospheric profiles

## Direct-to-Earth communication

- Radial line slot array antenna
- HGA articulation used to target cameras for panoramas of surrounding terrain

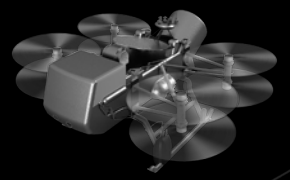
## MMRTG power source

- Charges battery to power flight and science activities and data transmission
- Heat output maintains nominal thermal environment in insulated lander body

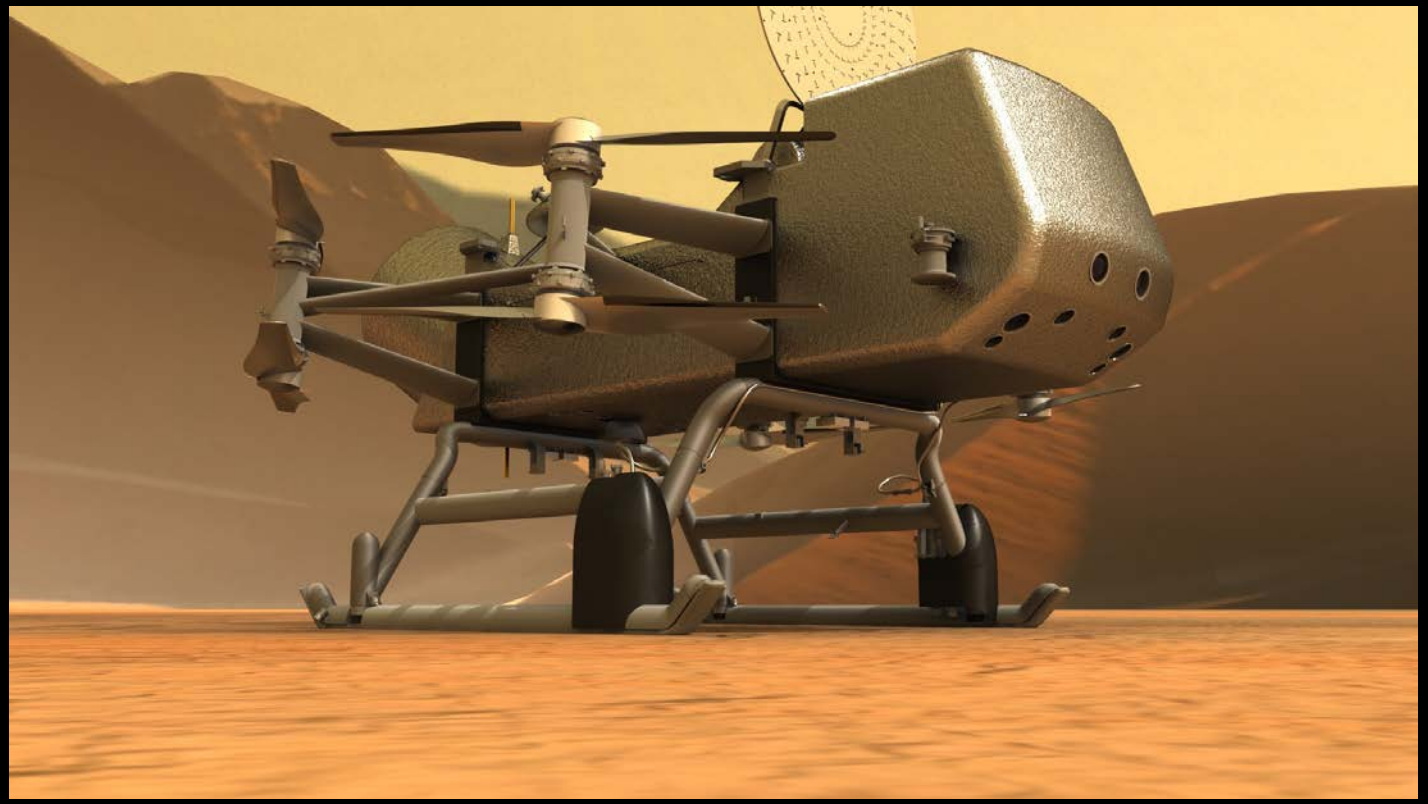
**Rotorcraft Lander**
*Surface configuration with HGA deployed*

Rotorcraft/Lander: APL, Moog, Collins, PSU, Sikorsky
Aeroshell & Cruise Stage: Lockheed Martin
EDL Analysis, Parachutes: NASA Ames / Langley
MMRTG: DOE / RPSO
Mission Ops / Navigation: APL / JPL

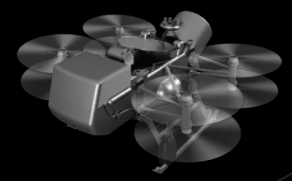
# Benefits and challenges of Titan's environment



