Instruments for *In Situ* Titan Missions

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Topics

***In situ* Missions to Titan:**

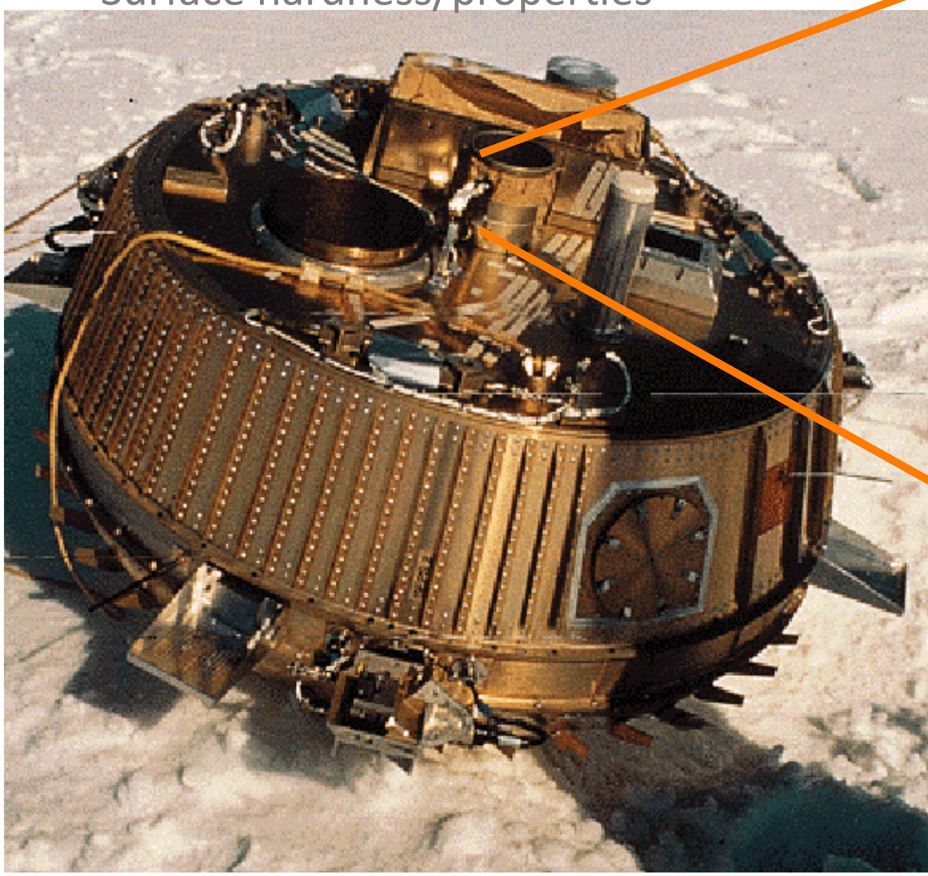
- Present
  - Cassini-Huygens Probe
- Future
  - PS Decadal Survey moved flagship mission to Titan into the next decade
  - However, one of the Step 1 Discovery Proposals (Titan Mare Explorer - TiME) has been selected for further study
  - Other concepts also viable if NASA supplies GFE

