THUNDER: A New Frontiers-class Titan orbiter mission concept from the NASA JPL Planetary Science Summer School. Rudi Lien[1]* & Cassandra Seltzer[2]*, Brandon Radzom[3], Ella Mullikin[4], Kimberly Bott[5,6], Gwendolyn Brouwer[7], David Burtt[8], Chloe Gentgen[2], Jewel Abbate[9], Victor Gandarillas[10], Austin Green[11], Tristen Head[12], Jonathon Hill[13], Jenny Larson[14], Nicholas Montiel[15], Regina Moreno[2], Nick Wagner[16], Piyumi Wijesekara[12], Alfred Nash[11], James Tuttle Keane[11], [1]University of Oregon (rlien@uoregon.edu), [2]Massachussets Institute of Technology (cseltz@mit.edu), [3]Indiana University, [4]Pennsylvania State University, [5]University of California, Riverside, [6]SETI Institute, [7]University of Hawai'i, [8]NASA Goddard Space Flight Center, [9]University of California, Los Angeles, [10]University of California, San Diego, [11]NASA Jet Propulsion Laboratory, [12]NASA Ames Research Center, [13]Arizona State University, [14]University of Central Florida, [15]University of Texas at Austin, [16]Baylor University. **co-first authors*

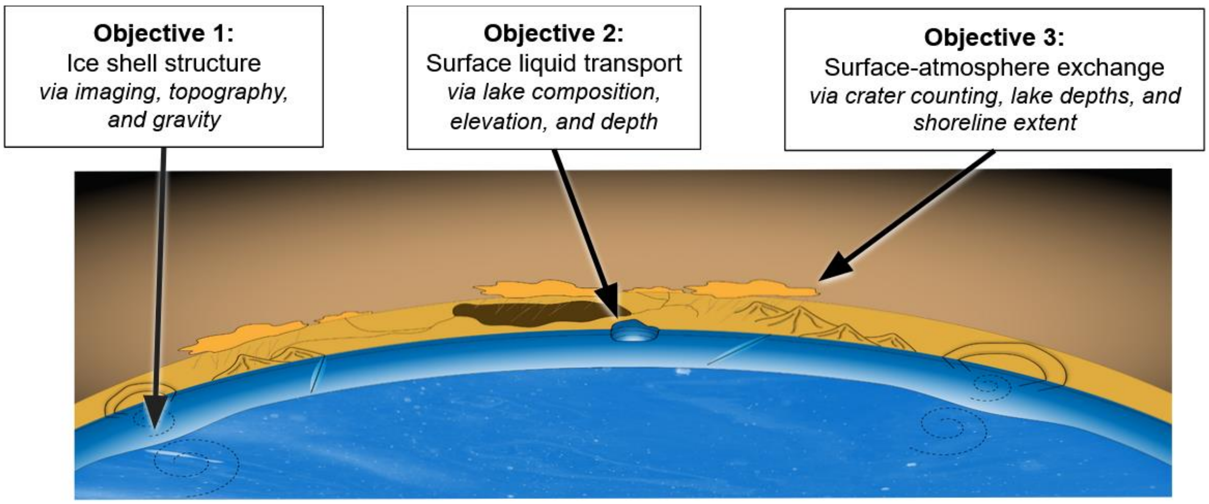

Figure 1. Schematic of THUNDER's science objectives, targeting the interior, surface, and atmosphere of Titan.

Introduction: Titan is unique in our Solar System: an icy ocean world with an Earth-like, dynamic hydrocarbon reservoir cycling through its interior, surface, and atmosphere. Titan's hazy atmosphere produces complex organic material, which has the potential to develop the necessary compounds for biologic activity if it moves through Titan's water ice bedrock to encounter the subsurface ocean. Here, we propose Titan's Hydrocarbons: Uncovering New Dimensions of Evolutionary pRocesses (THUNDER), a New Frontiers-class Titan orbiter mission concept. This mission responds directly to the Decadal Survey's call for a Titan Orbiter and follows the guidelines of the New Frontiers 4 (NF4) Announcement of Opportunity (AO) and NF5 draft AO. THUNDER will provide high-resolution global mapping of Titan's surface, exploring how Titan's hydrocarbon cycle has shaped its evolution through time.

Science Objectives: THUNDER has three science objectives (Figure 1):

Objective 1: Determine if Titan's ice shell has a convective layer that can facilitate material transport between the surface and ocean. The complex hydrocarbons created in Titan's atmosphere are possible precursors for biologically active molecules [1-2]. Material from the surface may be advected down into the ocean through tectonism, and hydrocarbons released during degassing of the rocky interior could be brought upwards to the surface through convection, resupplying the methane atmosphere and maintaining a stable Titan system through time. We can confirm the presence of such a subsurface convecting layer using three parameters: 1) admittance (the ratio of gravity to topography), 2) tectonic fabric, and 3) k_2 (the gravitational potential Love number).

