TITAN SINCE APOLLO.
R. D. Lorenz1, 1Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723, USA. ralph.lorenz@jhuapl.edu

Introduction – Titan circa 1970: Almost nothing was known about Titan before Apollo, except the exceptional fact that it had an atmosphere! The state of the art – with Titan as a purely astronomical object - was summarized in a 1973 workshop [1]. Polarimetry indicated the atmosphere was hazy, and the surface was speculated to be organic-rich and warmed by a greenhouse effect (figure 1). Debates about Titan’s climate mirrored those of Venus at the same period [2], and indeed the meagre spectroscopic data available on Titan then is similar to the current state of knowledge of best-studied exoplanets.

Figure 1: Hunten’s ‘best guess’ in 1973 – not universally accepted – proved remarkably accurate. Work by John Lewis pointed to an icy, volatile-rich constitution, perhaps even with a liquid water interior.

Voyager – Titan Takes Shape: The possibly warm surface of Titan, and the idea that methane photolysis might produce abundant organics motivated Titan as a prime target of the Voyager 1 encounter in 1980. This confirmed the greenhouse model (figure 1), with radio occultation setting the surface pressure and temperature at ~1.5 bar and 94 K. Voyager infrared spectra indicated at least 20 different organic compounds in Titan’s atmosphere, but the surface remained largely hidden. The 1980s ventured speculation about the prospect of a methane-ethane surface ocean, and motivated the formulation of the NASA/ESA Cassini-Huygens mission.

Hubble, Radar – Lifting the Veil: Near-infrared lightcurves (again now a frontline exoplanet technique) circa 1992 [3] showed the surface could be sensed through the haze and was heterogenous, and Goldstone radar experiments (Titan remains the furthest object studied by groundbased radar) suggested a mostly solid surface. The first maps of Titan by HST in 1994 showed bright and dark terrains at roughly the resolution the naked eye sees our own moon, but interpretation was challenging. Hubble data showed seasonal change in the atmospheric haze, and as large telescopes with adaptive optics systems emerged circa 2000, methane clouds were seen to come and go, suggesting an active hydrological cycle. It was established at this time that the biggest mysteries after Cassini would be the surface composition, and that surface mobility would be a key capability [3,4].

Cassini-Huygens – A World at Last: Beginning in 2004, Cassini data began to reveal ever-increasing areas of Titan’s surface at high resolution, both in the near-infrared (ISS and VIMS) and with RADAR. The details were initially inscrutable but intriguing. The Huygens descent in January 2005 was much easier to interpret – the landing site was evidently a streambed (figure 2), and the channel networks seen from above and dampness in the ground attested to at least episodic and recent fluvial activity e.g. [5].

Figure 2: Knee-high perspective from the Huygens probe, set against Apollo view with the same geometry.

A range of geomorphologies were identified from Cassini data, including mountainous Xanadu (the bright unit detected in lightcurves), the vast dark dunefields, and a small number of varied impact structures. The surface composition proved
challenging to determine, and claims of possible cryovolcanic features were contested amid debates of future flagship exploration of Titan and Europa. Data from Cassini’s CAPS and INMS instruments as the spacecraft dipped into the upper atmosphere demonstrated a rich organic chemistry, however.

As the mission went on, analyses of Titan’s rotation state from RADAR, Huygens data, and Cassini gravity measurements confirmed that Titan had an internal liquid water ocean.

Much attention in Cassini’s extended mission focussed on the hydrocarbon lakes and seas, first hinted at in ISS in 2004, but convincingly observed in 2006 onwards. Although ethane was detected by VIMS in 2008 in Ontario Lacus (the only large southern lake), the extensive northern seas were found in 2011 (via the radar-sounding of Ligeia Mare, detecting the seabed at 160m depth) to require a radio-transparent methane-rich composition, e.g. [6]. Transient features were observed in the seas, and many studies in extraterrestrial oceanography (e.g. wave generation, bubble formation, tidal currents and ocean mixing) began. Cassini data chronicled the complex seasonal evolution of the atmosphere, with the observation of a few storms and clouds at different latitudes, altitudes and seasons. The Titan textbooks have literally been (re)written [7,8] but many puzzles remain (e.g. [9] the fate of ethane and the question of cryovolcanism) and especially the composition of surface materials that might contain products of the interaction of abundant organics with liquid water [10].

The Future: With the completion of Cassini’s mission in 2017, observation by Earth-based assets will again come to the fore for some years.

Titan is more than just an Ocean World, and it is the most accessible of them in that its atmosphere permits easy Mars-like delivery of vehicles by entry shield and parachute. The low gravity and dense atmosphere entice exploitation by aerial mobility, and the 2007 Flagship study (the first comprehensive post-Cassini Titan concept [11]) advocated a dune lander, a hot-air balloon and an orbiter. An evolution (TSSM) planned a lake lander, balloon and orbiter, and the Decadal Survey endorsed the breadth of Titan science in these concepts. A standalone capsule (TiME) to explore Ligeia was a brave attempt to squeeze focussed Titan science in Discovery, relying on the special (but illusory) radioisotope power system (RPS) provisions in the 2012 competition. A number of other concepts have been considered, including airplanes (AVIATR) and flyby spacecraft (JET, E2T) but fitting Titan in the ESA M-class or Discovery is a formidable challenge.

The introduction of Ocean Worlds to the New Frontiers 4 target list in 2016, opened the way for major elements of Flagship/Decadal science to be addressed, albeit not all in one go, and two complementary missions were proposed. OCEANUS underscored the value of orbital science (the only mission type at Titan that can – just – be sustained by solar power). Dragonfly (figure 3), a relocatable lander exploiting the ‘drone revolution’ and an MMRTG to achieve aerial and landed science [12] was selected for a competitive Phase A study. If selected for implementation in 2019, it could land on Titan in 2034, and 2035, and 2036...

Conclusions: Titan has been transformed since Apollo from a dot in the sky to a diverse and rich world, ripe for further exploration by a variety of robotic vehicles, and one day, by humans directly [13].