National Aeronautics and Space Administration

Exploring Titan's Organic Mineralogy

Principal Investigator: Robert Hodyss (322); Co-Investigators: Morgan Cable (322), Tuan Vu (322), Michael Malaska (322), Mathieu Choukroun (322), Helen Maynard-Casely (Australian Nuclear Science and Technology Organization), Julia Greer (California Institute of Technology)

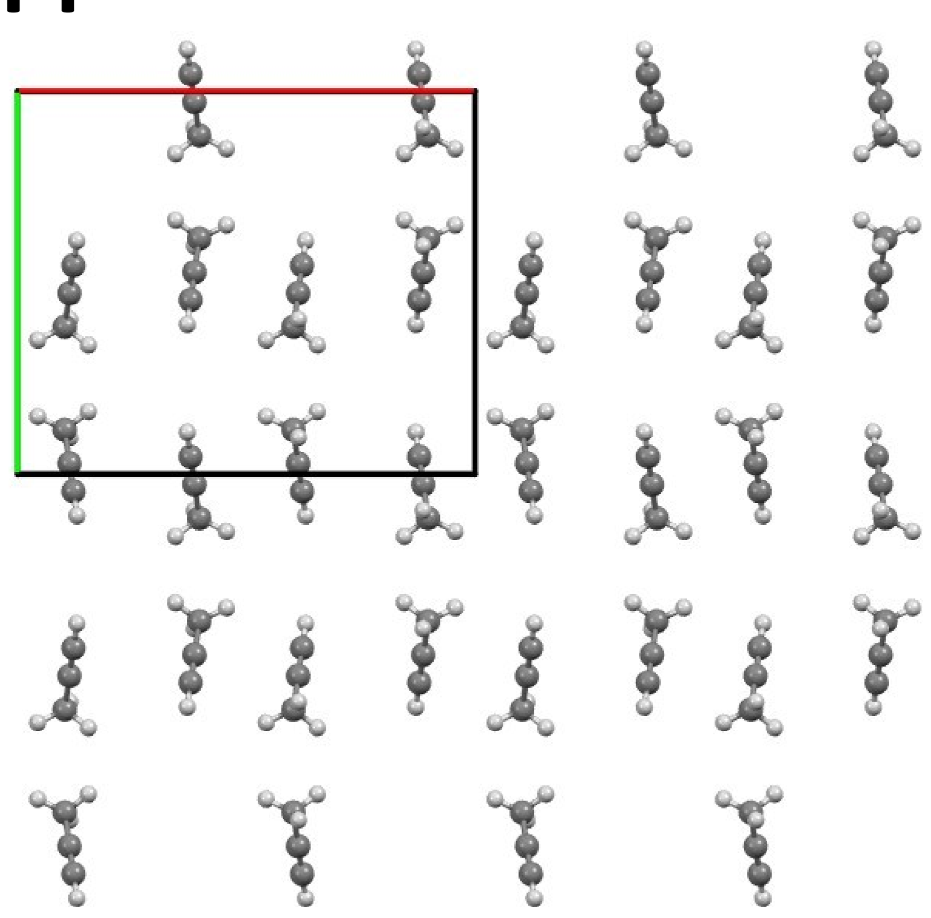
Program: FY22 R&TD Topics
Strategic Focus Area: Planetary Atmospheres and Geology