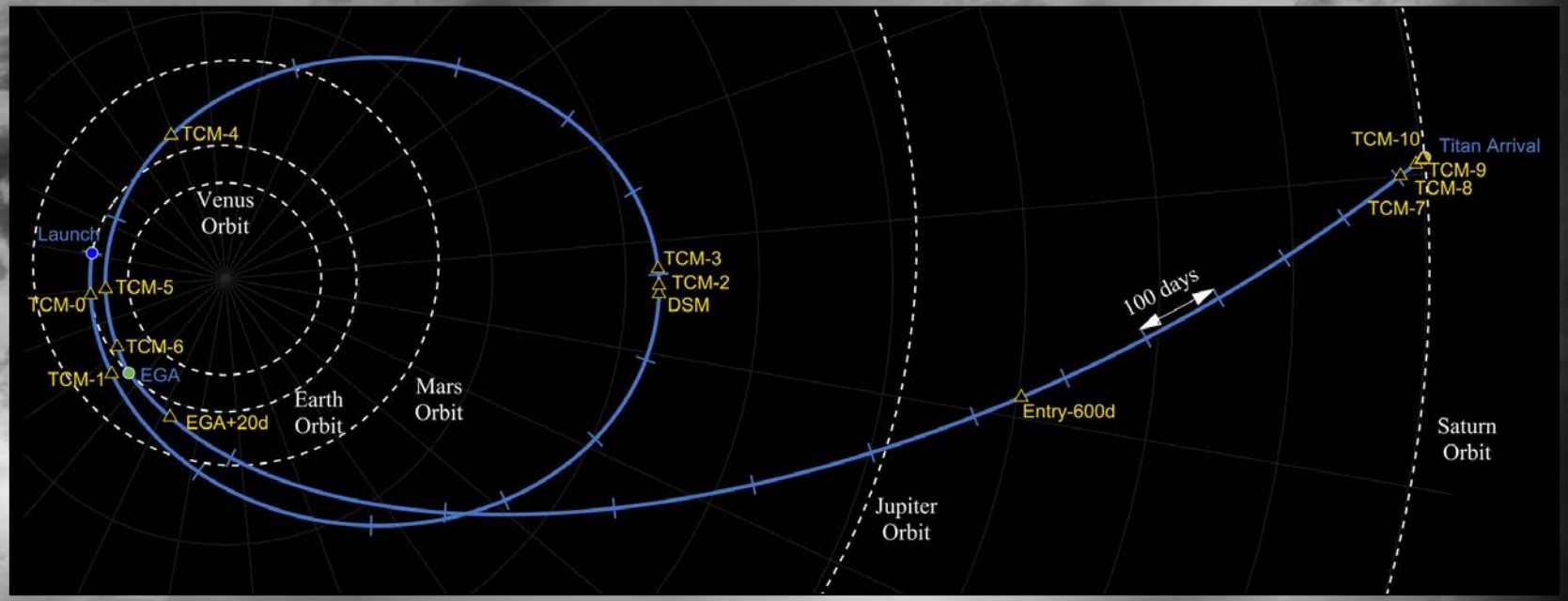
- Dense atmosphere
  - Enables aerial mobility; extended EDL sequence
  - Pneumatic sampling
  - Protection from radiation
- Dense atmosphere + long days and long seasons → calm conditions
  - Diurnal, seasonal, and spatial $\Delta T$ ~1 K
  - Characterized by Cassini-Huygens: Dragonfly arrives 1 Saturn year after Huygens
- Low T → passive cooling
  - Maintain samples at cryogenic temperature
- 8-10 AU from Earth → one-way light-time ~80 minutes
  - Autonomous flights and science operations
- 16-day Tsol / orbital period
  - Relaxed operations schedule

