

**EXPLORING THE SEAS OF TITAN: THE TITAN MARE EXPLORER (TiME) MISSION.** E.R. Stofan<sup>1</sup>, J.I. Lunine<sup>2</sup>, R.D. Lorenz<sup>3</sup>, O. Aharonson<sup>4</sup>, E. Bierhaus<sup>5</sup>, B. Clark<sup>6</sup>, C. Griffith<sup>7</sup>, A-M. Harri<sup>8</sup>, E. Karkoschka<sup>7</sup>, R. Kirk<sup>9</sup>, B. Kantsiper<sup>3</sup>, P. Mahaffy<sup>10</sup>, C. Newman<sup>4,14</sup>, M. Ravine<sup>11</sup>, M. Trainer<sup>10</sup>, H. Waite<sup>12</sup>, and J. Zarnecki<sup>13</sup>. <sup>1</sup>Proxemy Research, Rectortown, VA 20140; <sup>2</sup>Dipartimento di Fisica, Università degli Studi di Roma "Tor Vergata", Rome, Italy; <sup>3</sup>Applied Physics Laboratory, Johns Hopkins University, Laurel MD 20723; <sup>4</sup>California Institute of Technology, Pasadena, CA 91125; <sup>5</sup>Lockheed Martin, Denver, CO; <sup>6</sup>Space Science Institute, Boulder CO 80301; <sup>7</sup>LPL, U. Arizona, Tucson, AZ 85721; <sup>8</sup>Finnish Meteorological Institute, Finland; <sup>9</sup>U.S.G.S. Flagstaff, AZ 86001; <sup>10</sup>NASA Goddard SFC, Greenbelt, MD 20771; <sup>11</sup>Malin Space Science Systems, San Diego, CA 92191; <sup>12</sup>SWRI, San Antonio, TX 78228; <sup>13</sup>PSSRI, The Open University, Milton Keynes, UK MK7 6BJ. <sup>14</sup>Ashima Research, Pasadena, CA 91106

**Introduction:** The discovery of lakes in the northern hemisphere of Titan established that liquid hydrocarbons are present on the surface of the haze-shrouded moon [1], and the detection of ethane in Ontario Lacus near the South Pole confirmed that lakes are liquid-filled [2]. More than 400 lakes have been identified, most north of  $\sim 70^\circ\text{N}$ , with sizes that range from a few  $\text{km}^2$  to in excess of  $100,000 \text{ km}^2$  [3, 4]. The lakes and seas provide the first evidence for an active condensable-liquid cycle on another planetary body. The Titan Mare Explorer (TiME) (Fig. 1) is a Discovery-class mission that would constrain Titan's active methane cycle as well as its intriguing prebiotic organic chemistry by providing in situ measurements from the surface of a Titan sea.



Figure 1. The TiME lake lander with cruise stage.

**Background:** Titan's lakes and seas likely fill through rainfall and/or intersection with the subsurface liquid methane table, and likely hold some combination of liquid methane and liquid ethane. Titan's seas probably contain dissolved amounts of many other compounds, including admixtures of nitrogen and organic species: the seas represent a sink for the products of photolysis in the atmosphere. The methane cycle on Titan is dominated by precipitation near the poles and evaporation in equatorial regions, permitting the seas to persist in near the North and South Poles [5]. The stability of lakes and seas on Titan's surface depends upon the abundance of methane in the atmosphere-surface system, as well as liquid methane in the subsurface. Ethane, under Titan surface conditions, is a liquid, is a dominant product of methane stratospheric photochemistry, and its presence in the seas would

increase their stability against evaporation [6]. The methane/ethane ratio in the lakes is unknown and cannot be determined with current data, but ethane has been identified in Ontario Lacus [2], late winter tropospheric clouds (which must be largely methane) have been seen above the lakes region [7], and methane and ethane were detected by the Huygens probe mass spectrometer after landing [8]. Determining the methane/ethane ratio is critical to constraining the significance of the sources of methane. In addition to likely seasonal changes in lake composition and depth [7, 9], recent work has demonstrated that Titan's lakes and seas may take part in longer-term pole-pole transport forced by the changing astronomical configuration of the seasons, similar to the manner in which the glacial cycles of Earth and Mars are forced by Croll-Milankovich [10].

