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Cassini RADAR: 10 years at Titan

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Abstract

Cassini has turned Titan from a variegated orb into a dynamic world of exotic and yet also familiar landscapes. The Cassini RADAR investigation has been instrumental in that transformation. Here I review the highlights of how that process unfolded.

1. Introduction

Titan's atmosphere and organics made it a particular target of the Voyager mission, and the obscuration of the surface from Voyager's cameras left it the largest unexplored planetary landscape after Magellan mapped Venus. A Titan radar mapper was in fact considered as a standalone mission before Cassini was formulated, so a radar instrument was a natural element in Cassini's payload, with Titan as its central focus. While RADAR observations of other satellites as well as Saturn and its rings have been made, here we will focus on Titan results.

2. First Taste of Titan - TA

An early priority in Cassini planning was to try out different instruments in Titan observation, and part of the first flyby (TA, Oct 2004) was devoted to radar observations. Radiometer data showed unexpectedly high brightness temperatures, indicating an organic-rich surface composition rather than the water ice that was expected to dominate. Synthetic Aperture Radar (SAR) imaging worked as planned, with resolutions of ~350m achieved.

The area observed (around 50^{o}N, north of Xanadu) may in retrospect turn out to be one of the most inscrutable areas of Titan, and initial interpretation of the scene was challenging. Some suspected channels and alluvial fans were noted, as well as some lobate features suspected to be lava flows, and a circular feature (Ganesa Macula) initially suspected to be a pancake dome volcanic construct. The lack of topographic data, and indeed overall context, made these interpretations tentative.

2. T3 - A New World

T3 (Feb 2005), the first flyby after the Huygens encounter, was a full radar pass, and (as a Huygens backup pass) had a similar groundtrack to TA, but this time the radar covered a swath around 30^{o}N. This proved dramatically easier to understand. Two impact craters (Menrva - at 440km still the largest crater known on Titan, and Ksa, ~70km and still perhaps the freshest-looking crater on Titan) were seen, as well as a braided channel network instantly recognizable as of pluvial/fluvial origin (of course, the determination of Titan as hydrologically-modified world was convincingly made by Huygens images just weeks before). Some dark streaks ('cat scratches') were suspected to be of Aeolian origin, but were not certain.

4. T7 - Cut Off Short

T7 (Sep 2005) was eagerly awaited, offering the first high-latitude SAR imaging. The image swath showed a massive fluvial valley network flowing ~1500km south and terminating in a somewhat lacustrine-looking area, but the swath was cut short by a Solid State Recorder (SSR) pointer error on the spacecraft. Had this data not been lost, it might have discovered unambiguous lakes a year earlier than transpired.

5. T8 - Huygens Landing Site and the Dunes

Some consolation derived a month later from the T8 equatorial swath over Belet. This pass dramatically showed the equatorial dunes to be of the same spacing, height and morphology as the largest dunes on Earth. Additionally, a refined observation design stretched the pass along-track to cover the Huygens landing site, which was in fact identified by correlating dunes with dark streaks seen in the distance in the Huygens image mosaic.

5. T13 - Xanadu

T13 (Apr 2006), like T8 an equatorial orbit, covered the enigmatic bright region Xanadu. The SAR swath revealed Xanadu to be very rugged, with many mountains and several fossil impact structures, as well as long bright channel networks flowing south. Preliminary 'SARTopo' data – a novel technique – gave the surprising result that Xanadu was overall low in elevation, making us initially hesitant in adopting these data.

6. T16 - Lakes at Last

July 2006 brought images of the north polar regions (still in winter darkness) that showed clearly dozens of (literally) pitch-black lake-shaped features. Their radiometric properties and morphology were essentially unambiguous indication of surface liquids.

7. T25 - The Sea !

Feb 2007 brought images of a much larger body of liquid, the ~350km Ligeia Mare, the target of much study since. T28/29/30 saw more of Ligeia as well as part of Kraken Mare (hinted at in ISS data).

8. T30 - Titan takes Shape

Half of T30 (May 2007) of the pass was devoted to a long altimetry track. These data validated the SARTopo approach, paving the way for global topography analysis.

9.T43/4 - Cryovolcanic Controversy

Near-IR bright regions (Tui Regio/Hotei Arcus) suspected of possible cryovolcanic origin were targeted here (May 2008): interpretations as lacustrine vs volcanic continue to be debated. Some remarkably bright channels at the south edge of Xanadu were noted..suggesting spheroidal cobbles acting as 'cat's eye' reflectors to radar.

10. T49 Ontario

Altimetry over Ontario Lacus was key in interpreting its morphology, possible seasonal evolution, and establishing an absence of waves. The lake was so smooth and reflective that T49 altimetry data were saturated: T60 was redesigned to compensate, but that pass was lost due to DSN problems.

11. Titan's Spin and Stereo

Enough image overlaps had accumulated by this point (summer 2008) to allow a spin state to be determined for Titan, opening new avenues of enquiry in geodynamics (e.g a Cassini state, but excited by seasonal atmospheric torques). Studies are ongoing. The same overlaps permit stereo digital elevation models of local areas, greatly facilitating geological interpretation – the putative cryovolcano Doom Mons is one example.

13. A Global Picture Emerges

Data had accumulated by ~2009 to offer global perspectives on Titan's radiometry, backscatter, shape and hypsometry. The dichotomy between few lakes in the south and the extensive northern seas became apparent. The pattern of Titan's dune orientations, a key wind indicator - became a focus of , and challenge to, global circulation modellers.

14. T91/T92/T95--Sounding the Depth of Ligeia

Although global coverage also grows, Solstice Mission observations are targeted at several key areas, notably Titan's seas. Altimetry on T91 (May 2014) showed that Ligeia remains unruffled, but remarkably yielded a bottom echo showing it to be 170m deep. In combination with T92, stereo SAR and other analyses of Ligeia and the lakelands are underway. T95 HISAR allowed a near-complete map of the seas, paving the way for ocean models.

15. Future Plans and Lessons

Only six Titan radar passes remain: these will revisit the seas and Tui/Hotei, as well as extending topographic and imaging coverage as Titan's seasons progress. Wave detection on the seas is hoped for.

Flexibility in observation planning has been key to realizing the potential of the RADAR investigation. Coverage has been greatly extended by novel observation designs such as high-altitude single-beam SAR ('HiSAR'). New processing techniques such as SARtopo, the examination of amplitude statistics for sea surface roughness, and detection of subsurface echoes have emerged which were not anticipated when the instrument was proposed some ~25 years ago.