Objective 2: Determine whether Titan's major liquid hydrocarbon bodies are connected and exchanging material with each other through a subsurface reservoir. Titan and Earth are the only two bodies in the solar system with stable and long-lived surface liquids at present. If Titan hosts a reservoir of subsurface hydrocarbons connecting its current bodies of standing liquid [3], it may be the primary driver of Titan's near-surface hydrocarbon transport and geochemical exchange. We will use three parameters to understand whether liquid bodies on Titan's surface are and were connected: 1) the surface elevation of lakes and seas, 2) the relative ethane/methane compositions of lakes and seas, and 3) the total current surface liquid volume.

Objective 3: Determine if Titan is losing its atmosphere and surface liquids. Titan's methane hydrological cycle is unique in the Solar System, but it may not be permanent. Hydrogen in the atmosphere is quickly lost to space, and methane is irreversibly consumed by the processes which generate potentially prebiotic molecules. Thus, the atmosphere is expected to collapse in <30 Myr without replenishment of CH_4 and H_2 [4]. THUNDER will investigate whether Titan's hydrocarbon cycle is a permanent feature using two overarching physical parameters: 1) the sizes and depths of craters and 2) comparing past and present liquid surface inventory on temporal and spatial scales.

Payload & Concept of Operations (ConOps): The science objectives will be achieved using the following instrument suite: a visible-to-infrared (vis-IR) spectrometer; radar with Synthetic Aperture Radar (SAR), altimeter, and passive radiometer modes; and gravity science investigation via telecommunications. The mission requirements and instrument capabilities are shown in Table 1. The 2.5-m dual X- and Ka-band high gain antenna (HGA) is shared between the radar instrumentation and telecommunications (telecoms) subsystem.

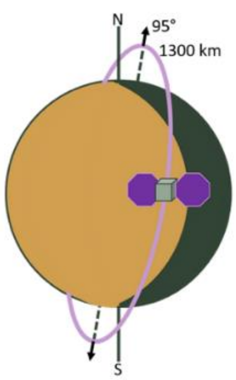

Figure 2. THUNDER science orbit at Titan.

THUNDER's ConOps cycle has three operational modes: (1) radar SAR: one orbit; (2) radar altimetry + vis-IR spectrometer: three orbits; and (3) gravity science/telecoms: two orbits. Science modes 1 and 2 operate on a 50% duty cycle per orbit, each followed by a recharge period. Passive radiometry can be done simultaneously with radar SAR and altimetry. Mode 3 requires two consecutive orbits (an ~8-hour window) for either gravity science or telecoms. The science objectives require 100% gravitational coverage, 83% surface coverage with Radar SAR and altimetry, and 42% surface coverage with the vis-IR spectrometer. The gravity science investigation requires ≥5 Earth months of orbit to resolve Titan's gravity field to spherical harmonic degree ≥15. Based on the spatial coverage requirements, data volumes (340 Mbits/day, uncompressed), and telecoms capabilities (12 kbps science downlink), the minimum science mission duration is 3.6 years. THUNDER is designed to maintain its science orbit for ≥4.6 years.

Instrument		Requirement	Capability
Vis-IR Spectrom.	Spatial Res.*	≤ 10 km	5 km
	Spectral Bandw.	0.93–3.2 μm	0.4-4.3 μm
	Spectral res.	≤ 25 nm	10 nm
	SNR / wavelength	≥ 30:1	≥ 45:1**
Radar - SAR Mode	Spatial Res.*	≤ 125 m	100 m
	Swath Width*	≥ 20 km	31 km
	Sensitivity	–20 dB	–26 dB
Radar - Altimeter Mode	Vertical Precision	≤ 1 m	20 cm
	Along Track Res.*	≤ 500 m	300 m
	Swath Width*	≤ 10 km	6.0 km
	Sensitivity	–20 dB	–22 dB
Radar - Radiometer Mode	Resolution*	149 km	124 km
	Sensitivity	0.75 K	0.6 K
Gravity Science	Included in telecoms		

*Table 1. Instrumentation requirements, capabilities, and margins. *Indicates most stringent requirements and capabilities at science orbit altitude of 1,300 km.*

Mission Design: THUNDER's launch window will open on July 24, 2034 for a planned ten-year cruise to Saturn orbital insertion. With a launch C_3 of 29.4 km^2/s^2, the flight vehicle's total predicted wet mass of 5,054 kg is compatible with high performance launch vehicle capabilities (≤5,880 kg). Cruise will be followed by a 2.8 year pump down to achieve Titan Orbital Insertion (TOI). After TOI, THUNDER maintains a circular, near-polar orbit (95-degree inclination) at 1,300 km altitude for the 4.6-year science tour (Figure 2). This science orbit is formulated to reduce atmospheric drag and optimize solar power while satisfying the science requirements. Total mission duration (post-launch) is 17.4 years.

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