Instrument Constraints and Necessary Science Goals

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Instruments identified from Titan Studies and Constraints on Potential Future in situ Instruments
Titan Studies

• Many studies conducted over the last decade
• Each study has built upon the last
• NASA appointed Science Definition Teams for the last two studies
• Titan Saturn System Mission is the latest Flagship mission - 2008
• Decadal Survey Study on Titan Submersible conducted 2010
Titan has a complex organic factory in the atmosphere which deposits the products on the surface.
In Situ Measurements

• Lakes
• Atmosphere
• Dunes
  – Physical properties
  – Geophysical properties
  – Chemical composition
  – Geological measurements
  – Etc.
High Priority Science Questions
(established by joint science definition team)

• Goal A: Explore Titan, an Earth-Like System
  – What is Titan’s climate like?
  – How does it change with time?
  – What can it teach us about Earth’s climate?

• Goal B: Examine Titan’s Organic Inventory—A Path to Prebiological Molecules
  – What kind of organic chemistry goes in Titan’s atmosphere, in its lakes and seas, and underground?
  – Is the chemistry at the surface mimicking the steps that led to life on Earth?
  – Is there an exotic kind of life—organic but totally different from Earth’s—in the methane/ethane lakes and seas?

• Goal C: Explore Enceladus and Saturn’s magnetosphere—clues to Titan’s origin and evolution
  – What is the source of geysers on Enceladus?
  – Is there life in the source water of the geysers?

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A short-lived Probe/Lander with liquid surface package would land in northern lake

Dedicated Titan orbiter would deliver the in situ elements and also be used for data relay

A hot-air balloon (Titan montgolfière) would float at 10 km above the surface around the equator with altitude control

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## Model instruments in the planning payload on the montgolfière

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
<th>Science Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIS</td>
<td>Balloon Imaging Spectrometer (1–5.6 µm).</td>
<td>Mapping for troposphere and surface composition at 2.5 m resolution</td>
</tr>
<tr>
<td>VISTA-B</td>
<td>Visual Imaging System with two wide angle stereo cameras and one narrow angle camera</td>
<td>Detailed geomorphology at 1 m resolution</td>
</tr>
<tr>
<td>ASI/MET</td>
<td>Atmospheric Structure Instrument and Meteorological Package</td>
<td>Record atmosphere characteristics and determine wind velocities in the equatorial troposphere</td>
</tr>
<tr>
<td>TEEP-B</td>
<td>Titan Electric Environment Package</td>
<td>Measure electric field in the troposphere (0–10 kHz) and determine connection with weather</td>
</tr>
<tr>
<td>TRS</td>
<td>&gt;150 MHz radar sounder</td>
<td>Detection of shallow reservoirs of hydrocarbons, depth of icy crust and better than 10 m resolution stratigraphic of geological features</td>
</tr>
<tr>
<td>TMCA</td>
<td>1–600 Da Mass spectrometer</td>
<td>Analysis of aerosols and determination of noble gases concentration and ethane/methane ratios in the troposphere</td>
</tr>
<tr>
<td>MAG</td>
<td>Magnetometer</td>
<td>Separate internal and external sources of the field and determine whether Titan has an intrinsic and/or induced magnetic field</td>
</tr>
<tr>
<td>MRST</td>
<td>Radio Science using spacecraft telecom system</td>
<td>Winds from tracking the montgolfière</td>
</tr>
</tbody>
</table>

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# Model instruments in the planning payload on the lander

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<tr>
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<tr>
<td>TLCA</td>
<td>Titan Lander Chemical Analyzer with 2-dimensional gas chromatographic columns and TOF mass spectrometer. Dedicated isotope mass spectrometer.</td>
<td>Perform isotopic measurements, determination of the amount of noble gases and analysis of complex organic molecules up to 10,000 Da.</td>
</tr>
<tr>
<td>TiPI</td>
<td>Titan Probe Imager using Saturn shine and a lamp</td>
<td>Provide context images and views of the lake surface</td>
</tr>
<tr>
<td>ASI/MET-TEEP</td>
<td>Atmospheric Structure Instrument and Meteorological Package including electric measurements</td>
<td>Characterize the atmosphere during the descent and at the surface of the lake and to reconstruct the trajectory of the lander during the descent</td>
</tr>
<tr>
<td>SPP</td>
<td>Surface properties package</td>
<td>Characterize the physical properties of the liquid, depth of the lake and the magnetic signal at the landing site</td>
</tr>
<tr>
<td>LRST</td>
<td>Radio Science using spacecraft telecom system</td>
<td>Winds from tracking the lander</td>
</tr>
</tbody>
</table>
As stated in the initial Study Questionnaire document:

The purpose of the study is to determine the technical feasibility and cost of a lake probe mission both as an element of a future Titan flagship mission and as a standalone New Frontiers mission. A secondary objective is to identify the technology developments required to make such a mission possible in the next decade.
Science Goals

SGa: To understand the formation and evolution of Titan and its atmosphere

SGb: To study the lake-atmosphere interaction in order to determine the role of Titan’s lakes in the methane cycle

SGc: To study the target lake as a laboratory for pre-biotic organic chemistry in both water (or NH3 enriched water) solutions and non-water solvents

SGd: To understand if Titan has an interior ocean
Titan Lake Probe

Science Instrumentation

- **SGa: Atmospheric Evolution**
  - Lake Composition Analyzer (LCA)
- **SGb: Lake/atmosphere interaction**
  - Other Properties (OP)
  - Meteorological Package (MP)
- **SGc: Lake chemistry**
  - Lake Composition Analyzer (LCA)
  - Lake Properties Package (LPP)
  - Other Properties (OP)
- **SGd: Interior structure**
  - Lake Properties Package (LPP)

