CASSINI IMAGING OBSERVATIONS OF TITAN'S HIGH-LATITUDE LAKES. E. P. Turtle[1], J. E. Perry[2], A. S. McEwen[2], R. A. West[3], A. D. DelGenio[4], J. Barbara[4], D. D. Dawson[2], C. C. Porco[5], [1]Johns Hopkins Univ. Applied Physics Lab., Laurel, MD 20723, Elizabeth.Turtle@jhuapl.edu; [2]Univ. Arizona, Tucson, AZ 85721; [3]JPL, Pasadena, CA 91109; [4]NASA GISS, New York, NY 10025; [5]Space Science Inst., Boulder, CO 80301.

Introduction: Titan is the only satellite in our Solar System with a substantial atmosphere, the origins and evolution of which are still not well understood. Its primary (>90%) component is nitrogen, with a few percent methane and lesser amounts of other species [1-2]. Methane and ethane are stable in the liquid state under the temperature and pressure conditions in Titan's lower atmosphere and at the surface [3-5]; indeed, clouds inferred to be composed of methane and ethane have frequently been detected [6-11]. Photochemical processes acting in the atmosphere convert methane into more complex hydrocarbons, creating Titan's haze and destroying methane over relatively short timescales [12-13]. In order to explain the current levels of methane in the atmosphere, assuming that we are not observing Titan at an unusual time in its history, it has been hypothesized that Titan has surface and/or subsurface reservoirs of liquid methane, which serve to resupply the atmosphere [14-15]. Knowledge of the distribution of liquids on Titan's surface provides constraints essential to furthering our understanding of Titan's methane cycle.

Early observations of Titan's surface revealed albedo patterns [16] interpreted as dark hydrocarbon liquids occupying topographically low regions between higher-standing exposures of bright, water-ice bedrock [17-18]. Observations of Titan's surface made by Cassini-Huygens show the bright and dark regions in greater detail [11], and have provided evidence of channels carved by flowing liquids and of liquids currently ponded in lakes and seas [19-20]. Although the Huygens probe's observations, which include channels and rounded cobbles on the surface [19] and liquid methane detected in the very near surface [21-22], were made at low latitudes, it is not the long-observed equatorial dark areas which appear to currently hold liquids. Instead these regions appear to be covered by seas of dunes composed of particulate hydrocarbon material [23], while the presence of liquids has been demonstrated at high northern latitudes [20].

The compositions of the materials responsible for Titan's observed albedo variations are still not well understood; however, morphologic interpretations of observations by Cassini and Huygens, appear to have confirmed hypotheses that darker regions are relatively low elevations where liquid and solid hydrocarbons, which are expected to have precipitated from the atmosphere in substantial quantities over Titan's history [17], have accumulated, while brighter regions represent higher-standing exposures of less-contaminated water-ice or brighter organic material [11, 19, 24-27].

Cassini ISS Observations: Cassini's Imaging Science Subsystem (ISS) has been observing Titan for almost four years, beginning during final approach to the Saturnian system in Spring 2004 [11] and continuing through the 40 targeted Titan encounters that Cassini has performed through early January 2008. Titan's atmosphere obscures its surface almost completely at visible wavelengths [28], so the ISS cameras include narrow bandpass filters at 938 nm and IR polarizer filters [29] to take advantage of a window in methane's absorption spectrum in the near-infrared where the optical depth of Titan's complex organic atmospheric haze is lower and the fact that the haze is highly polarized near phase angle 90º [30]. However, even with these filters, scattering by haze particles limits the best resolution that can be achieved to ~1 km [29]. Despite the challenges presented by Titan's atmosphere, to date Cassini has imaged almost all of Titan's illuminated surface at resolutions of tens of kilometers and a substantial fraction of the surface at significantly better resolution, down to the limit imposed by atmospheric scattering. These observations have been combined to produce a 938-nm albedo map of the surface.

The brightness variations revealed by ISS are due to the presence of surface materials with different albedos rather than topographic shading. Even high-phase-angle images are likely to reveal only albedo markings: (1) an icy satellite of this size is not expected to have topographic relief high enough that shadows would be detectable at kilometer scales [31]; and (2) atmospheric scattering severely reduces the contrast between slopes facing towards and away from the Sun. Observations repeated with different illumination angles have not revealed changes consistent with topographic shading.

The most direct way for ISS to identify liquid on Titan's surface is by detection of enhanced signal at the specular point. If the geometries between observations with repeat coverage of the same area are such that the location of the specular point is different, the ratio of the two observations can be used to distinguish between inherent albedo and specular enhancement and improve the level of sensitivity in the detection level. If either of the specular points covered contained liquid, the signal would be expected to be enhanced by ≥10% [32-33] over an area the size of which depends on surface roughness: narrow for a calm liquid, broader for a surface disturbed by waves. Although ISS has observed the specular point at numerous locations at low latitudes on Titan's surface [33], detailed analysis has detected no enhancement, indicating no substantial coverage of the surface by liquid in these areas, consistent with other observations. Indeed, there have been no reports of specular reflections at visible or IR wavelengths in almost a decade of Earth-based observations or in Cassini observations targeting the specular point [32]. Unfortunately, illumination geometry prevents observations of the specular point at high latitudes, where there is more compelling evidence for the presence of surface liquids, except at high phase angles where atmospheric scattering prevents useful ISS observations of the surface.