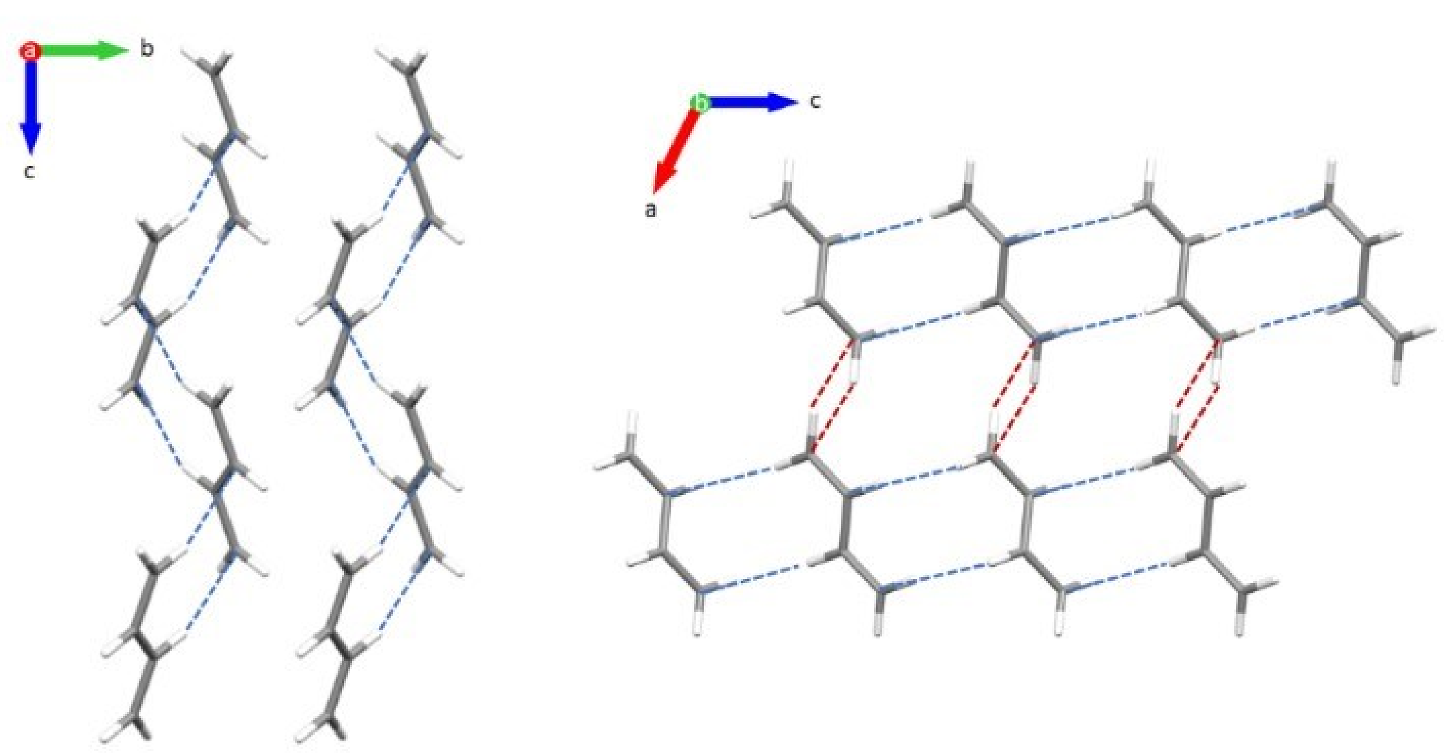
Objectives

Understanding the material properties of Titan's cryogenic organics is critical for future surface missions to Titan. Our proposed efforts will deliver a new, comprehensive understanding of the physicochemical properties of the most common Titan surface organics.

The overall objective of this work is to measure the physical and mechanical properties, morphology, heat capacity, and microstructure of the most probable major organic mineral constituents within Titan's surface (i.e. benzene, naphthalene, acrylonitrile), and to use this information to (1) provide the basic scientific foundation for constraining the extent of surface geological processes and (2) determine technological requirements for in-situ surface sampling instruments. These physical parameters will be used to make specific predictions of geochemical processes that should occur on Titan's surface and subsurface, and estimates of their extent and surface expression and tie them to Cassini's observations of features on Titan's surface.