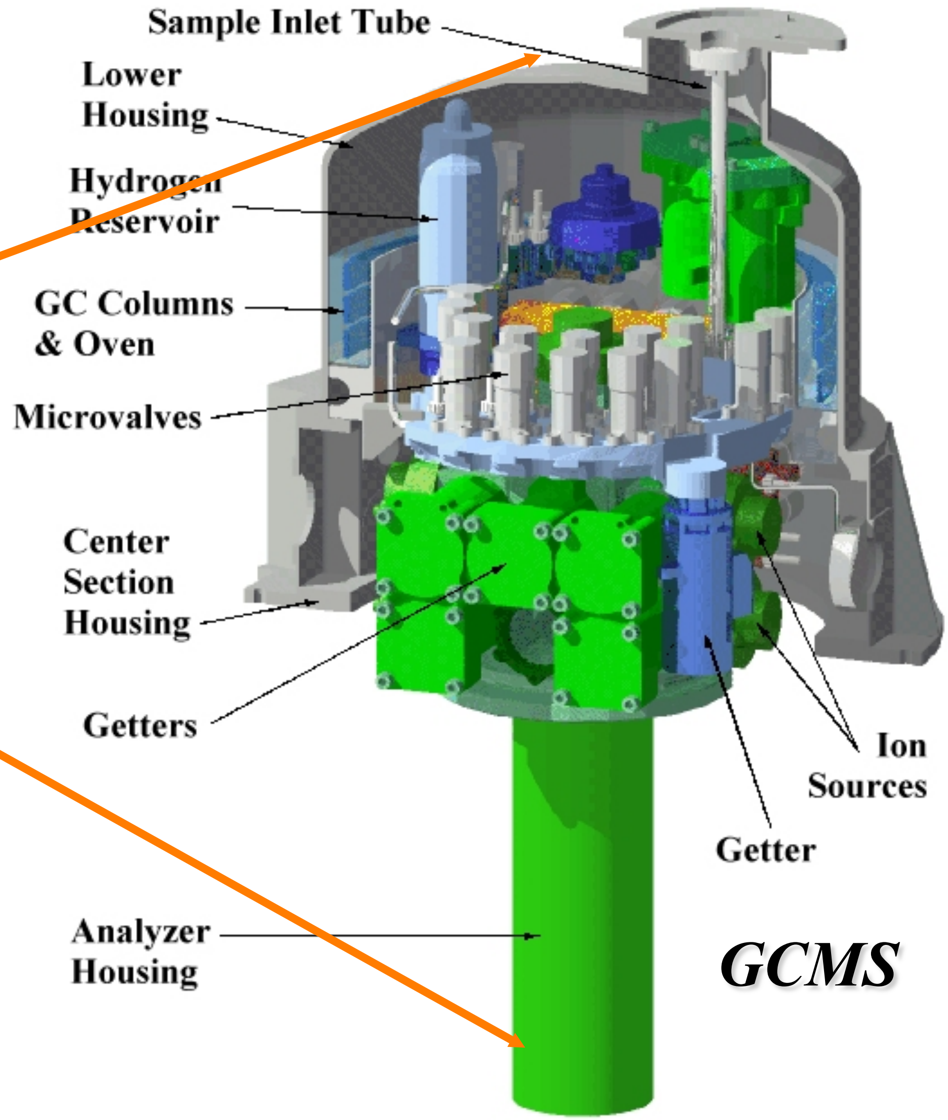
Focus of this presentation:

- What we have done - existing Huygens *in situ* instruments
- What can be done in the near term with existing technology
- What instruments do we need for flagship missions
- Review Titan in situ instrument requirements
- What technologies are needed for in situ instruments in a comprehensive future mission.

What we did well – Huygens Probe Instruments

- In-situ T,P, electric fields
- Wind speeds
- Cloud properties
- Images
- Near-IR spectra of surface
- In-situ chemical composition (gases, aerosols)
- Surface hardness/properties

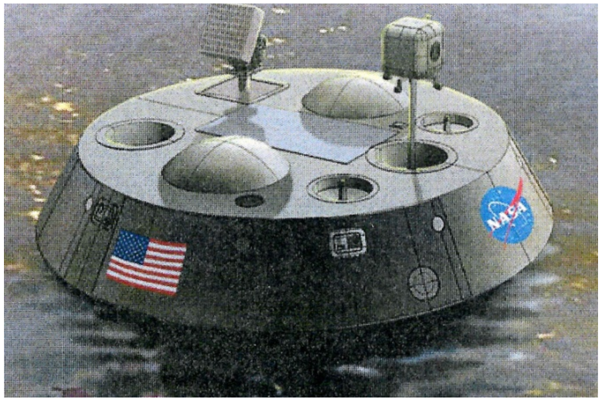




Present In situ Discovery Mission Concept

Titan Mare Explorer (TiME)

TiME: Titan Mare Explorer
PI: Ellen Stofan



<u>Mission & Science Team:</u>

PI: Ellen Stofan, Proxemy
Project Mgmt: APL
S/C: LM
Ops: LM, JPL (nav)
Payload: APL, GSFC, MSSS
Deputy PI: J. Lunine, UA
Project Scientist: R. Lorenz, APL

<u>Mission</u>:

Lander msn to Titan's *Ligeia Mare* methane-ethane polar sea, 96 days on surface

<u>Goals</u>:

- Understand Titan's methane cycle through study of a Titan sea.
- Investigate Titan's history & explore the limits of life

<u>Instruments:</u>

- Meteorology & physical properties (MP3)
- Mass Spec for Lake Chemistry (NMS),
- Descent and Surface Imaging Cameras