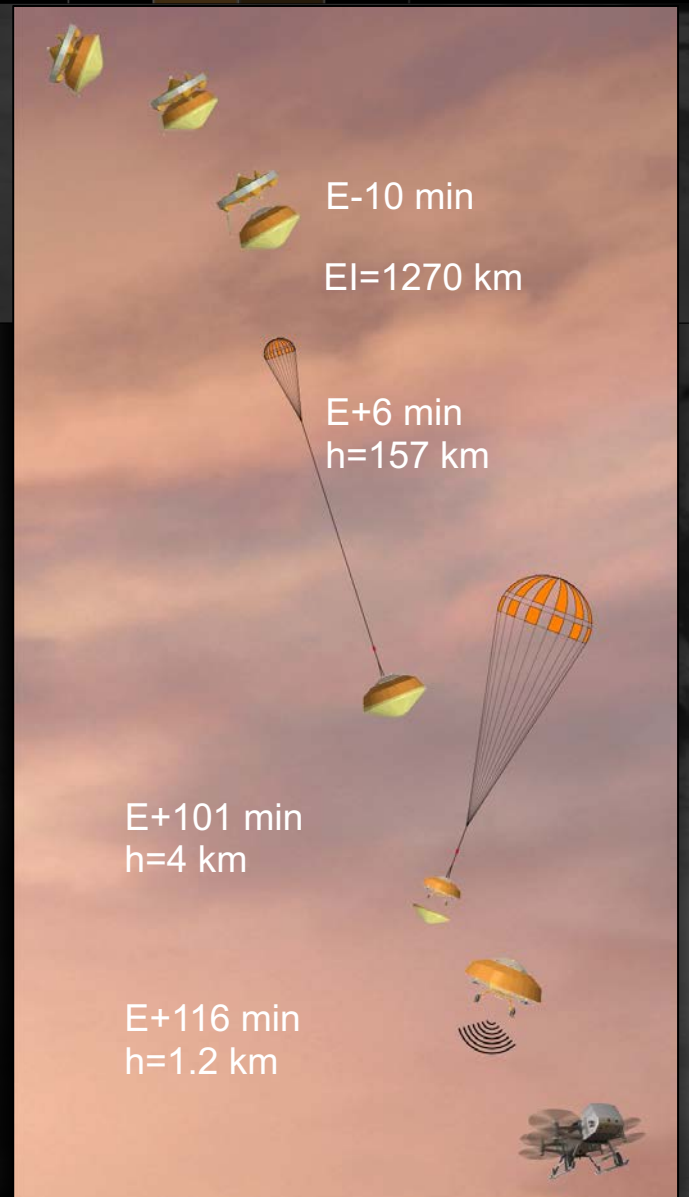


# Dragonfly mission timeline

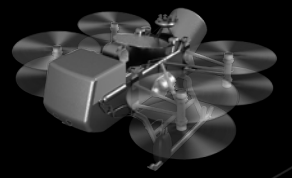


- Launch June 2027, and Titan arrival by 2034
  - Direct atmospheric entry
  - Similar latitude and same time of year as descent of Huygens probe

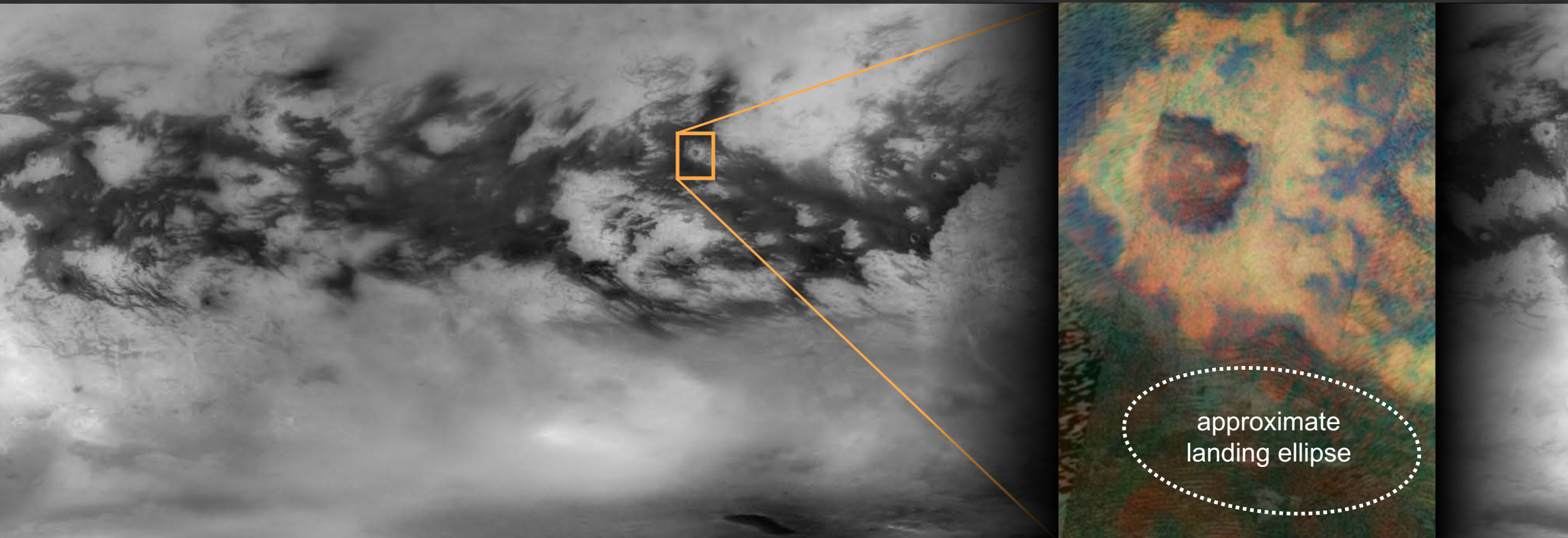


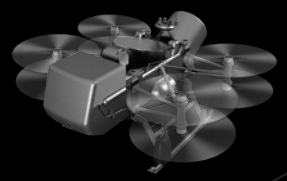
# Dragonfly landing site and region of exploration