Approach and Results



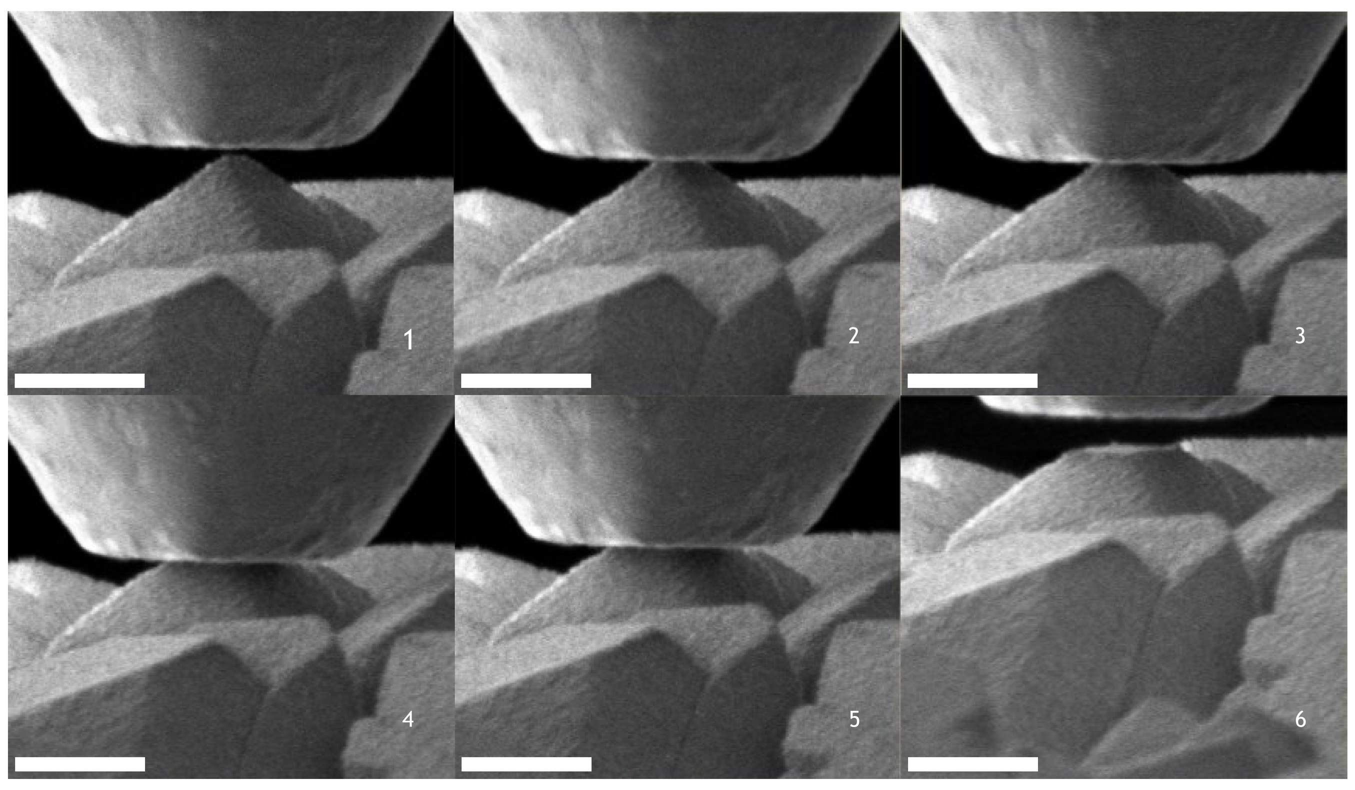


Crystal structures of propyne (top) and butadiene (bottom) determined for the first time by this project.

