Titan Flagship Study

Report to OPAG

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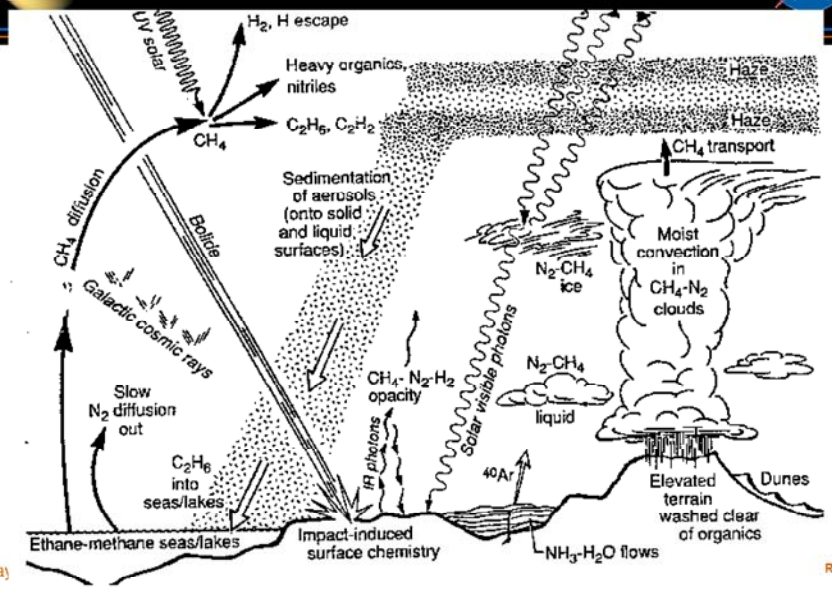
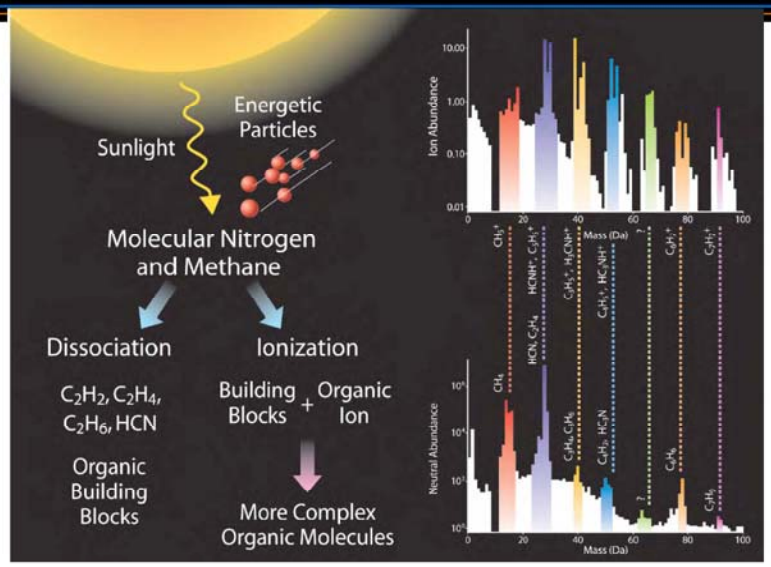
Titan System Science