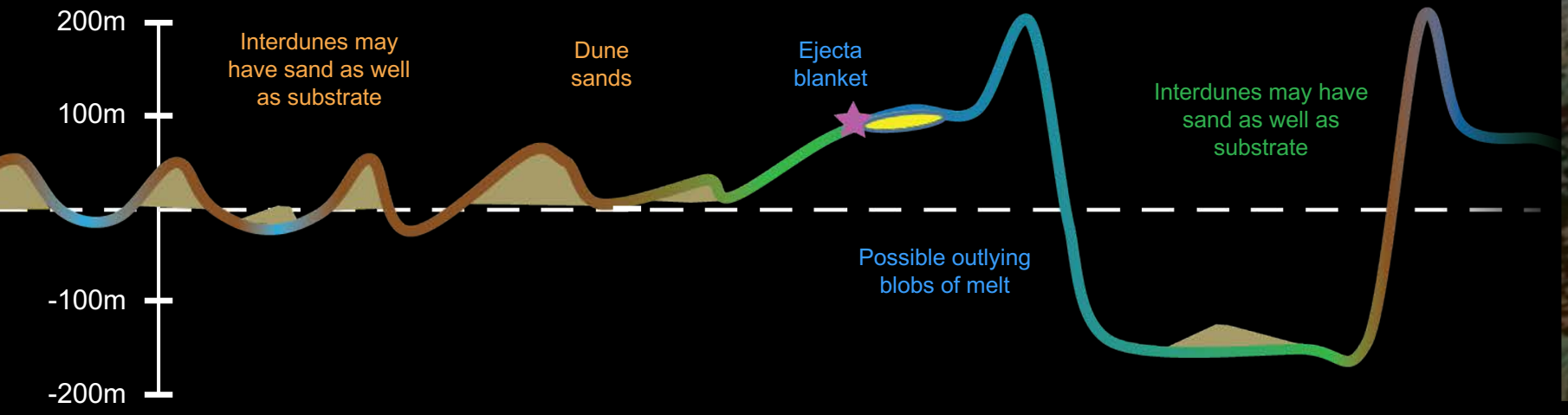
- Initial landing site provides access to a variety of materials
  - Sand dunes: organic sediments
  - Interdune areas: materials with a water-ice component
  - Selk impact crater: materials where organics may have mixed with liquid water impact melt