- **OP**
  - Dielectric constant
  - Speed of sound sensor
  - Temperature sensor
  - Pressure sensor
  - Refractive index
  - Turbidimeter
  - Densitometer
  - Accelerometer

- **LCA**
  - GC x GC MS
  - FTIR spectrometer

- **LPP**
  - GC x GC MS
  - Temperature sensor
  - Refractive index
  - Speed of Sound sensor
  - Turbidimeter
  - Permittivity meter
  - Echo sounder
  - Refractive index
  - Accelerometer
  - Magnetometer

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Ways to think of translating the science to instruments
Traceability Matrix is the road from goals to instruments

<table>
<thead>
<tr>
<th>MISSION GOALS</th>
<th>SCIENCE OBJECTIVES</th>
<th>SCIENCE INVESTIGATIONS</th>
<th>REQUIRED MEASUREMENTS/DETERMINATIONS</th>
<th>PLANNING MEASUREMENT APPROACH</th>
<th>PLAN INSTR.</th>
<th>DATA PRODUCTS</th>
<th>MISSION REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal A: How does Titan function as a system; to what extent are there similarities and differences with Earth and other solar system bodies?</td>
<td>O8: Determine the state of internal differentiation, whether Titan has a metal core and an intrinsic magnetic field, and constrain the crustal expression of thermal evolution of Titan’s interior.</td>
<td>I1: Map interior structure of Titan.</td>
<td>M1: Global gravity field to at least degree six. Doppler accurate to 50 μm/s with 60 s integration periods.</td>
<td>A1: Relative velocity between the spacecraft and ground station determined from Doppler tracking with an accuracy up to 50 μm/s with 60 s integration periods (Ka-band link stability $10^{-12}$ after all calibrations including accelerometer for non-gravitational forces).</td>
<td>RSA</td>
<td>Coefficients of spherical harmonic expansion of gravity field for further analysis and interpretation in terms of internal structure. The static degree-two gravity field will lead to constraints on the global density structure of the interior. Time variations of the degree-two field will lead to investigating the tidal response of the satellite and constraining its viscoelastic structure and crustal structure.</td>
<td>Prefer mapping phase orbit height of 1500 km</td>
</tr>
<tr>
<td>Goal B: To what level of complexity has prebiotic chemistry evolved in the Titan system?</td>
<td>O1: Determine the processes leading to formation of complex organics in the Titan atmosphere and their deposition on the surface.</td>
<td>I1: Assay the speciation and abundances of atmospheric trace molecular constituents.</td>
<td>M1: Abundances of monomer and polymer organic species and inorganic species with a detectability of &lt;1 ppb and an accuracy of better than 3% over an altitude range from 30–1500 km.</td>
<td>A1: Passive Thermal-infrared Fourier Transform spectrometry, in the region from 30–1400 wavenumbers (7–333 μm); resolution 0.1–3.0 wavenumber.</td>
<td>TIRS</td>
<td>Thermal and compositional maps and profiles of the stratosphere (50–450 km) with altitude and latitude.</td>
<td>Limb and nadir viewing on polar orbit, rotation in</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>A2: Submillimeter sounding at 540–640 GHz with resolution 300 khz and 10% precision in retrieved abundances.</td>
<td>SMS</td>
<td>All/lat maps of selected organics</td>
<td>Limb viewing from polar orbit, in-track and off-track orientation</td>
</tr>
</tbody>
</table>
The sample preselected from Cassini based on geology and spectra of organics

- Monomers (enantiomers) Elemental analysis
  - Excessive O (>> 10 ppm)
    - Carboxylic acid
    - Amino acids
    - Imides, Nucl. bases
    - Special arrangement (deviation from statistical)
      - Even vs. odd, etc.
      - Enantio-excess
      - Get really excited
  - Low O (10 ppm)
    - Nitriles, Amines, PAH
    - Azo-heterocycles
    - Special arrangement (deviation from statistical)
      - Even vs. odd, etc.
      - Enantio-excess
      - Get modestly excited
  - Metals (catalyst for polyacetylene)
    - No pattern
      - Abundances as from Titan photochemistry
      - Get excited
  - Chirality (diastereomers)
    - Deviation from random polymerization?
      - Yes
        - Analyze Potential for encoding? Potential for catalysis?
          - No
            - Quit polymer branch
      - No
        - Sub-units go to monomers
  - Oligomers (extraction)
    - Get excited
    - Slow down
    - Quit entirely (go back to Mars)

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Capability for IR/Vis/UV spectroscopy and fluorescence studies should be provided at several points in the analysis scheme.

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Constraints on Titan in situ instrument systems

• Low Mass
  – Cryogenic mechanisms
  – Electronics that can survive Titan ambient (~94K)
  – Dual purpose structures
  – Reduction in harnessing
  – Etc.

• Low Power

• Low volume

• High resolution

• High sensitivity

• Provide representative data (operations /miniaturization)

• Autonomy required

• High reliability

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Constraints on Titan In situ instrument systems (Continued)

• Long lifetime (could be as long as 15 years including cruise)
• Manageable data rate
• Easily calibrated
• Must have compatible sample handling mechanisms
• Able to withstand extreme environments
• Able to withstand launch loads
• Accommodates Planetary Protection and Contamination Control requirements
• Space-flight qualifiable
• Thermally stable
• May have to withstand thermal cycling
• Flexibility
• KISS

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