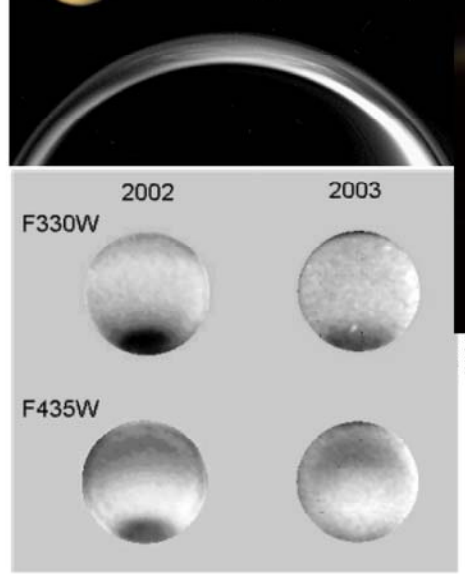
May

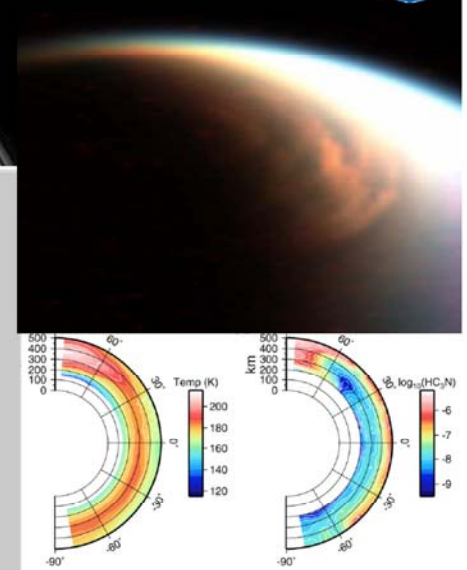
RL 2

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)

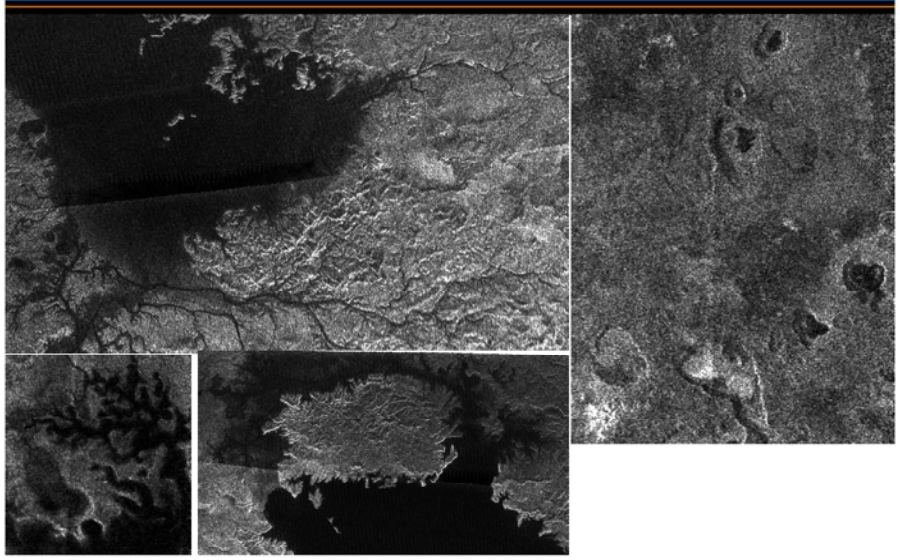


Dramatic time-variable anomalies in temperatures, gas abundances, haze and cloud structure in high latitude winter, bounded by polar vortex (cf ozone hole on the Earth)