<u>Efficient Trajectory:</u>

- Launch 2016
- Cruise 7.5 years (EGA, JGA)
- Entry 2023

<u>Mission Features:</u>

- Focused science objectives
- High-heritage instruments
- Simple cruise, no flyby science
- Simple surface operations
- ASRGs, launch vehicle are GFE

TiME Science Objectives

•***Science Objective 1.*** Determine the chemistry of seas to constrain Titan's methane cycle, look for patterns in the abundance of constituents in the liquids and analyze noble gases.
Instruments: Mass Spectrometer (MS), Meteorology and Physical Properties Package (MP3).

•***Science Objective 2.*** Determine the depth of the Titan sea to determine sea volumes, and thus, organic inventory.
Instrument: Meteorology and Physical Properties Package (Sonar) (MP3).

•***Science Objective 3.*** Constrain lacustrine processes on Titan by characterizing physical properties of sea liquids and how they vary with depth.
Instrument: Meteorology and Physical Properties Package (MP3).

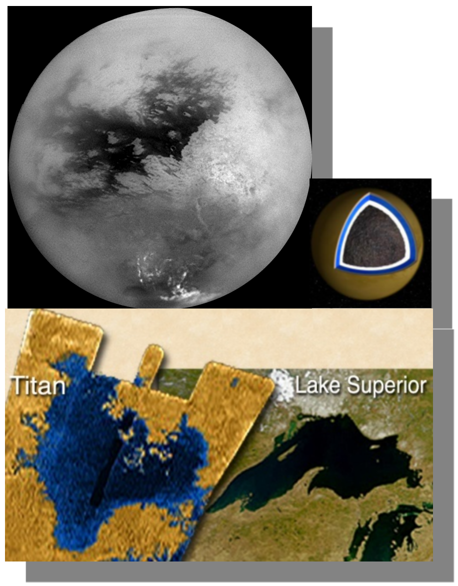
•***Science Objective 4.*** Determine how the local meteorology over the seas ties to the global cycling of methane on seasonal and longer timescales.
Instrument: Meteorology and Physical Properties Package (MP3).

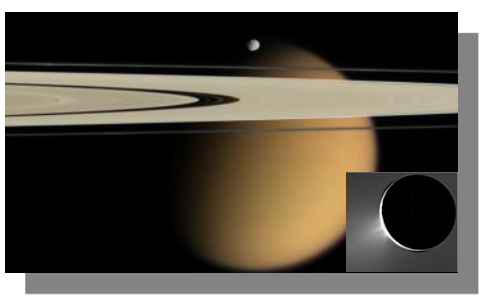
•***Science Objective 5.*** Analyze the nature of the sea surface and if possible, shorelines, to constrain physical properties of sea liquids and better understand origin, evolution, and subsurface methane/ethane hydrology of Titan lakes and seas.
Instrument: Descent and Surface Imagers (DI, SI).

Future In situ Flagship Mission Concept

Titan Saturn System Mission

A proposed future flagship mission concept derives from science goals that address a wide range of planetary science disciplines





Cassini Imaging Team /ISS/ PL/NASA

- Goal A: Explore Titan, an Earth-Like System

  How does Titan function as a system? How are the similarities and differences with Earth, and other solar system bodies, a result of the interplay of the geology, hydrology, meteorology, and aeronomy present in the Titan system?