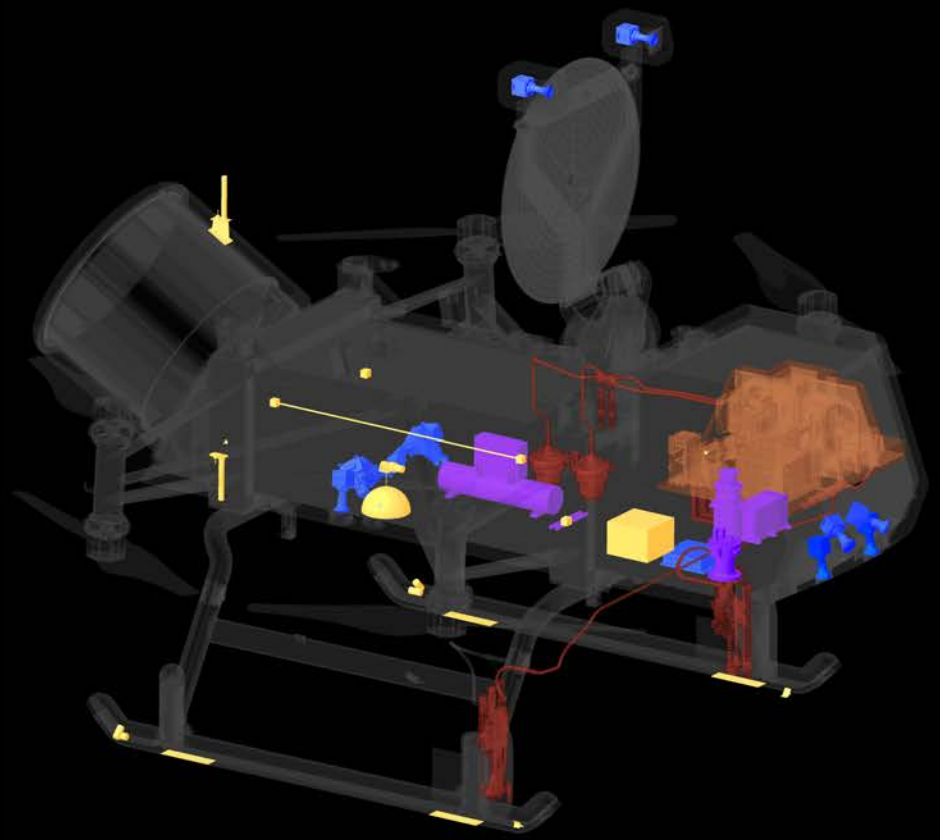
# Dragonfly exploration strategy



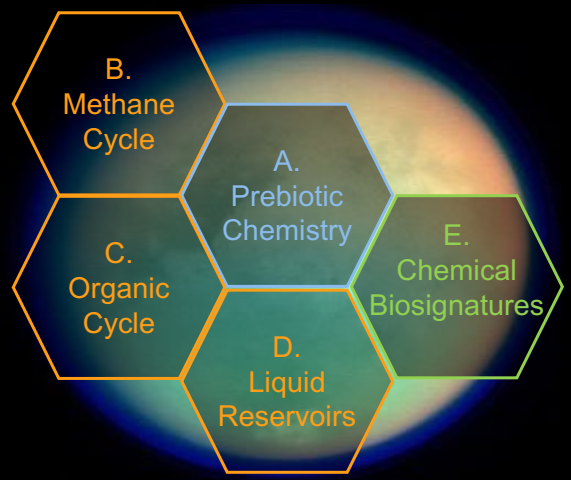
- ~3.3 years, ~74 Tsols (Titan days) of science operations
  - Traverse distance up to ~180 km (112 miles)
  - Exploration of ~25-30 unique sites



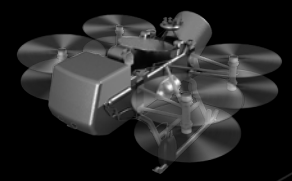

# Multidisciplinary science measurements

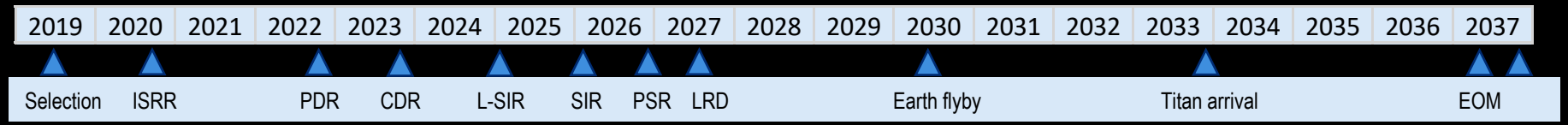


- **DraMS:** Mass Spectrometer
- **DrACO:** Drill for Acquisition of Complex Organics
- **DraGMet:** Geophysics & Meteorology Package
- **DragonCam:** Camera Suite
- **DraGNS:** Gamma-ray Neutron Spectrometer



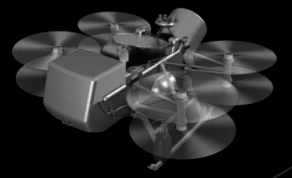
# Dragonfly Project timeline






- Project has worked to accommodate NASA updates to the available budget profile
  - Seeing substantial increases industry-wide in supply-chain lead times and costs
- Next milestone review is PDR in October 2022
  - Internal System Requirements Review in August 2020
  - Subsystem & instrument PDRs scheduled starting in May 2022
- Launch in June 2027 → Titan arrival by 2034
  - Benefits of the latest NASA profile update:
    - Shorter cruise trajectory accelerates and also enhances mission science return – higher MMRTG power output at arrival allows additional science measurements and increased data downlink
    - Avoids inner Solar System tour → reduces spacecraft design risk, simplifies thermal and telecom design, and simplifies and shortens cruise operations, which also mitigates Phase E costs with shorter cruise duration

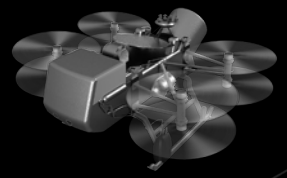
# Dragonfly Project status and recent activities



- Preliminary design development and testing
  - Priority has been team safety under COVID-19 pandemic, which continues to limit in-person activities at some institutions
  - Focus is on technology maturation activities, requirements and interface definitions, and risk reduction
  - Dragonfly has only a few technical developments, and they are on track
    - Two have been eliminated through design trades
- Power System
  - Completed ~75% of hardware breadboard testing and have begun engineering model (EM) design work for some assemblies
- PICA-D heat shield material in production
- Mobility subsystem engineering development
  - Progressive test campaign has demonstrated autonomous takeoff, flight, and optical navigation; upcoming iteration will have autonomous landing
  - Rotor and motor development going well, with tests planned in Langley facilities this summer