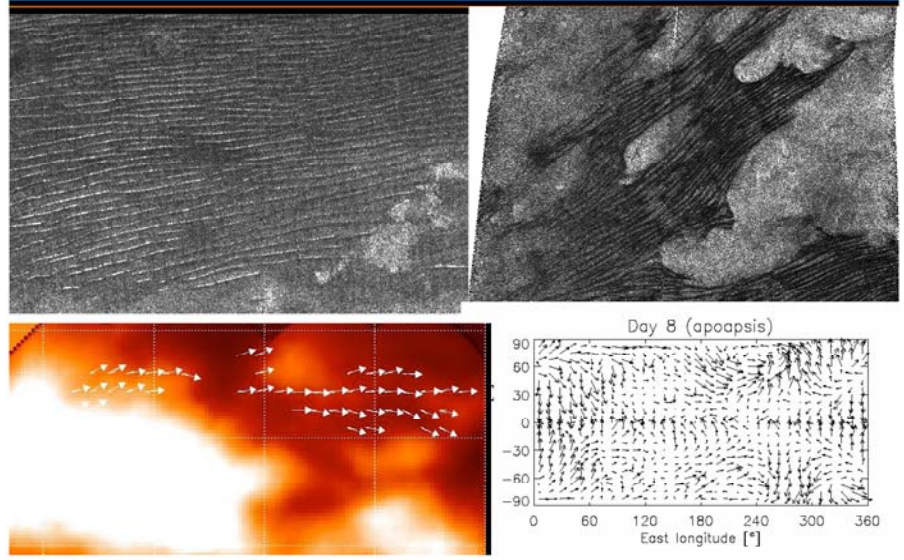




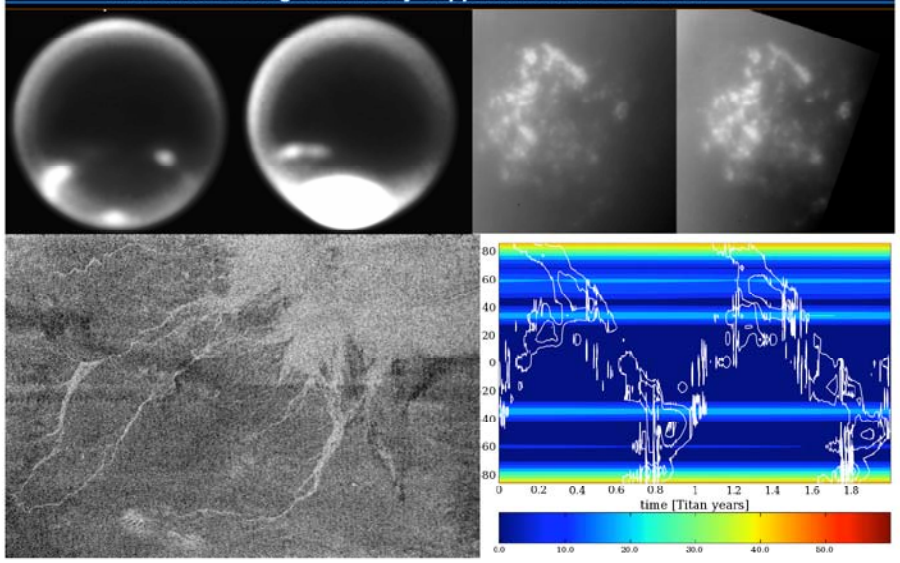
Polar Lakes, Seas and Channels. Morphologic evidence of changing inventory of liquid. Role of subsurface liquids? Seasonal variations? Geological variations? Tides?



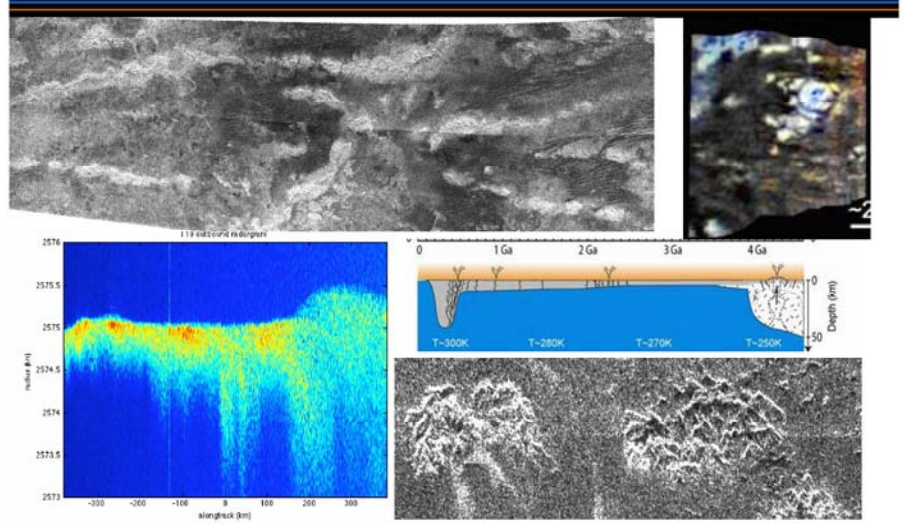
Massive fields of giant organic dunes cover ~20% of the planet. Linear dunes shaped by topographically modified tidal winds? What is the sand, why are dunes found only at low latitudes ?



Titan is to Earth's hydrological cycle what Venus is to the Greenhouse effect – taken to extremes. Seasonally-dependent weather, but typically long drought between heavy rainstorms. Is methane being continually supplied from the interior?



Ice crust atop water-ammonia ocean. Emerging evidence of mountain belts and cryovolcanism.



