TWILIGHT ON KRAKEN : THE LOST OPPORTUNITY TO EXPLORE TITAN SEAS UNTIL ~2040.

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Introduction: The Titan Mare Explorer (TiME) mission concept captured the public imagination and defied preconceptions about what was possible in the Discovery program. It did so through broad scientific appeal addressed with a focussed payload, the simplicity of unguided descent and splashdown, Direct-to-Earth communication, and an enabling Radioisotope Power Source (RPS), namely the Advanced Stirling Radioisotope Generator (ASRG). The march of Titan's seasons (pushing the northern seas into darkness, and precluding DTE after the mid-2020s), and NASA's limited RPSs, mean the opportunity has been lost.

Timeline: TiME was originally proposed in response to NASA's November 2007 DSMCE call for mission concepts enabled by the ASRG (recall that Titan's seas were first observed only in early 2007). Selected for study, the concept proved viable (the study considered arrival in 2022) and was developed further on APL and Lockheed Martin internal funds with a view to proposal to the Discovery Announcement of Opportunity, originally anticipated in 2009, but delayed until mid 2010. TiME was one of 3 missions selected for Phase A ($3M) study and possible flight, out of some 28 proposals.

The Phase A study laid out in detail the various aspects of implementation with a view to launch in 2016 and arrival at Ligeia Mare (78^{o}N) in 2023, from test plans to data archiving. Instruments (including a sonar transducer and the liquid inlet for a mass spectrometer) were prototyped and tested in cryogenic conditions, environmental models defined and splashdown tests performed, retiring all the major concerns about such a daring mission. However, NASA's non-selection of TiME in August 2012 was soon followed by revelations of delays in, and then cancellation of, the ASRG program upon which the concept rested. While design solutions were then developed to perform a TiME-like mission with the poorer-performing MMRTG (more mass, less power, more waste heat) at Kraken Mare (down to 64^{o}N, with DTE as late as ~2027), NASA groundruled all RPS out of the 2014 Discovery call.

The March of Seasons: Titan northern midsummer is in 2017 (hence, the objective of the Cassini Solstice Mission). Thereafter Earth visibility and solar illumination of the seas progressively degrades. While sea surface winds are predicted to decline in the 2020s (initially favorable, avoiding the risk of large waves, this eventually erodes the prospect of wave science - after circa 2026 a capsule will sit motionless on a stagnant sea) the winter stratospheric jetstream builds up, increasing landing dispersions and increasing the risk of missing the sea with a passive parachute descent. Thus even if a relay spacecraft were available to provide data return after DTE closes, safe descent becomes more challenging, and air-sea exchange becomes less interesting.

Science - A Moving Target: Among the many unknowns motivating TiME were the composition of the seas (not only the bulk methane/ethane/propane ratios, as a reservoir in the Titan climate system, but also the prospect of Ligeia as a sink for the myriad of photochemical products, and possible subsequent processing in the liquid), the depth of Ligeia, and the unknown meteorological variations at Titan's surface. In fact, Cassini's recent radar measurement of the depth of Ligeia (170m) requires the sea to be exceptionally RF-transparent, suggesting it is abundant in neither complex organics (especially polar nitriles) nor in suspended material. Furthermore, a growing understanding of Titan's climate system suggests there may be a gradient in the (methane/ethane) composition of the seas, since constrictions inhibit their mixing on seasonal timescales. Thus measurement at a single location does not completely characterize the ocean system.

These considerations make a battery-powered capsule (which could make a point composition- and depth-measurement only; survival in Titan's cold of only a few hours is too short to meaningfully measure diurnal meteorological variations or observe ocean drift) scientifically risky (it may just confirm what we already know) and unappealing (leaving many questions unanswered). Indeed, such landers were considered and rejected in the 2007 'Billion-Dollar-Box' study and the Decadal Survey as not providing adequate science return. That said, a multiprobe mission making measurements in different parts of the sea could clear the bar without RPS, if a relay capability were available. Multiple landers would presumably challenge the Discovery cost envelope, however.

What Next?: Illumination of the seas will resume in the late-2030s (for which Jupiter flybys may facilitate delivery), and DTE becomes feasible circa 2040. In the meantime, other Titan exploration concepts may come to the fore. As investigated in detail in the 2006 Titan Explorer Flagship study, a Titan orbiter has tremendous and wide scientific potential. In-situ exploration ideas include balloons and airplanes. All these ideas rely on RPS for meaningful science return. None, however, have the charm, efficiency and boldness of TiME.