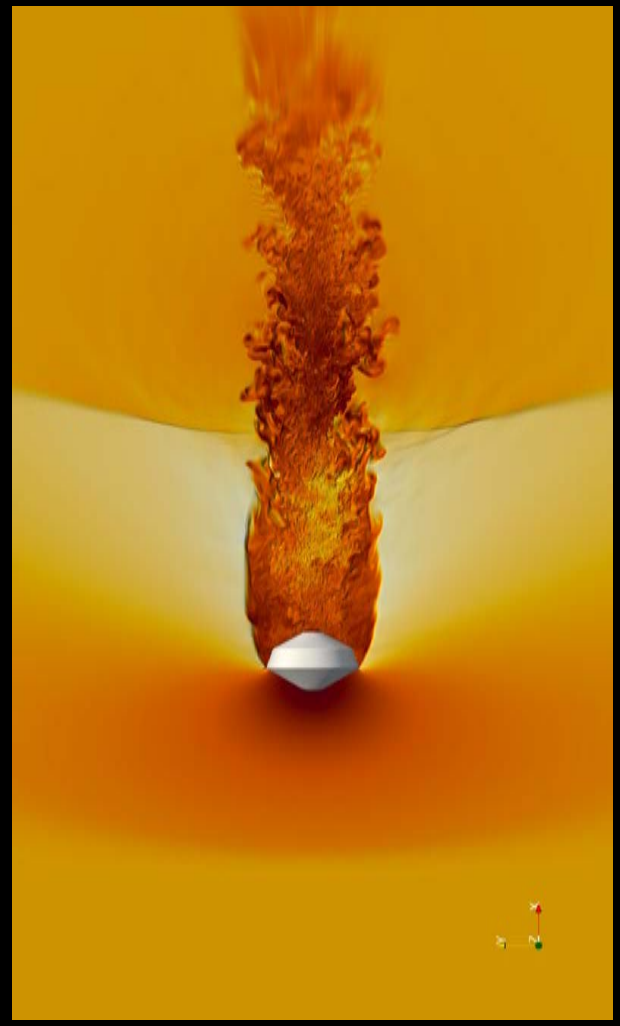
# Recent activities

## Testing and modeling the Titan environment



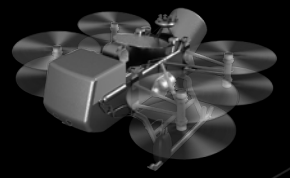
*Testing in NASA Langley 14x22 wind tunnel for CFD validation*


*CFD model development*



# Recent activities

## Octocopter platform flight testing

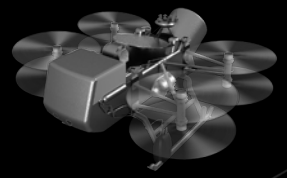




- Half-scale integrated test platform (ITP) demonstrated real-time NavCam imaging; guidance and control algorithms on flight-like hardware and software; close matches between optical navigation and GPS data from flight; autonomous takeoff, hover, hop, and scouting flights

# Recent activities

## Octocopter platform flight testing



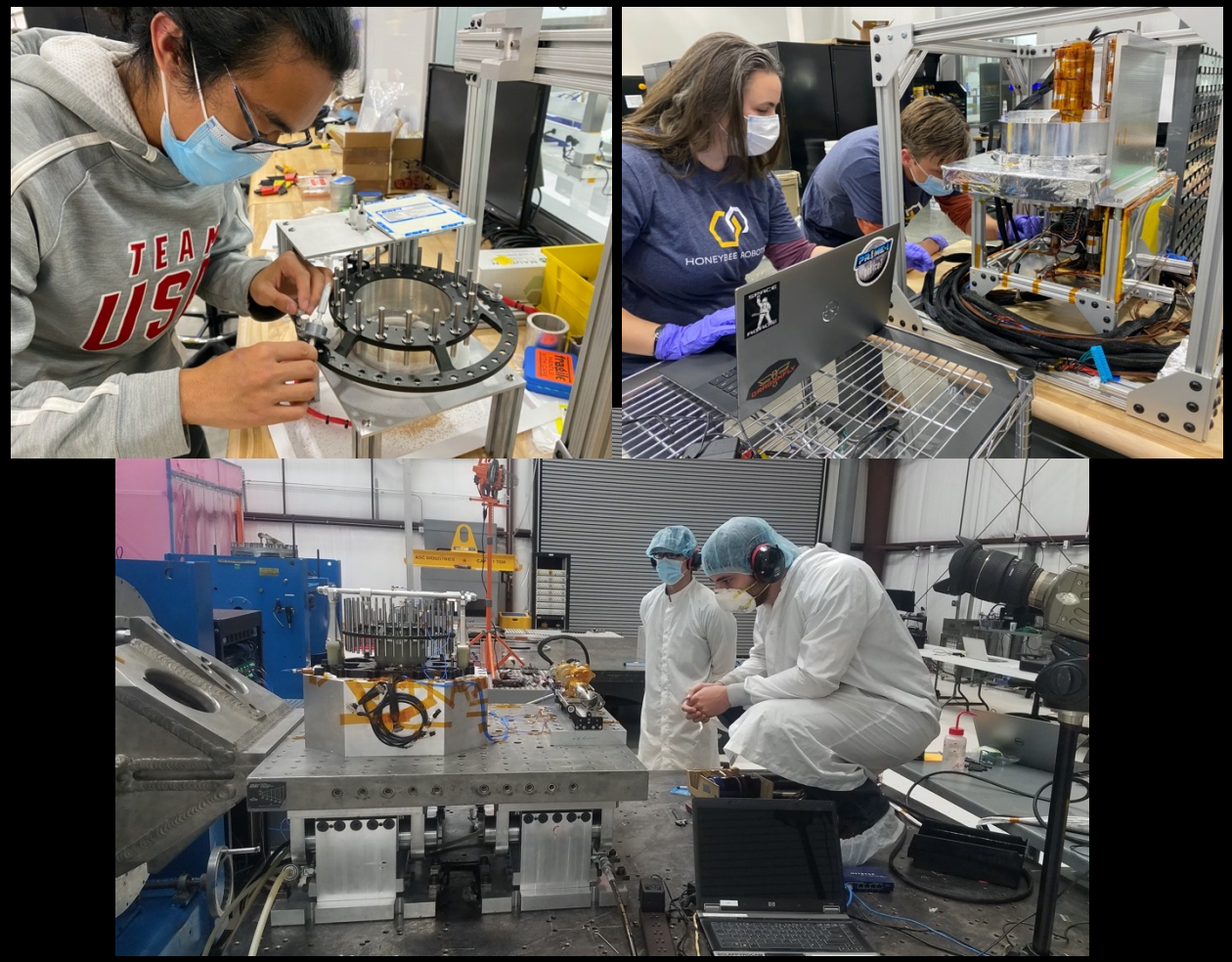
- Half-scale integrated test platform (ITP) with hardware and software similar to what will fly on Dragonfly, including eight independent rotor assemblies, flight computer and digital image processor, navigation camera, inertial measurement unit (IMU) with comparable gyroscopes and accelerometers, and initial versions of image processing and flight control algorithms
- Demonstrating guidance and control algorithms; optical navigation; autonomous takeoff, hover, hop, and scouting flights

