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TITAN MARE EXPLORER (TiME): FIRST IN SITU EXPLORATION OF AN EXTRATERRESTRIAL SEA. E.R. Stofan¹, R.D. Lorenz², J.I. Lunine³, O. Aharonson⁴, E. Bierhaus⁵, B. Clark⁶, C. Griffith⁷, A-M. Harri⁸, E. Karkoschka⁷, R. Kirk⁹, B. Kantsiper², P. Mahaffy¹⁰, C. Newman^{4,14}, M. Ravine¹¹, M. Trainer¹⁰, H. Waite¹², and J. Zarnecki¹³. ¹Proxemy Research, Rectortown, VA 20140; ²Applied Physics Laboratory, Johns Hopkins University, Laurel MD 20723; ³Dipartimento di Fisica, Università degli Studi di Roma "Tor Vergata", Rome, Italy, ⁴California Institute of Technology, Pasadena, CA 91125; ⁵Lockheed Martin, Denver, CO; ⁶Space Science Institute, Boulder CO 80301; ⁷LPL, U. Arizona, Tucson, AZ 85721; ⁸Finnish Meteorological Institute, Finland; ⁹U.S.G.S. Flagstaff, AZ 86001; ¹⁰NASA Goddard SFC, Greenbelt, MD 20771; ¹¹Malin Space Science Systems, San Diego, CA 92191; ¹²SWRI, San Antonio, TX 78228; ¹³PSSRI, The Open University, Milton Keynes, UK MK7 6BJ. ¹⁴Ashima Research, Pasadena, CA 91106

Introduction: Prior to Cassini, oceans of liquid hydrocarbons were thought to cover much of the surface of Titan. Initial data from Cassini-Huygens instead found the equatorial and mid-latitude regions to be dry, characterized by riverbeds and 'seas' of dunes [1-3]. The discovery of lakes in Titan's northern hemisphere established that liquid hydrocarbons exist on the surface of the haze-shrouded moon [4], and the detection of the presence of ethane in Ontario Lacus near the South Pole confirmed that lakes are liquid-filled [5]. Near the north pole, more than 400 lakes have been identified, predominantly north of ~ 70°N, with sizes that range from a few square kilometers to in excess of 100,000 km² [7, 8]. The lakes and seas fill through rainfall and/or intersection with the subsurface liquid methane table, and providing the first evidence for an active condensable-liquid hydrological cycle on another planetary body. The Titan Mare Explorer (TiME) is a Discovery-class mission that lands in a Titan sea, and provides in situ measurements to constrain Titan's active methane cycle as well as its intriguing prebiotic organic chemistry.

Many aspects of the lakes and seas of Titan are unknown, including their composition, physical properties, depths, and shoreline characteristics, but are key parameters for constraining the liquid cycle, and thus are the key targets for the TiME mission. Titan's lakes and seas are likely to contain some combination of liquid methane and liquid ethane, with admixtures of nitrogen and organic species. Titan's methane cycle is dominated by evaporation in equatorial regions and precipitation near the poles, allowing the lakes and seas to persist in polar regions [9]. Therefore, the stability of lakes and seas on Titan's surface is dependent upon the abundance of methane in the atmosphere-surface system, as well as liquid methane in subsurface alkanifers. Ethane, a dominant product of methane stratospheric photochemistry, is liquid under Titan surface conditions, and its presence in the lakes and seas would add to their stability against evaporation [10]. The methane/ethane ratio in the lakes cannot be constrained with current data, but both methane and ethane were detected evaporating into the Huygens

probe mass spectrometer after landing [11], ethane has been detected in Ontario Lacus [5], and late winter tropospheric clouds (which must be largely methane) appeared above the lakes region [12]. Constraining this ratio is critical to determining the significance of the sources of methane. In addition to likely seasonal changes in lake composition and depth [10,13], Titan's lakes and seas may participate in longer-term pole-pole transport forced by the changing astronomical configuration of the seasons, much like the Croll-Milankovich forcing of glacial cycles on Earth and Mars [14].

In addition to ethane, methane and nitrogen Titan's seas will likely contain dissolved amounts of many other compounds – the seas represent a sink for the products of photolysis in the atmosphere. It is not inconceivable 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 yield far-from-equilibrium abundance patterns or mimic the functionality of biological systems [15,16]. Only in-situ chemical analysis can yield insight into these speculative possibilities.

Mission Description: The target for the TiME mission is Ligeia Mare, at 78°N, 250°W. It is one of the largest seas identified to date on Titan, with a surface area of ~100,000 km². Kraken Mare, to the south of Ligeia, is a potential backup target. The mission is directly responsive to goals from the 2003 Solar System Decadal Survey [17], including the goal of understanding volatiles and organics in the solar system, by directly measuring the organics on another planetary object, and understanding planetary processes, by performing the first active measurement of a liquid cycle beyond Earth. This Discovery concept would test the Advanced Stirling Radioisotope Generators (ASRGs) in both a deep space and non-terrestrial atmosphere environments, and would pioneer low-cost, outer solar system missions.

Science objectives for the mission include measuring the chemistry of the sea to determine their role as a source and sink of methane and its chemical products, determining the depth of the sea to help constrain

organic inventory, ascertaining marine processes including the nature of the sea surface and sea circulation, determining sea surface meteorology, and constraining prebiotic chemistry in the sea. Instruments include a mass spectrometer, imaging systems and a physical properties and meteorology package. Launch opportunities include January 2015 and 2016, with arrivals in 2022 and 2023, respectively. The Earth and sun remain above the horizon for the three month minimum lifetime, during which TiME collects and transmits data on the sea. Therefore, a launch prior to 2020 is enabling for this mission, as launch dates after that date arrive in northern winter, after the sun and Earth have set, making direct to Earth transmission infeasible, and minimizing science observations.

TiME's high heritage instruments, GFE power and launch systems, simple surface operations and benign entry, descent and landing conditions make a lake lander mission to Titan achievable in Discovery. TiME science is fundamental, and will 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 our solar system.

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