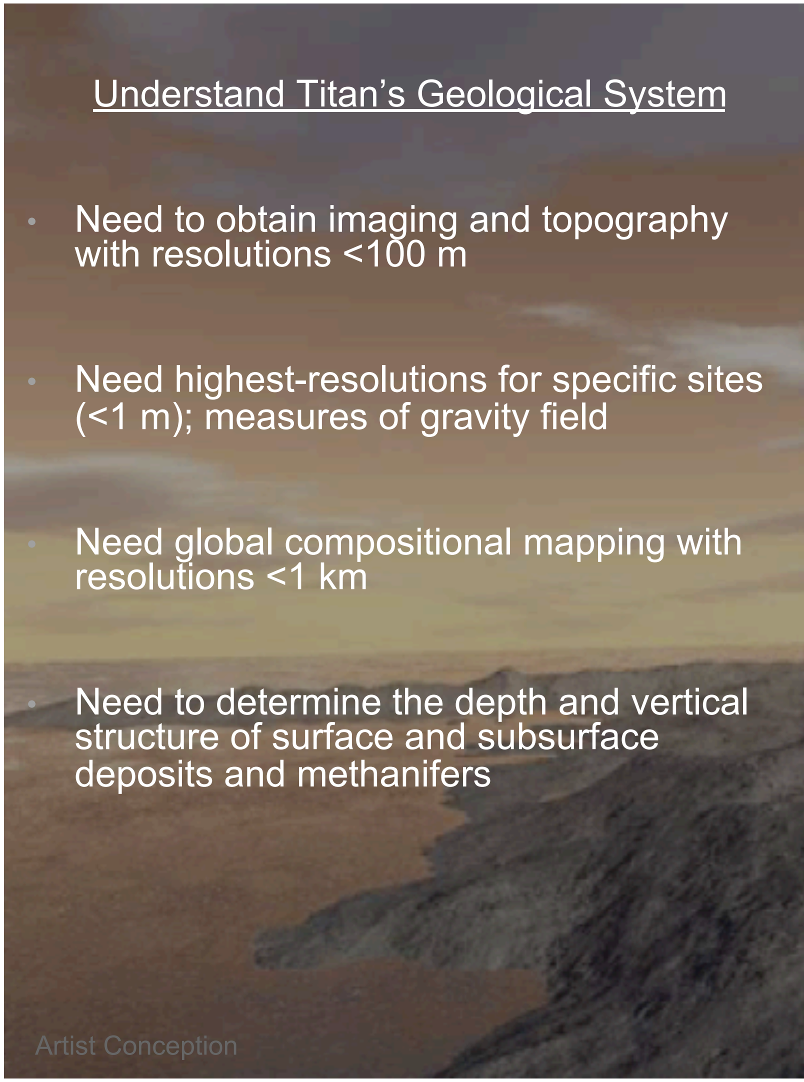
- Goal B: Examine Titan's Organic Inventory—A Path to Prebiological Molecules

  What is 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 origin of life in the Solar System?

- Goal C: Explore Enceladus and Saturn's magnetosphere— clues to Titan's origin and evolution

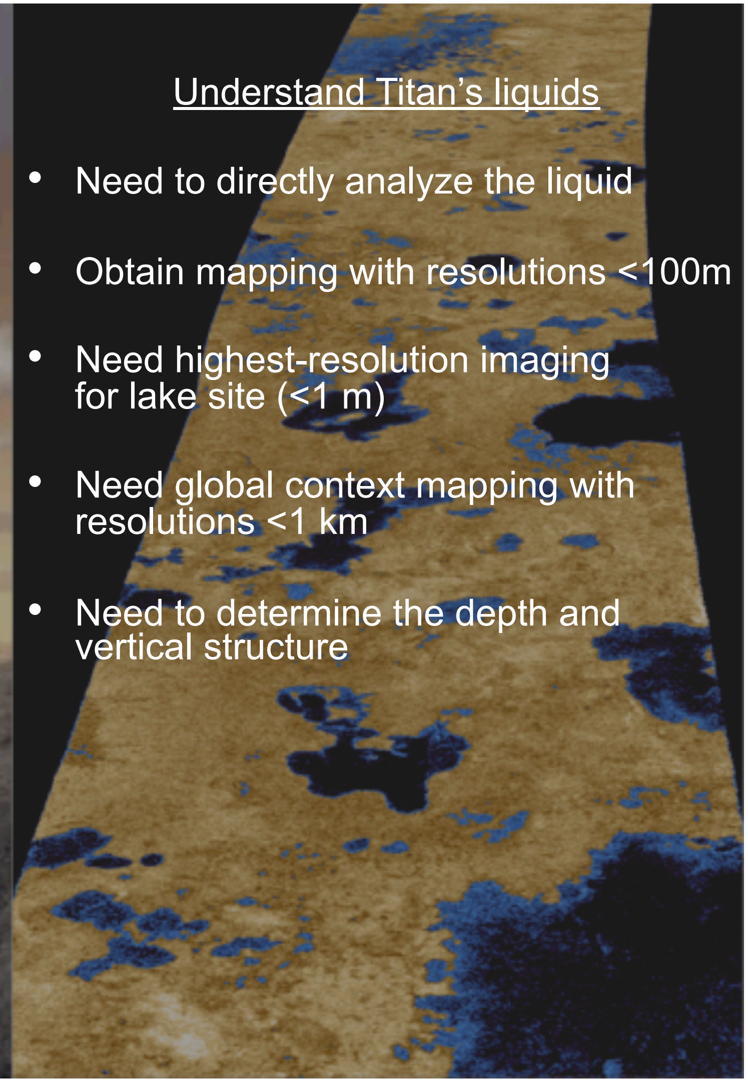
  What is the exchange of energy and material with the Saturn magnetosphere and solar wind? What is the source of geysers on Enceladus? Does complex chemistry occur in the geyser source?

