Draft version October 14, 2022
Typeset using LaTeX twocolumn style in AASTeX63

New Frontiers Titan Orbiter

Jason W. Barnes,[1] Alexander G. Hayes,[2] Jason M. Soderblom,[3] Shannon M. MacKenzie,[4] and Sam Birch[2]

[1] University of Idaho; Department of Physics; Moscow, Idaho 83844-0903, USA
[2] Cornell University; Department of Astronomy; Ithaca, New York 14853, USA
[3] Massachusetts Institute of Technology; Department of Earth and Planetary Sciences; Cambridge, Massachusetts 02139, USA
[4] Applied Physics Laboratory; Johns Hopkins University; Space Exploration Sector; Laurel, Maryland 20723, USA

1. MISSION

We describe here the Titan Orbiter that will be incorporated into the New Frontiers 6 and New Frontiers 7 competition rounds as recommended by the Deacadal Survay. The mission would complement *Dragonfly* [1] with global geology, geophysics, and atmospheric science. The New Frontiers Titan Orbiter (NFTO) seeks to answer science questions suggested by *Cassini* discoveries :

1. How does Titan's surface affect its atmospheric circulation, and how does atmospheric circulation drive surface geological and hydrological processes?
2. What is the extent of Titan's water-ocean mantle, and how does Titan's interior drive surface processes, including tectonism and cryovolcanism?

We envision a science instrument package including at least (but not limited to) fine-resolution (25 m/pix or better) surface imaging (NIR camera or radar), altimetry (RADAR or near-infrared laser), weather imaging (wide-field camera), and gravity tracking. The measurements to be made would transform our understanding of Titan in a manner perhaps parallel to that achieved at Mars by *Mars Global Surveyor*.

2. INSTRUMENTS

We suggest here a possible complement of four remote sensing campaigns: high-resolution surface imaging, global altimetry, weather and change-detection monitoring, and radio science for spacecraft tracking.

Surface Imaging *Cassini*'s imaging with RADAR, VIMS, and ISS transformed Titan from an orange ball into a diverse, active, and exciting world. True surface resolution of RADAR and the best VIMS and ISS imaging was ∼1 km (surface sampling could be as fine as 250 m/pixel, but speckle noise and low SNR hampered Nyquist-sampled actual resolution), and at surface sampling $<$ 350 m/pixel RADAR only covered 20% of the surface. NFTO would achieve global ($>$ 90% coverage) coverage at 10x better resolution than *Cassini* – finer than 100 m resolution using 25 m or better pixel scale [2] . Overlapping images would allow generation of local Digital Elevation Models with vertical accuracy down to tens of meters. Global imaging would reveal changes in Titan's dynamic surface since the *Cassini* mission. The imaging could in principle be acquired by either a synthetic aperture radar or a near-infrared imager [2].

Weather & Surface Change Imaging Titan's dynamic atmosphere exhibits variations in cloud cover, haze, and even occasional dust storms. These atmospheric phenomena lead to changes in the appearance of Titan's surface on the timescale of weeks. To constrain weather processes, NFTO would measure cloud evolution, track cloud movement, and observe surface changes. A wide-angle near-infrared camera could observe Titan's dayside both on repeated adjacent orbits and over the course of single orbits. Imaging in three near-infrared colors could provide altitude discrimination and constrain reflective properties. Ideally, the weather-monitoring instrument would also be designed to identify specular reflections [3] to constrain the extent, variation, and roughness [waves; see 4] of liquids covering Titan's surface.

Altimetry Our experience studying planetary geology (in particular Earth and Mars) has made clear that global topography plays a key role in driving surface geology (particularly hydrology). Present knowledge of Titan's topography is inadequate to understand those surface processes. Accurate global surface topography would reveal the extent of watersheds [5], the nature of mountain-building [6], crater relaxation [7], the vigor of surface runoff and flows [8], the effects of topography on atmospheric circulation [9], the strength of surface materials and their susceptibility to erosion [10], and the role of subsurface liquid methane flow [11]. We expect that global topographic maps will transform our understanding of Titan in the same way that they did our understanding of Mars [12].

Corresponding author: Jason W. Barnes
jwbarnes@uidaho.edu

Repeat accurate orbital altimetry of the same areas at different orbital phase can also directly measure the deformation of the crust from internal convection and tidal forces, revealing the level of activity in the interior. Determination of tidal Love numbers from altimetry and gravity will place strong constraints on Titan's interior structure [13; 14]. Altimetric and imaging observations of Titan's seas over the course of its orbit around Saturn would allow us to directly measure the level of tidal sloshing within and between methane seas.