# Recent activities

## Payload development

- DraMS development
- DrACO testing
- DraGNS strategy for PNG simplification
- DraGMet seismometer prototype tests
- DragonCam design trades

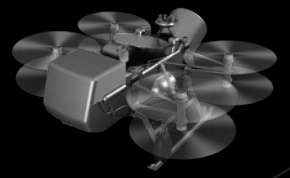
*Dragonfly Mass Spectrometer (DraMS) testing at GSFC*



*Drill for Acquisition of Complex Organics (DrACO) testing at Honeybee Robotics*

# Recent activities

## Payload development



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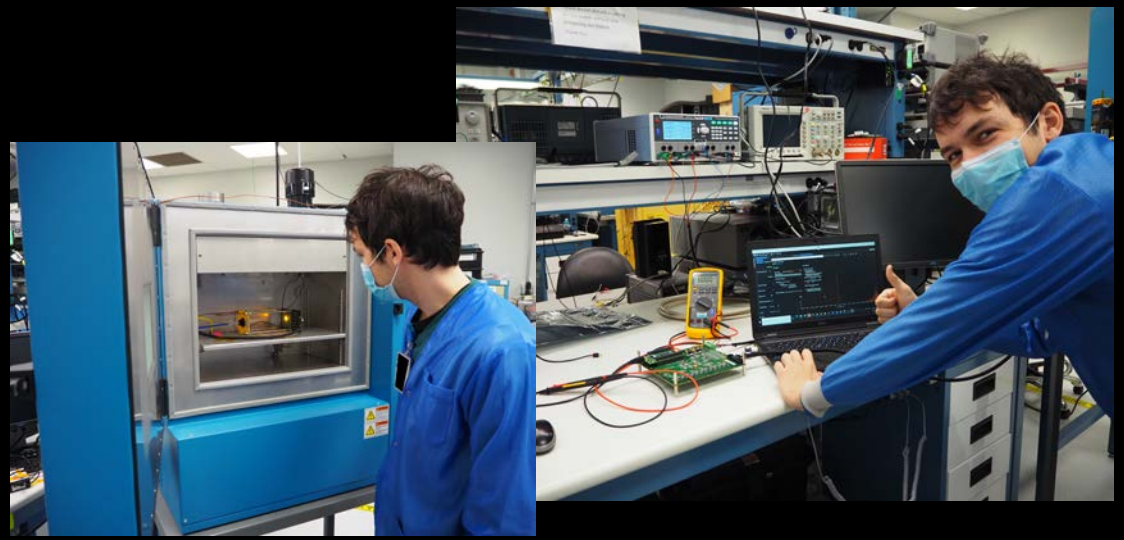
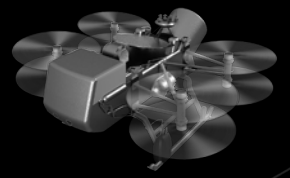