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)	Aeronomy, Chemistry
Rosaly Lopes (JPL)	Geology (volcanism)
Scot Rafkin (SwRI)	Meteorology
Devon Burr (SETI)	Geology (fluvial)
F. Mike Flasar (NASA GSFC)	Climate, Thermal IR remote sensing
Andrew Steele (CIW)	Astrobiology, In-Situ Chemistry
Gerald Schubert (UCLA)	Geophysics, Atmospheric dynamics
Kevin Baines (JPL)	Atmospheres, Near IR Spectroscopy
Bill Kurth (U. Iowa)	Magnetosphere, Radio methods
Jonathan Lunine (U. Arizona)	Surface/atmosphere. Origins
Dale Cruikshank (NASA Ames)	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 Rappaport, 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

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

OBJECTIVE 1: Titan's Origin and Evolution

What is the original composition of rocks and ices that formed Titan and what is the extent of differentiation and geochemical processing that has occurred since the initial 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.

OBJECTIVE 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 complex interplay of the geology, hydrology, meteorology, and aeronomy present in the Titan system? (Investigations NOT prioritized)

Investigation 1

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

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.

OBJECTIVE 3: Organics and Life's Origins

What is the extent of, and what are the processes responsible for the complexity of Titan's organic chemistry in the atmosphere, within its lakes, on its surface, and in its putative subsurface water ocean and how does this inventory differ from known abiotic organic material in meteorites and therefore contribute to our understanding of the organic chemistry and the possible origin of life in the Soar System?

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

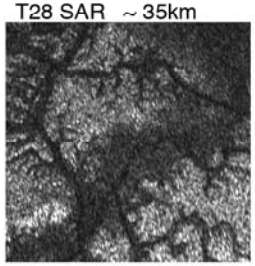
Determine if chemical modification of organics on the surface may have occurred, in particular possible hydrolysis of tholins by transient liquid water into pyrimidines, amino acids, e.g.via impact melt or cryovolcanic deposits.

Investigation 4

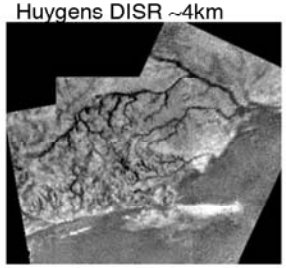
Determine the role of abiotic/biotic synthesis of organics on or near the surface as the result of reactions on mineral surfaces and/or as the result of interior processes, such as serpentinization and condensation of hot gases in the colder atmosphere.

Orbiter – Balloon – Lander : A Multiscale Architecture for Exploring a Diverse Multiscale Surface

T28 SAR ~ 35km



Huygens DISR ~4km



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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.

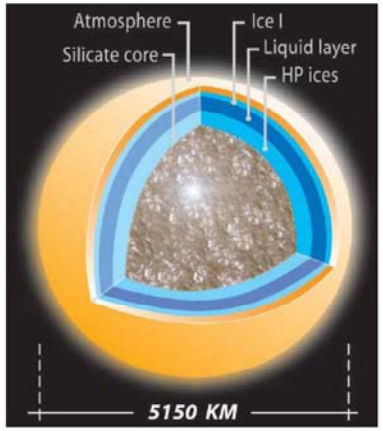
Atmosphere (via optical scattering and enforced high altitude of orbiter) makes mid-scale (~1-10m resolution) difficult to acquire e.g. by HiRISE-type instrument. Lander would not see wide diversity of terrain during descent.

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.

Orbiter – Balloon – Lander Synergy : The Whole is Greater than the Sum of the Parts