Some examples of science requirements on Titan's surface



Understand Titan's Geological System

- Need to obtain imaging and topography with resolutions <100 m
- Need highest-resolutions for specific sites (<1 m); measures of gravity field
- Need global compositional mapping with resolutions <1 km
- Need to determine the depth and vertical structure of surface and subsurface deposits and methanifers



Understand Titan's liquids

- Need to directly analyze the liquid
- Obtain mapping with resolutions <100m
- Need highest-resolution imaging for lake site (<1 m)
- Need global context mapping with resolutions <1 km
- Need to determine the depth and vertical structure

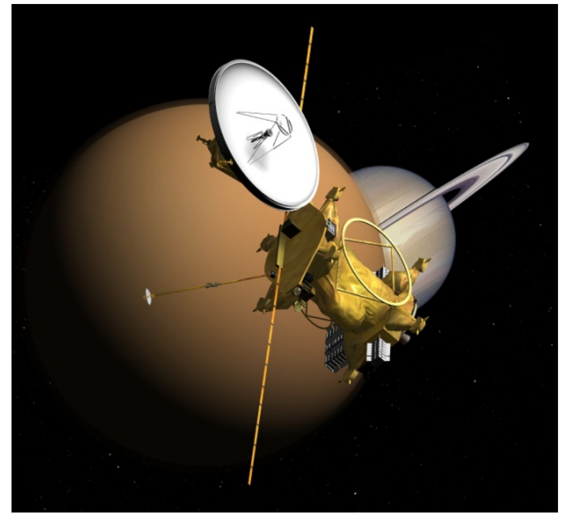
NASA/JPL

Proposed baseline mission architecture would combine a remote sensing mission with detailed *in situ* measurements

Combining

- An orbiter (first of Saturn, with Enceladus flybys, then dedicated to Titan),
- A hot-air balloon/montgolfière,
- A North-pole lake-landing probe

Dedicated Titan Orbiter would also be used for relay



National Aeronautics and Space Administration

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

A short-lived probe/ lander with chemical analysis package would land in a northern lake

Conceptual designs
Artist's concepts NASA/JPL

Model instruments in the planning payload on the montgolfière

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

Model instruments in the planning payload on the lander

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

In Situ Instrument Constraints and Emerging Technologies

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

Constraints on Titan In situ instrument systems

- 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"

Highlights from Keck Institute for Space Studies Workshops

1. Solution State Nuclear Magnetic Resonance is a perfect instrument for non-destructive identification of organic functional groups - it works better under Titan conditions, esp. in the lakes.

2. Automated microfluidic sample processing unit can provide the ability to perform complex movement of samples between instruments as well as provide separations and extractions.

3. Advances in high resolution, high sensitivity Mass Spectrometry can simplify the overall complexity of a chemical analysis suite by eliminating the need for complicated gas chromatography.

4. Physical measurements of aerosols in Titan's atmosphere are possible - may differ from those in common use in Earth atmosphere measurements.