*DragonCam LED testing at APL*


*DraGMet testing in Titan Pressure Environment Chamber (TPEC) at APL*

# Recent activities

## Hardware testing in the Titan environment – APL's TPEC in great demand

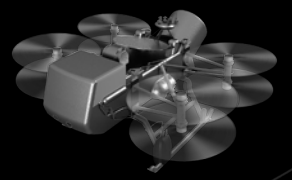


*DrACO and DraGMet testing in APL's Titan Pressure Environment Chamber (TPEC)*

# Recent activities

APL's large Titan pressure chamber construction is progressing well

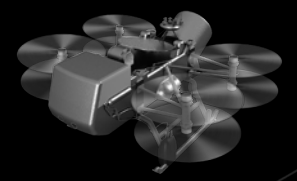
# Dragonfly Project status



- Science requirements and operations
  - Level 1 requirements reviewed with NASA, and Program Level Requirements Appendix (PLRA) signed
  - Refinement of surface operations and ground-in-the-loop flow for different Tsol scenarios
  - Titan environment specifications established, Science peer review in April 2022
- Rules of the Airways (RotA) developed as living document for entire Dragonfly Team
  - Dedicated Working Group has compiled RotA with full Dragonfly Team input and review
  - Informed by other examples and reviewed with APL EEO
  - Annual review and signatures
- Planetary Protection and Communication Plans are being developed with NASA
- National Environmental Policy Act (NEPA) Environment Assessment (EA) worked with NASA, RPS, DOE and being readied for public release on 4/10
- International agreement with CNES has been signed; JAXA, DLR in progress

# Dragonfly Student and Early Career Guest Investigator Program: Broadening Mission Participation

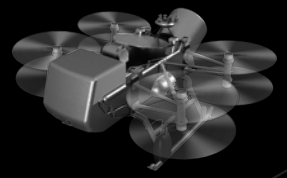
**Quick et al., 2021: https://www.hou.usra.edu/meetings/lpsc2021/pdf/2653.pdf**



| Cohort | Project | Dragonfly Team Mentors | Grad Student Guest Investigators |
|---|---|---|---|
| 1<br>2021-23 | Seismic investigation of Titan's interior using full waveform modeling | Mark Panning, JPL | **Andrea Bryant**, University of Chicago, Physics |
| | Spectral/compositional library for interpretation of DragonCam / DraGNS measurements | Shannon MacKenzie & Richard Miller, APL | **Karla Negrete**, University of Maryland Baltimore County (UMBC), Mechanical Eng. |
| | Development of the DragonCam microscopic imager multispectral LED arrays | Jorge Núñez, APL | **Brianna Wylie**, Florida Agricultural & Mechanical University (FAMU), Mechanical Eng. |
| 2<br>2022-24 | Tuning DraGNS' Interpretations to Titan's Surface | Ann Parsons, GSFC & Patrick Peplowski, APL | **Anna Engle**, Northern Arizona Univ. (NAU), Astronomy and Planetary Sci. |
| | Development of DraMS Instrument Operational Guidelines | Melissa Trainer, GSFC | **Will Suero Amparo**, New Jersey Institute of Tech., Biomedical Engineering |

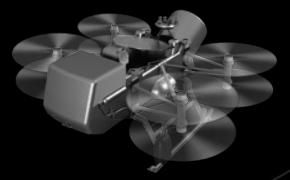
- First two cohorts of the Dragonfly Student Guest Investigator Program selected (2020 & 2021)
- Goals of Program
  - Extend opportunities for graduate students to work with *Dragonfly* scientists and engineers
  - Encourage broader participation by making it easier for students who ***don't*** already have connections to *Dragonfly* or NASA spacecraft missions and/or who ***don't*** have a planetary science background
  - Provide networking opportunities and to expand training of the next generation of mission team members and leaders
- Applications being accepted for 3rd cohort (2022-2024): https://dragonfly.jhuapl.edu/Student-Opportunities/

# Community engagement



- Broad range of disciplines
  - Multi-instrument *Cassini-Huygens* analysis
  - Lab work, e.g., generating tholins for testing
  - Testing sample acquisition and transfer
  - Aeronautics: wind-tunnel and flight testing, rotor design, CFD modeling
  - AR/VR simulations for spacecraft design and planning and executing operations
- Opportunities for engagement
  - NASA Participating Scientist Program
  - Complementary Dragonfly Student and Early Career Guest Investigator Program
  - NASA meeting observers and H2O Programs
  - Community workshops and town halls at scientific conferences
    - Titan Through Time, August 2021
    - AbSciCon, May 2022

# Upcoming activities and engagement

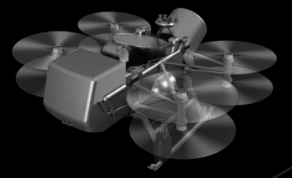


- On track with technology maturation and requirements and interface definitions, leading up to subsystem/instrument PDRs starting in May 2022 and mission PDR in October 2022

- Applications for the 3rd cohort of the Dragonfly Student Guest Investigator Program (2022-24)
  - https://dragonfly.jhuapl.edu/Student-Opportunities/
- Partnered with Virginia State University in NASA's Here To Observe (H2O) program 2021-2022
- Q&A Panel at AbSciCon https://agu.confex.com/agu/abscicon21/meetingapp.cgi/Session/154457

# Octocopter platform flight testing

https://dragonfly.jhuapl.edu/Gallery/




http://dragonfly.jhuapl.edu