Titan Flagship Study
Report to OPAG

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Titan is a massive factory of complex organic molecules, with rich ion and neutral chemistry driven by a variety of energy sources (solar UV, GCRs and magnetospheric electrons)

Dramatic time-variable anomalies in temperatures, gas abundances, haze and cloud structure in high latitude winter, bounded by polar vortex (cf ozone hole on the Earth)
Titan Flagship SDT

- SDT appointed by HQ from community volunteers at beginning of the year.
- Titan is a thematically broad target – 12-person SDT (barely) covers range but does not cover all possible instrument techniques
- Weekly telecons began end January
- 3 2-day meetings (March 1-2 APL; April 5-6 SwRI San Antonio; June 18-19[20] APL)
- Presentation to OPAG 2 May – solicitation of community feedback

SDT Composition

Ralph Lorenz (cochair*)
J. Hunter Waite (cochair)
Rosaly Lopes (JPL)
Scoot Rafkin (SwRI)
Devon Burr (SETI)
F. Mike Flasar (NASA GSFC)
Andrew Steele (CIW)
Gerald Schubert (UCLA)
Kevin Baines (JPL)
Dill Kurth (U. Iowa)
Jonathan Lunine (U. Arizona)
Dale Cruikshank (NASA Ames)

Aeronomy, Chemistry
Geology (volcanism)
Meteorology
Geology (fluvial)
Climate, Thermal IR remote sensing
Astrobiology, In-Situ Chemistry
Geophysics, Atmospheric dynamics
Atmospheres, Near IR Spectroscopy
Magnetosphere, Radio methods
Surface/atmosphere, Origins
Organics, Ices, Near IR Spectroscopy

*APL study scientist.

Community Input

Many colleagues have responded to our queries about instrument capabilities etc.
Frank Crary, Mike Janssen, Bob West, Bruce Bills, Nicole Hapapport, Chris Webster, Sam Gulkis, Ali Safaenelli, Keith Raney, Emmanuel Lellouch, Roger Clark, Phil Callahan, Sami Asmar, Darrell Strobel, Bruce Banerdt, others

SDT Work

Science Objectives discussed in TSDT-1 meeting, iterated in splinter groups by email.
Discussion of synthesis document into near-final state (prioritized investigations) with measurement objectives done in TSDT-2.
Architecture discussions. Definition of floor.
Developed statement of ‘What will Orbiter achieve compared to Cassini?’
More SDT Work

Discussion of season / arrival date (no strong preference; CBE late 2020s will be complementary to Cassini)

Discussion of orbit geometries (preferences for mapping, gravity, occultations, aerosampling, etc.) Evolving orbit ideal.

Environment (atmosphere profile, potential landing sites, etc.) specification drafted

Payload operations under discussion in Phase II

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SDT Work

Science Objectives formulated after review of
- 2003-2013 Decadal Survey Report
- Decadal Survey Titan Community White Paper
- 2006 Solar System Roadmap
- OPAG Pathways Document
- OPAG Titan Working Group presentations
- TIPEx Study, TOAM study, Visions Missions
- Billion $ Box Study
- (Europa SDT Objectives)

Titan top-level objectives mirror questions 1-3 of Roadmap Questions (Origin; Evolution/Process; Origin of Life). Per Europa SDT, investigations in 1 & 3 prioritized. Investigations in 2 largely formulated in Billion $ Box study

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OBJECTIVE 1: Titan's Origin and Evolution
What is the original composition of rocks and ice that formed Titan and what is the extent of differentiation and geochemical processes that have occurred since the latest formation? How do we explain the similarities and differences between Titan's structure and that of other solar system bodies?

Investigation 1
Determine the state of internal differentiation. Understand the heat sources and thermal evolution of Titan. Determine if Titan has a metallic core and an intrinsic magnetic field. Determine the extent and origin (tidal vs tectonic) of Titan's seismic activity.