5. A single Seismometer is possible for studying the interior and dynamic surface processes of Titan.

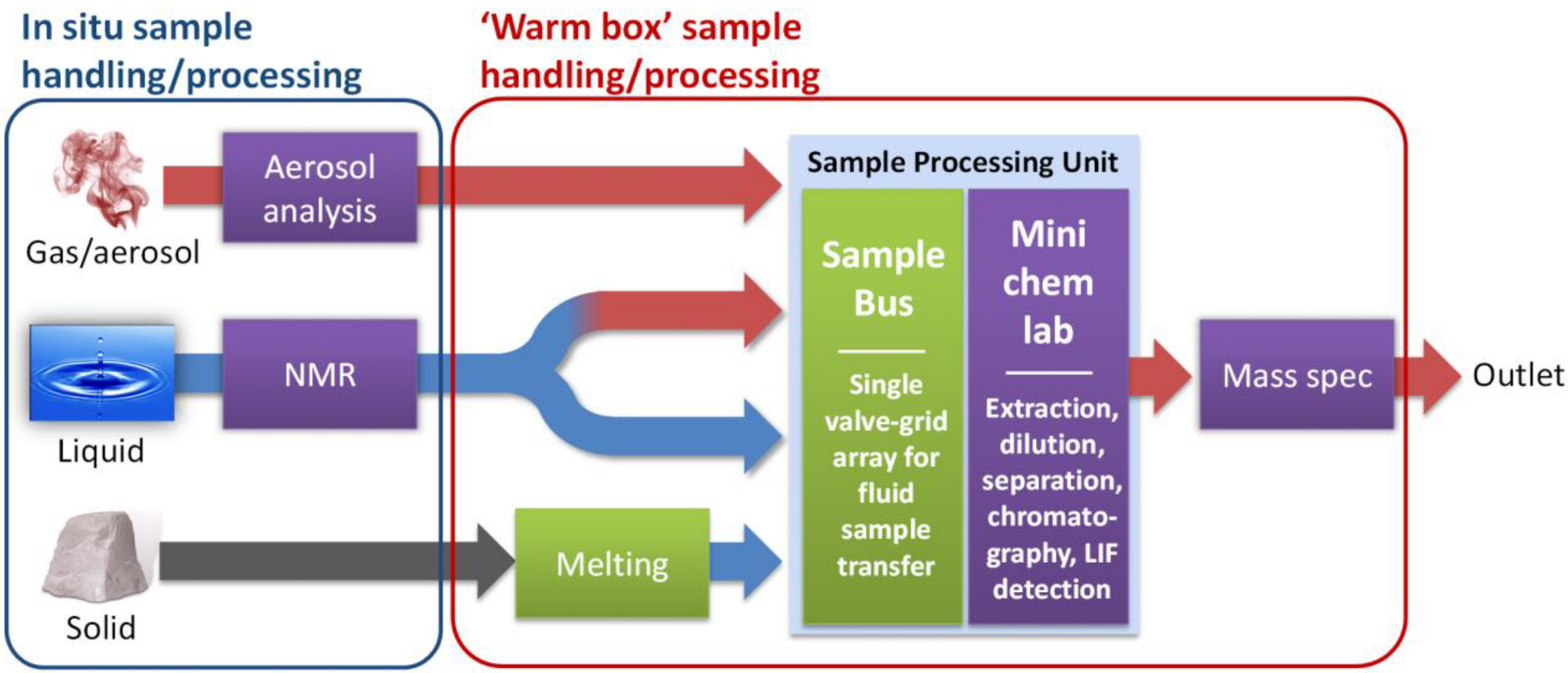
6. Designing electronics that perform well at 95K is possible; progress has been made in recent years, but developing low power cryogenic circuits that meet the demands of many of the in situ instruments is still a work in progress.

7. Light weight power sources continue to be a major challenge for long-lived, landed missions to Titan. Development of RHU-battery combination have a lot of potential for in situ instruments.

8. Packaging materials for long-lived, low temperature in situ Titan missions are available, but design of substrates and the characterization and testing of novel materials is critical.