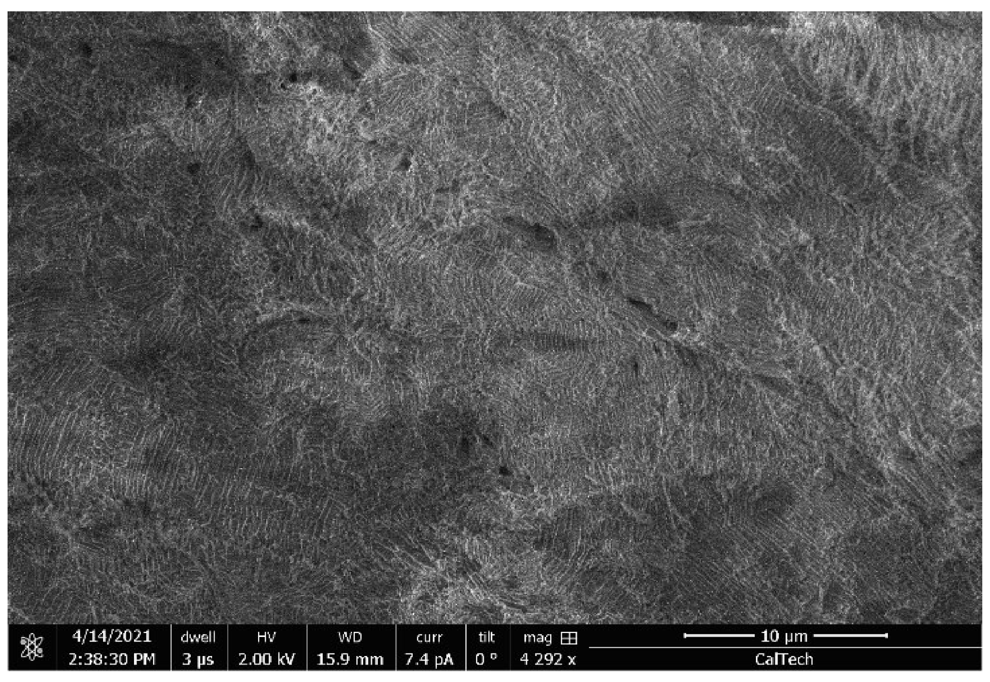
Significance/Benefits to JPL and NASA

Our highly interdisciplinary work represents the first comprehensive investigation of the physical and chemical properties of the solid phase of the organic minerals that make up Titan's surface. Over the past decade, our labs at JPL have developed extensive, state-of-the-art capabilities for the study of organic materials at cryogenic temperatures. We are currently the world leaders in the study of Titan organic minerals. Our collaboration with Prof. Greer at Caltech has added novel cryogenic nanomechanical testing instrumentation to our capabilities, and this collboration is continuing through JROC funding. No other laboratories have these combinations of instrumentation and expertise.

This work has helped retain and advance JPL's leadership in Titan surface chemistry, is complementary to the ongoing Titan NAI (PI Rosaly Lopes), and would likely help capture Dragonfly Participating Scientist positions, and enable JPL to be significantly involved in the science of Dragonfly.



Compression tests on single crystals of benzene at cryogenic temperatures (125 K) have allowed us to measure the yield stress, ~2 GPa. We have performed analogous tests on a acetonitrile. Greer lab, Caltech



Solid crystalline acetonitrile at 143 K, exhibiting crystal steps of ~ 200 nm.

Publications:

[A] Vu, Tuan; Maynard-Casely, Helen; Cable, Morgan; Choukroun, Mathieu; Malaska, Michael; Hodyss, Robert;, 1,3-Butadiene on Titan: Crystal Structure, Thermal Expansivity, and Raman Signatures, Acs Earth Space Chem, accepted

[B] Wenxin Zhang, Xuan Zhang, Bryce W. Edwards, Lei Zhong, Huajian Gao, Michael J. Malaska, Robert Hodyss, Julia R. Greer, Deformation Characteristics of Solid-state Benzene: a Step towards Understanding Planetary Geology. Nature Communications, in review.

[C] Lapôtre, M.G.A., Malaska, M.J., Cable, M.L., 2022. Global sedimentary cycle on Titan sustained by grain sintering and Earth-like transport frequency. Accepted in JGR.

[D] Hodyss, R.; Vu, T. H.; Choukroun, M.; Cable, M. L., A simple gas introduction system for cryogenic powder Xray diffraction. J Appl Crystallogr 2021, 54, 1268-1270.

[E] Cable, M. L.; Runcevski, T.; Maynard-Casely, H. E.; Vu, T. H.; Hodyss, R., Titan in a Test Tube: Organic Co- crystals and Implications for Titan Mineralogy. Accounts Chem Res 2021, 54 (15), 3050-3059.

[F] Vu, T. H.; Maynard-Casely, H. E.; Cable, M. L.; Hodyss, R.; Choukroun, M.; Malaska, M. J., Anisotropic thermal expansion of the acetylene-ammonia co-crystal under Titan's conditions. J Appl Crystallogr 2020, 53, 1524-1530.

[G] Ennis, C.; Cable, M. L.; Hodyss, R.; Maynard-Casely, H. E., Mixed Hydrocarbon and Cyanide Ice Compositions for Titan's Atmospheric Aerosols: A Ternary-Phase Co-crystal Predicted by Density Functional Theory. Acs Earth Space Chem 2020, 4 (7), 1195-1200.

[H] Cable, M. L.; Vu, T. H.; Malaska, M. J.; Maynard-Casely, H. E.; Choukroun, M.; Hodyss, R., Properties and Behavior of the Acetonitrile-Acetylene Co-Crystal under Titan Surface Conditions. Acs Earth Space Chem 2020, 4 (8), 1375-1385.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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PI/Task Mgr. Contact Information:
Email: Robert.P.Hodyss@jpl.nasa.gov