Investigation 2
Determine geochemical constraints on bulk composition, the delivery of nitrogen and methane to the surface, and exchange of surface materials with the interior over geologic time.

Investigation 3
Determine the depth of any subsurface liquid water ocean, its thickness and electrical conductivity and the lateral variations in thickness and rigidity of the overlying icy crust.

Investigation 4
Characterize and assess the relative importance today and throughout time of Titan's geologic, oceanographic and geomorphological processes e.g., cryovolcanic, aeolian, tectonic, fluvial, lacustrine, hydraulic, impact and erosion.

Investigation 2: Titan as a System
How does Titan function as a system? How do we explain the similarities and differences between Titan and other solar system bodies, in the context of the concept of internal gradations and the spectrum of possible bodies in the solar system? (Investigations NOT prioritized)

Investigation 2
Determine the composition of volatiles and condensates in the atmosphere and at the surface, including hydrocarbons and nitriles, on both regional and global scales, in order to understand the hydrocarbon-based hydrologic cycle.

Investigation 3
Determine the three-dimensional circulation of the atmosphere and local dynamics (e.g., convection, planetary waves), as a means to understanding the role of transport in atmospheric chemistry and weather, including precipitation processes.

Investigation 4
Determine the role of the interaction of Titan's upper atmosphere and ionosphere with Saturn's magnetosphere in determining the evolution and climatology of Titan's atmosphere, especially the loss of materials and as a source of free energy and heat for driving the chemistry and dynamics. Determine the chemical pathways by which the nascent tholin formation takes place in the upper atmosphere.

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**Investigation 1**
Determine the extent of organic chemical evolution on Titan that could lead or has led towards life.

**Investigation 2**
Determine the chemical pathways leading to formation of complex tholin pre-cursors at all altitudes in the Titan atmosphere and their modification and deposition on the surface.

**Investigation 3**
Determine if chemical modification of organics on the surface may have occurred, in particular possible hydrolysis of tholins by transient liquid water into pyrimidines, amino acids, e.g. via impact melt or cryovolcanic deposits.

**Investigation 4**
Determine the role of abiotic/abiotic synthesis of organics on or near the surface as the result of reactions on mineral surfaces and/or as the result of interior processes, such as serpentinization and condensation of hot gases in the colder atmosphere.

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A long-lived multi-element architecture enables powerful synergistic science via simultaneous measurements at different places or scales.

E.g. Titan's interior structure

Orbiter can measure gravity field and topography, and changes therein due to tidal forcing. Orbiter can measure external magnetic field and ionosphere forcing.

Simultaneously, lander magnetic measurements can isolate induced response from external forcing. Also detects seismic activity excited by tides and the crustal response.

Lander-Orbiter ranging/doppler improves gravity tracking of orbiter, and yields precision measurement of rotation state via lander geodesy.

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To understand the processes shaping Titan needs information on all scales – e.g. for fluvial processes need large-scale networks and topography, mid-scale observations to understand e.g. runoff threshold and floor fill, and small scale to characterize sediment itself.

Atmospheric (via optical scattering and enforced high altitude of orbiter) makes mid-scale (~1-10m resolution) difficult to acquire e.g. by HiRISE-type instrument. Lander would not see wide diversity of terrain during descent.

An aerial platform like a balloon bridges the scale gap – wide coverage at high resolution. Reduces risk for future lander missions by characterizing terrain hazards.
Example – Altimetry Coverage

Titan orbiter
Groundtracks
for 20 days in
85 deg orbit
(mission >1000
days!)—
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Ample crossover
opportunities for
precision,
observation of
tides

20km footprint,
Doppler-sharpened
to ~1.5km in along-
track direction

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Altimetry over Polar Seas

Science Opportunities from Orbit Evolution
(primarily due to Saturn perturbation)
Trades still being explored

South pole aero capture into 85 deg orbit, 1700km circular. Beta = 20. Decreases
through zero at ~20 deg/year

Beta < 10 brings surface occultations up to polar latitudes (plus low phase angle
for spectral mapping.) Increase towards Beta=50 at end allows (grazing)
occlusion of ionospheric peak but does not reach lower atmosphere.