Post-Cassini, many aspects of the lakes and seas of Titan will remain unknown, including their composition, physical properties, depths, and shoreline characteristics, all critical to understanding Titan's active methane cycle. Titan's lakes and seas are also an important astrobiological target. It cannot be ruled out that further chemistry may take place on the surface, yielding prebiotic molecules impossible to form in the gas phase. It has even been suggested that autocatalytic chemical cycles might produce far-from-equilibrium abundance patterns or mimic the functionality of biological systems [11, 12]. The only way to understand Titan's methane cycle, its climate, and these speculative possibilities of its prebiotic chemistry are through in-situ chemical analysis and observations.

**Mission Description:** The Titan Mare Explorer is a lake lander, which would float on the surface of a sea, performing chemical, meteorological and visual observations. The primary target for the mission is Ligeia Mare ( $78^\circ\text{N}$ ,  $250^\circ\text{W}$ ) (Fig. 2), one of the largest seas mapped to date on Titan with a surface area of  $\sim 100,000 \text{ km}^2$ . Kraken Mare, to the south of Ligeia, is a potential backup target. TiME science objectives are: 1) measure the sea chemistry to determine their role as a source and sink of methane and its chemical prod-

ucts, 2) measure the sea depth to help constrain organic inventory, 3) constrain marine processes including sea circulation and the nature of the sea surface, 4) determine sea surface meteorology, and 5) constrain prebiotic chemistry in the sea. TiME instruments include a mass spectrometer, a physical properties and meteorology package, and imaging systems. The science objectives of TiME are directly responsive to goals from the 2003 Solar System Decadal Survey [13], including understanding volatiles and organics in the solar system, through TiME measurements of organics on another planetary object, and understanding planetary processes, through TiME's first in situ measurements of a liquid cycle beyond Earth.

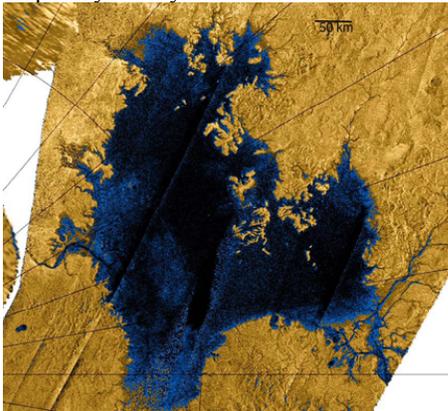


Figure 2. False-color Cassini Radar image of Ligeia Mare, primary target for the TiME mission.

TiME launch opportunities include January 2015 and 2016, with arrivals in 2022 and 2023, respectively. Both Earth and sun remain above the horizon for the three-month minimum lifetime of the mission, during which TiME collects and transmits data from the sea surface. Therefore, a launch date for TiME before 2020 is enabling, as launching after that date results in an arrival during northern winter, after the sun and Earth have set, making direct to Earth transmission infeasible, and minimizing science observations of the sea surface, atmospheric phenomena, and shorelines.

The TiME Discovery mission would test the Advanced Stirling Radioisotope Generators (ASRGs) in deep space as well as a non-terrestrial atmosphere. Its high heritage instruments, simple surface operations, government-furnished launch and power systems, and relatively benign entry, descent and landing conditions make a lake lander mission to Titan achievable as a Discovery-class mission. TiME would return data from Titan in by 2023, provide the first in situ exploration of an extraterrestrial sea, the first in situ measurements of an active liquid cycle beyond Earth, and aid in understanding the limits of life in the solar system.

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**References:** [1] Stofan, E.R. et al. (2007) *Nature*, 445, doi:10.1038/nature05438. [2] Brown, R.H. et al. (2008) *Nature*, 454, 607-610. [3] Hayes, A. et al. (2008) *Geophys. Res. Lett.*, 35, doi:10.1029/2008GL033409. [4] Mitchell, K. et al. (2009), *J. Geophys. Res.*, in review. [5] Rannou, P. et al. (2006) *Science*, 311, 201-205. [6] Mitri, G. et al. (2007) *Icarus*, 186, 385-394. [7] Brown, R.H., et al. (2008) *AGU, 89(53), Fall Meet. Suppl.*, Abstract P12A-03. [8] Niemann, H.B. et al. (2005) *Nature*, 438, 779-784. [9] Tokano, T. (2009), *Astrobiology*, 9, 147-164 [10] Aharonson, O. et al. (2009) *Nature Geoscience*, 2, 851-854 [11] 'Limits of Organic Life in Planetary Systems', (2007) National Research Council, 116pp. [12] Lunine, J. I. (2009), *Proceedings of the American Philosophical Society*, in press. [13] 'New Frontiers in the Solar System: An Integrated Exploration Strategy' (2003) National Research Council, 248pp.