Gravity Accurately measuring the spacecraft acceleration in orbit would allow us to use Titan's gravity field to probe the interior [15; 16; 17]. *Cassini*'s flybys constrained Titan's gravity field to degree 5 [18]; spending a much greater fraction of its time near to Titan, and moving at a much slower velocity, a Titan orbiter would provide a more comprehensive view. These higher order harmonics can distinguish between models of crustal thickness variation — Pratt vs. Airy isostasy with respect to Titan's equator-to-pole topographic variations [19]. When combined with tidal measurements, gravity provides a method for peering into Titan's interior, where it could reveal the vertical extent of Titan's water ocean and whether or not its lower boundary abuts a silicate mantle or a layer of high-pressure ice [albeit with potential model dependence; 20]. A thin crust would facilitate surface-ocean interaction.

Gravity observations might also reveal whether Titan's interior exerts active tectonic stresses on the lithosphere, building and supporting mountains, causing extension, or possibly forcing cryovolcanic liquids to the surface.

3. TECHNOLOGY CHALLENGES AND OPPORTUNITIES

Challenge: Solar Power at Titan Efficient and inexpensive power at Titan might be a challenge for NFTO. Radioisotope power clearly works, as we saw with *Cassini*. Solar power might be possible at Saturn, but Jupiter is the furthest that it has been thus far demonstrated. If the challenges of low intensity and low temperature can be solved, then solar power for NFTO might help it to fit within the New Frontiers cost cap.

Challenge: Laser Altimetry through Titan's Hazy Atmosphere Radar altimetry has been demonstrated at Venus and Titan previously. Laser altimetry, however, can be cheaper and more effective as shown at the Moon, Mars, and Mercury. A longer-wavelength 2-micron laser altimeter operating in an infrared atmospheric spectral window could achieve performance at Titan similar to that of optical laser altimetery at airless worlds and Mars.

Opportunity: Bandwidth from 10AU Without multiple powerful radioisotope power sources like *Cassini*, the data return from NFTO will be a function of how efficiently each Joule of energy produced during the mission can be used to produce bits of data return. Large deployable high-gain radio antennas or optical communication might serve better than conventional approaches.

Opportunity: Aerocapture at Titan Mass-efficient conventional delivery of an orbiter to Titan would entail multiple rocket burns and a multi-year gravity-assist tour through the Saturn system. If Titan's atmosphere could be used instead either via direct aerocapture or using aerogravity-assists, then mass delivery to Titan orbit might be done with lower mass and cost than the conventional approach.

REFERENCES

[1]J. W. Barnes, et al. (2021) *Planetary Science Journal* 2(4):130.

[2]J. W. Barnes, et al. (2020) *The Planetary Science Journal* 1(1):24.

[3]K. Stephan, et al. (2010) *Geophys. Res. Lett.* 37:L7104.

[4]J. W. Barnes, et al. (2014) *Planetary Science* 3(1):3.

[5]R. D. Dhingra, et al. (2018) *Icarus* 299:331.

[6]J. Radebaugh, et al. (2007) *Icarus* 192:77.

[7]C. D. Neish, et al. (2013) *Icarus* 223:82.

[8]D. M. Burr, et al. (2006) *Icarus* 181:235.

[9]S. M. MacKenzie, et al. (2019) *Journal of Geophysical Research (Planets)* 124(7):1728.

[10]V. Poggiali, et al. (2016) *Geophys. Res. Lett.* 43:7887.

[11]A. G. Hayes, et al. (2017) *Geophys. Res. Lett.* 44:11.

[12]D. E. Smith, et al. (1999) *Science* 284:1495.

[13]J. M. Wahr, et al. (2006) *J. Geophys. Res.(Planets)* 111(E10):E12005.

[14]A. Genova, et al. (2016) *Icarus* 272:228.

[15]L. Iess, et al. (2010) *Science* 327:1367.

[16]L. Iess, et al. (2012) *Science* 337:457.

[17]G. Mitri, et al. (2014) *Icarus* 236:169.

[18]D. Durante, et al. (2019) *Icarus* 326:123.

[19]C. A. Nixon, et al. (2018) *Planet. Space Sci.* 155:50.

[20]S. D. Vance, et al. (2018) *J. Geophys. Res.(Planets)* 123:180. arXiv:1705.03999.