Very small ∆V needed to maintain low eccentricity. If
allow eccentricity to grow, orbit evolves to provide
aerosampling

Minimum permissible altitude is flexible. Strawman plan is for ~00 days of
aerosampling orbits (providing several Titan days, with 20 degrees of periapsis
latitude sweep). ~20 m/s ∆V.

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OPAG Report, RL 21

OPAG Report, RL 22

OPAG Report, RL 24
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<tr>
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<tbody>
<tr>
<td>Radar Surface Mapping</td>
<td>~25% coverage at 300m-1 km SAR resolution. Few per cent at 12km. Global coverage at 20 km resolution (Magellan ~10% at 100km)</td>
<td>~35% coverage by high-resolution SAR. ~10% lower-resolution (~10km) (~30 GB)</td>
<td>100% at 100m</td>
</tr>
<tr>
<td>Near-IR Surface Mapping</td>
<td>~1% coverage of better than 2km/pixel Near-global coverage at 10-20km. Spectral Resolution 3/A5=200</td>
<td>Few % at 2km/pixel (? ~40 GB)</td>
<td>99%+ at 100m (dependant on season)</td>
</tr>
<tr>
<td>Interior Structure</td>
<td>J2, C22</td>
<td>Tidal love number k2 to 7.0</td>
<td>Coefficients to order 5 or 6. Robust k2</td>
</tr>
<tr>
<td>Topography</td>
<td>~10,000km of altimetry tracks, ~20km footprint, 50m resolution (MOLA ~20 million km, 200m footprint, 1km resolution)</td>
<td>~15,000km</td>
<td>~5,000,000km at 20m or better (plus lake tides to 1.5m)</td>
</tr>
<tr>
<td>Teopsphere</td>
<td>~10 radio occultations</td>
<td>~14 radio occultations</td>
<td>Microwave soundings plus several anctons occultions</td>
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<tr>
<td>Transport</td>
<td>~10 radio occultations, ~4 solar and stellar occultations. Few encountered (7) hours of mid/lower IR spectral observation (yielding composition maps etc.)</td>
<td>~14 radio occultations, ~15 noon and midnight occultations. Few more hours of IR</td>
<td>Microwave, mid/lower IR, stellar and ionospheric monitoring</td>
</tr>
<tr>
<td>Ionosphere</td>
<td>~50 profiles. Some neutral-only. Total ~300 nights mid/low-500/2000km</td>
<td>~50 profiles. ~150 min</td>
<td>Hundreds of deep soundings. ~3 years below 2500km</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>~60 magnetic field observations above the ionosphere – one or two perhaps below peak</td>
<td>~70 observations on last 3 years below 2500km</td>
<td>~1000 orbits</td>
</tr>
<tr>
<td>Total Time within 16,000km</td>
<td>~50 hours</td>
<td>~40 hours</td>
<td>~1.4 yrs (~30,000 km)</td>
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</tbody>
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**Hot-air balloon (‘Montgolfière’) can make several times round-the-world flights.**

Exploit (predictable?) tidal winds to direct drift…
Lander-Launched Micro-UAV for Titan Science

A 1kg Titan UAV could fly for several hours (vertical launch off lander) — augments/replaces descent imager landing site context (stereo, λ, lander in scene), plus boundary-layer meteorology profiling.

Can have much smaller wing area in Titan low gravity, thick atmosphere (or could fly 9x slower)

Possible implementation as competed student experiment?

USMC has hundreds of Back-packable Dragon Eye UAVs. Mass 2.7 kg. Endurance ~60 minutes on battery. Range ~10km. Video to backpack/laptop control station. Cruising speed 35 km/h.