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

E.g. Titan's interior structure

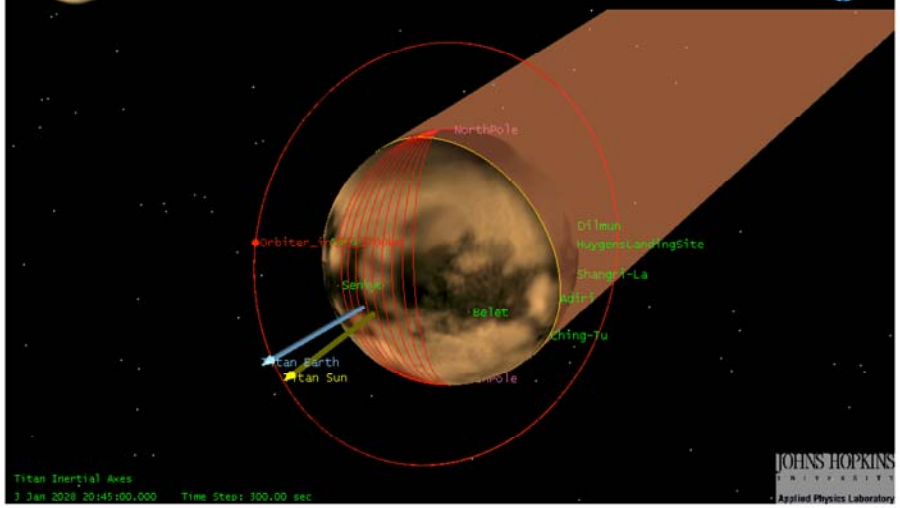


Orbiter can measure gravity field and topography, and changes therein due to tidal forcing. Orbiter can measure external magnetic field and ionosphere forcing.

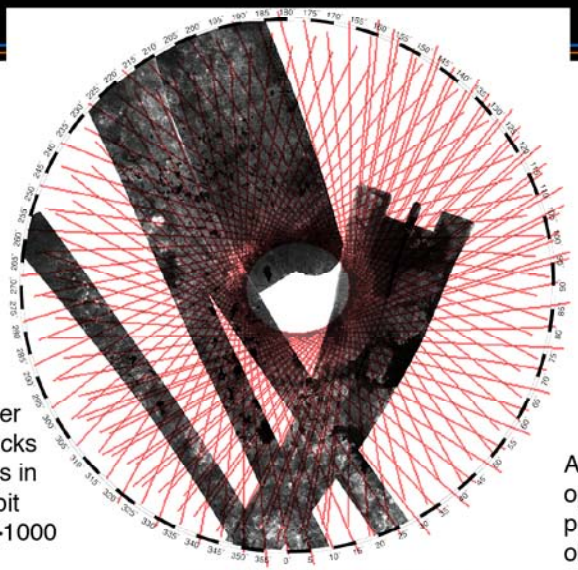
Simultaneously, lander magnetic measurements can isolate induced response from external forcing. Also detects seismic activity excited by tides and the crustal response.

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

1700km Mapping Orbit (tbc)



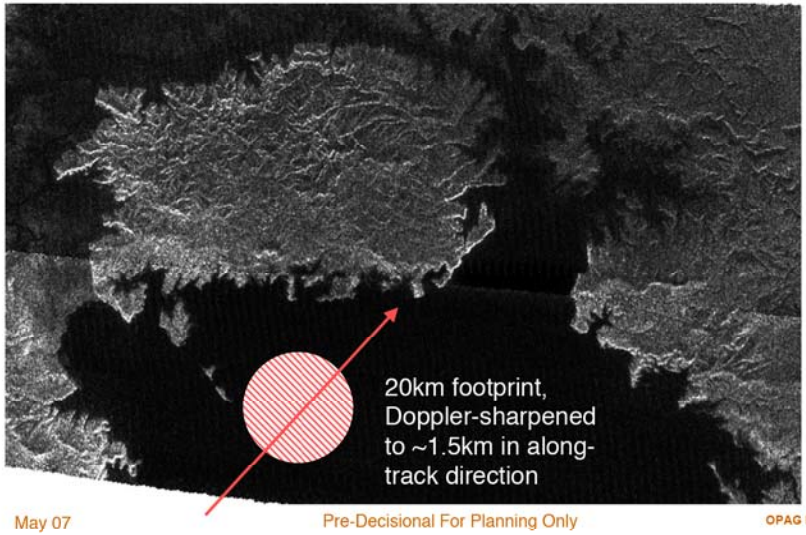
Example – Altimetry Coverage



Titan orbiter Groundtracks for 20 days in 85 deg orbit (mission >1000 days!)