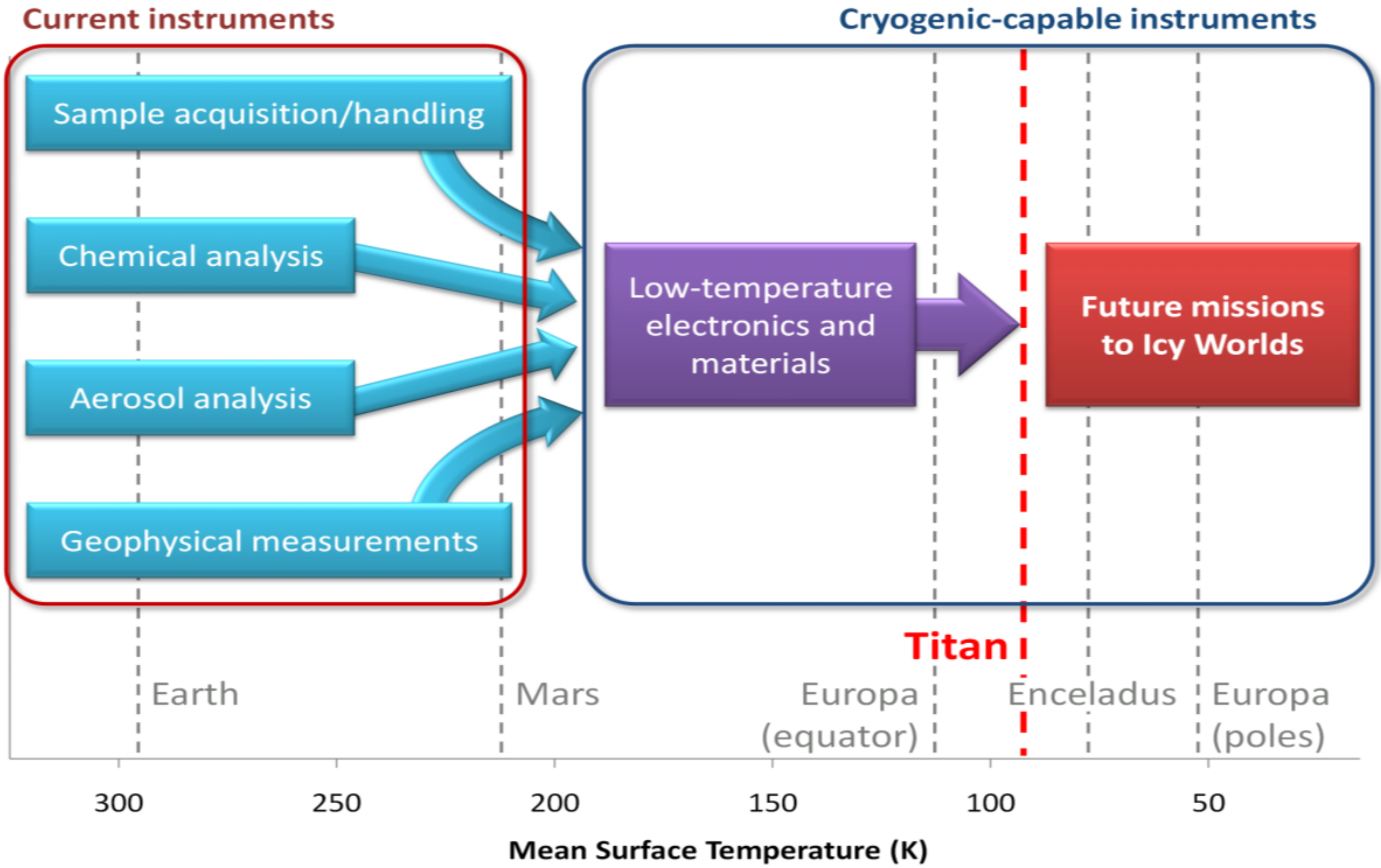
A copy of the report: http://kiss.caltech.edu/workshops/titan2010/index.html.

Within 5 years



Flow chart of multiphase sample handling (green) and in situ chemical analysis (violet). Gas/vapor phases are shown in red arrows, liquid in blue and solid in gray. Aerosol analysis and solution state NMR can both be performed in the ambient Titan environment prior to entry into the lander 'warm box'. Sample transfer between downstream instruments (mini chem lab and mass spec) will be performed using an automated reprogrammable valve array (sample bus), which handles both gas and liquid phases so volatiles from vaporized liquid samples (forked arrow) are also captured. Abbreviations: nuclear magnetic resonance spectroscopy (NMR), laser-induced fluorescence (LIF).

Within 10 years



Goal of KISS study in terms of electronics and materials. All current instruments required for (1) sample acquisition and handling, (2) chemical analysis, (3) aerosol analysis and (4) geophysical measurements which have been designed to operate at Earth or Mars ambient temperatures, must be adapted to operate in the cryogenic conditions of the Titan environment (red dashed line). This will also enable future missions to other icy worlds such as Europa and Enceladus.

Summary

- We know how to make basic measurements that answer focused scientific questions
- More complex, comprehensive scientific questions require more complex comprehensive instrumentation
- Technically, these instruments can be developed within the decade
- Development of technologies for in situ Titan instruments extends the capabilities of all *in situ* planetary missions
- Development of smaller, light weight, low power instruments means more instruments can be placed on the lander/balloon thereby doing more scientific measurements – and learning more!