Interpretations: The morphologies of the albedo patterns observed on Titan's surface appear to reflect a wide variety of geological features: linear boundaries likely indicate faulting and tectonic control; bright, roughly east-west, streamlined shapes suggest aeolian processes, consistent with RADAR observations of expanses of dunes covering the dark equatorial regions [23]; narrow, curvilinear lines that wind across the surface appear could be dark material on the bottom of fluvial channels; Ontario Lacus, a dark feature near the South Pole that is 237 km long with a smooth margin is suggestive of a lake [34]; circular albedo features, although relatively uncommon, have usually been confirmed to be impact structures [35], further evidence for a geologically young surface; and other, more complex, patterns still defy easy interpretation.

ISS imaged Titan's South Polar region in July 2004 and June 2005, revealing numerous dark surface features: in all we have documented over 50 features south of 69° S, ranging from 237-km-long Ontario Lacus to some just under 10 km across and covering a total area of ~120,000 km^2. Many of the features large enough to be well resolved have smooth boundaries. There is also a much larger dark feature extending to relatively high southern latitudes, Mezzoramia. RADAR observations of this region were interpreted as representing a shoreline beyond which the surface became smooth, perhaps a dry lakebed [36].

More recent observations by ISS of northern latitudes as the approaching equinox brings improved illumination have revealed an extensive low-albedo surface feature with a very complex boundary. The structure is more than 1100 kilometers long and at its northernmost extent coincides with a large liquid-filled region identified in overlapping RADAR swaths [37].

There is substantial evidence supporting the interpretation that dark high-latitude features observed by ISS are lakes or lakebeds. The channels observed clearly demonstrate that the surface has been modified by flowing liquid. Persistent, episodic south-polar cloud activity, exhibiting convective behavior associated with precipitation, was observed in 2004 common until a few years ago. RADAR data interpreted similar features around the North Pole to be liquid-filled lakes, including the portions of the large northern dark feature identified by ISS that RADAR has also observed [20, 37]. ISS provides a complementary view to that of RADAR, with almost complete global coverage, including the South Pole at resolutions of several hundred meters to several kilometers. These observations reveal low-albedo features at high latitudes which combine to cover well over 600,000 km^2, almost 1% of Titan's total surface area; however, as shown by as shown by [38], even if all of these features are filled with liquid, they do not appear to provide enough methane to keep Titan's atmosphere resupplied for a substantial amount of time, unless the lakes are unexpectedly deep or other subsurface reservoirs exist.

References: [1] Broadfoot et al. (1981) *Science* 212, 206-211 [2] Hanel et al. (1981) *Science* 212, 192-200 [3] Tyler et al. (1981) *Science* 212, 201-206 [4] McKay et al. (1997) *Icarus* 129, 498-505 [5] Samuelson et al. (2002) *Space Sci. Rev.* 104, 191-208 [6] Griffith et al. (1998) *Nature* 395, 575-578 [7] Griffith et al. (2005) *Science* 310, 474-477 [8] Griffith et al. (2006) *Science* 313, 1620-1622 [9] Schaller et al. (2006) *Icarus*, 182 224-229 [10] Schaller et al. (2006) *Icarus* 184, 517-523 [11] Porco et al. (2005) *Nature* 434, 159-168 [12] Strobel (1982) *Planet. Space Sci.* 30, 839-848 [13] Yung et al. (1984) *Ap. J. Suppl.* 55, 465-506 [14] Lunine et al. (1983) *Science* 222, 1229-1230 [15] Lunine (1993) *Rev. Geophys.* 31, 133-150 [16] Smith et al. (1996) *Icarus* 119, 336-349 [17] Lorenz and Lunine (2005) *Planet. Space Sci.* 53, 557-576 [18] Griffith et al. (2003) *Science* 300, 620-630 [19] Tomasko et al. (2005) *Nature* 438, 765-778 [20] Stofan et al. (2007) *Nature* 445, 61-64 [21] Niemann et al. (2005) *Nature* 438, 779-784 [22] Lorenz et al. (2006) *MAPS* 41.1705L [23] Lorenz et al. (2006) *Science* 312, 724-727 [24] Elachi et al. (2005) *Science* 308, 970-974 [25] Elachi et al. (2006) *Nature* 441, 709-713 [26] Soderblom et al. (2006) *B.A.A.S.* 38, 52.08 [27] Barnes et al. (2007) *Icarus* 186, 242-258 [28] Richardson et al. (2004) *Icarus* 170, 113-124 [29] Porco et al. (2004) *Space Sci. Rev.* 115, 363-497 [30] West and Smith (1991) *Icarus* 90, 330-333 [31] Perron and de Pater (2004) *GRL* 31, L17S04 doi:10.1029/2004GL019802 [32] West et al. (2005) *Nature* 436, 670-672 [33] Fussner (2006) M.S. thesis, U. Arizona [34] McEwen et al. (2005) *B.A.A.S.* 37, 53.04 [35] Lorenz et al. (2007) *GRL* 34, L07204 doi:10.1029/2006GL028971 [36] Lunine et al. *Icarus* in press [37] Lopes et al. (2007) *EOS* 88, 569-570 [38] Lorenz et al. *GRL* in press.