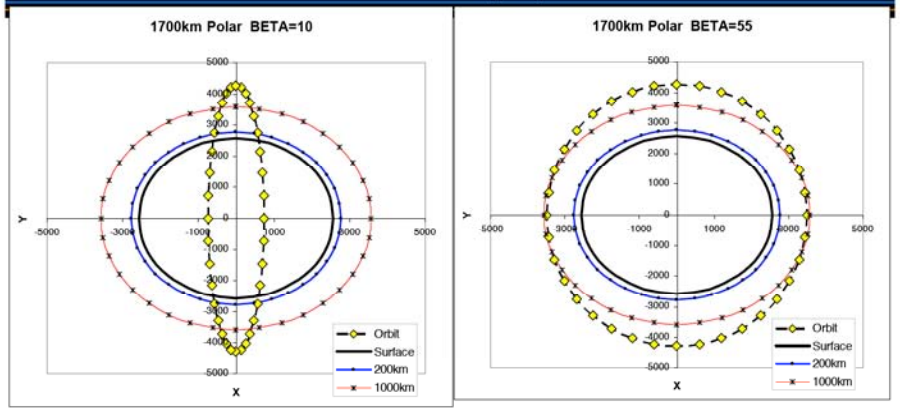
Ample crossover opportunities for precision, observation of tides

Altimetry over Polar Seas



Science Opportunities from Orbit Evolution (primarily due to Saturn perturbation)

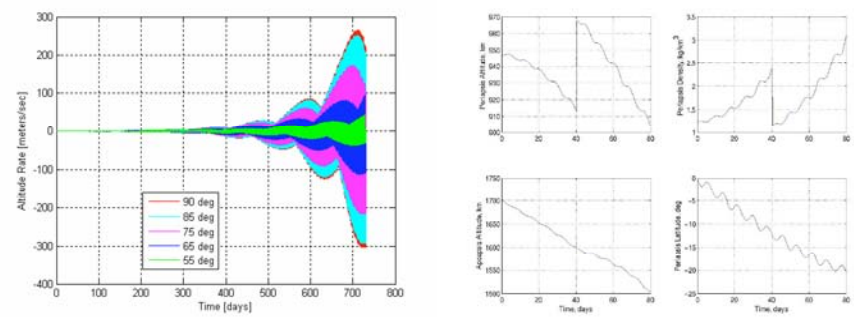
Trades still being explored



South pole aerocapture 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) occultation of ionospheric peak but does not reach lower atmosphere.

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



Minimum permissible altitude is flexible. Strawman plan is for ~80 days of aerosampling orbits (providing several Titan days, with 20 degrees of periapsis latitude sweep). ~20 m/s ΔV.

Measurement	Cassini Nominal Mission (through July 2008)	Cassini Extended Mission (2008-2010)	Flagship Mission
Radar Surface Mapping	~25% coverage at 300m-1 km SAR resolution. Few per cent at 1-2km Global coverage at 20+ km resolution (Magellan ~100% at 100m)	~35% coverage by high-resolution SAR, ~10% lower-res (1-2km) (~30 GB)	100% at 100m
Near-IR Surface Mapping	<1% coverage at better than 2km/pixel Near-global coverage at 10-20km. Spectral Resolution $\lambda/\Delta\lambda$~200	Few % at 2km/pixel ? (~80 GB)	90%+ at 100m (depending on season)
Interior Structure	J2. C22.	Tidal love number k2 to +/- 0.1 (interior ocean ~0.2 ; without ~0.0)	Coefficients to order 5 or 6. Robust k2
Topography	~10,000km of altimetry tracks, ~20km footprint, 50m resolution (MOLA ~ 20 million km, 200m footprint, 1m resolution)	~15,000km (3 GB?)	~5,000,000km at 20m or better (plus lake tides to 1.5m)
Troposphere	~10 radio occultations	~14 radio occultations	Microwave soundings plus ~several hundred occultations
Stratosphere	~10 radio occultations. ~4 solar and stellar occultations. Few hundred (?) hours of mid/far IR spectral observation (yielding composition maps etc.)	~14 radio occultations, ~15 solar and stellar occs. Few more hundred hrs IR	Microwave, mid/far IR, stellar and radio occultations
Ionosphere	~30 profiles. Some neutrals-only. Total ~100 mins ram-pointed 950<2500km	~50 profiles. ~150 mins	Hundreds of deep samplings. >3 years below 2500km
Magnetic Field	~40 magnetic field observations above the ionosphere – one or two perhaps below peak	~ 70 observations as left. 1 low observation likely to be below ion peak	~5000 orbits
Total Time within 10,000km	~40 hours ?	~ 60 hours ?	~ 3-4 yrs (~30,000 hrs)

Orbiter – Balloon – Lander : A Multiscale Architecture for Exploring a Diverse Multiscale Surface

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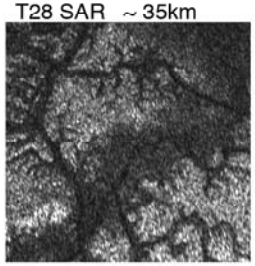

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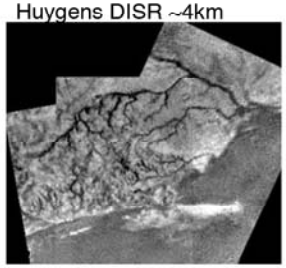

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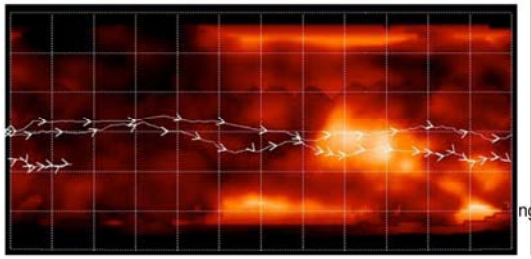
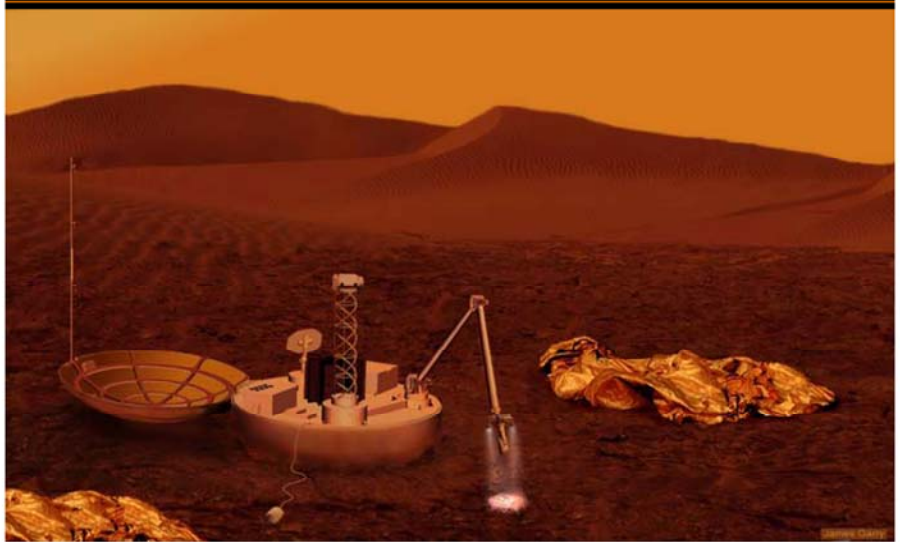
An aerial platform like a balloon bridges the scale gap – wide coverage at high resolution. Reduces risk for future lander missions by characterizing terrain hazards.

Hot-air balloon ('Montgolfière') can make several times round-the-world flights.

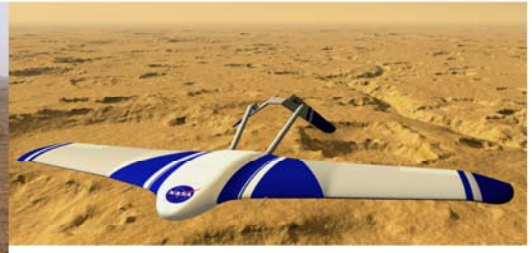
Exploit (predictable?) tidal winds to direct drift…



Titan Lander (artist's concept only – not a design!) meets surface chemistry/astrobiology objectives, plus long-term (1 yr) seismic/magnetic and meteorological monitoring.



Lander-Launched Micro-UAV for Titan Science



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.

~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 5x slower)

Possible implementation as competed student experiment ?

Science Trace Matrix (still being iterated for consistency with objectives document) guides architecture & payload selection

(Payloads are strawman only – not only set that meets goals)