Titan is the 2nd-largest satellite in the solar system, larger than planet Mercury and is unique in having a thick nitrogen atmosphere. Like other large icy satellites, it likely has a silicate core, and a layer of liquid water (preserved by ammonia acting as an antifreeze) a few tens of km beneath its organic-rich icy surface which has been modified by impact, tectonics and cryovolcanism.

Titan’s Landscape is being actively modified by Earth-like processes, forming sand dunes, river channels and lakes.

- Giant organic sand dunes, 10’s km long, 150m high, near Titan’s Equator (Cassini RADAR)
- (dry) river channels at midlatitudes
- Lake and river channel near North

Cassini RADAR images of impact crater and tectonic mountains
Cassini VIMS (Near-IR) maps show a spectrally-diverse surface
INMS Mass Spectral Analysis

BENZENE:
- spectral deconvolution
- altitude variation

VIMS Detection of Benzene on Titan’s Surface

Titan goals

- Define the methane cycles at Titan
  - short term methane hydrological cycle (like the water cycle on Earth)
  - long term conversion cycle of methane to complex organics (like the carbon cycle on Earth)

This scientific goal is very broad and quite complex, therefore only a flagship mission can address the topic in a comprehensive manner. However, smaller missions could address specific elements of this topic.
**Preliminary Conclusions**

1. Motivated by Cassini-Huygens new findings we suggest that Titan science can best be organized around the global cycle of carbon.
2. Considering both the potential science value of future missions and the cost suggests that there are two mission scenarios that achieve an adequate science value to cost ratio:
   a) an independent balloon mission and
   b) an independent Titan orbiter mission.
3. The study is ongoing and comments are welcome.
1. Sources of Methane
Infrared and/or radar observations that survey the extent of volcanic activity or venting and its time history are important. In situ sampling of the composition of outgassing from vents, geysers or cryo-volcanoes, (including measurement stable isotopic abundances) is critical to understanding the source mechanism.

2. Condensation and Cloud Formation
The meteorological processes that lead to methane rainfall (and hail) on Titan are an appealing analog to rainstorms in the Earth’s evolving climate. Near-infrared remote sensing is important to characterize daily and seasonal patterns of cloud systems and the precipitation beneath them, as well as the tropospheric wind patterns that control the spatial variation of methane humidity. In situ observations are also critical for understanding the condensation and precipitation process.

3. Conversion of Methane to Complex Organics in the Upper Atmosphere
Cassini data indicate that ion neutral chemistry in the upper atmosphere initiated by ionization and dissociation of methane and nitrogen is the key to complex organic formation. To fully understand this process, ion and neutral mass spectra, that can measure a wide range of masses (including both negative ions and small -1000 Dalton - condensation nuclei) will be needed.

4. Aerosol Formation
The formation and modification of complex organic aerosols takes place from 1000 km down to the surface, although remote observation of many of these altitudes is challenging. In situ measurements might include aerosol mass spectrometer like those used on earth onboard airplanes and balloons. This is an intriguing process that may effectively transport and deposit volatiles from the thermosphere/mesosphere into the warm stratosphere and almost certainly produces the larger aerosols Marty saw in the troposphere. Determination in the far infrared and/or microwave of the gas composition in the stratosphere and its seasonal variation, and the measurement of winds, is also important in this region.

5. Surface Organic Inventory
It is important to understand how much methane is in communication with the atmosphere (notably, this is a factor in determining long-term stability of Titan’s climate), as well as to determine the amount of processed organic material that has accumulated on the surface. Mapping of the extent of surface deposits may be partly accomplished by Cassini, but subsurface radar sounding will be required to measure the depth of deposits. In situ determination of the lake and sand-dune composition would be most exciting.

6. Geomorphological Processes and Transport of Organics
Titan’s strikingly varied landscape appears to be the result of a balanced mix of geomorphological processes seen on Earth – erosion and transport by methane rainfall and rivers, transport by aeolian processes – as well as impact, tectonism and cryovolcanism. High-resolution imaging and topographic data are needed to characterize these processes.

7. Surface Composition
The varied organic surface composition on Titan is of critical astrobiological interest. Beyond the mere accumulation of aerosols, surface processing by physical processes (erosion, deposition) and, crucially, chemical modification (cryovolcanism, impact melt) leads to higher degrees of chemical complexity that demand sophisticated in-situ characterization. Candidate approaches may include raman and gcms techniques. This should include careful isotopic characterization at the <0.1 per mil level, as well as radiocarbon measurement.
Titan Mission Options that might fit under $1B

Saturn Orbiter / Multiple Titan Flyby
- partial 2 micron mapping, upper atmosphere flythroughs. But is this enough advance on Cassini to justify $1B?

Titan Lander (battery powered, relay via carrier stage)
- few hours, surface composition. Only worthwhile if ~3-4 such landers?

Titan Long-Lived Lander (RPS Power, Direct-to-Earth)
- seismic, meteorological monitoring, plus surface composition

Titan Orbiter
- 2 micron mapping, radar, aeronomy. But requires either severe propulsion capability, or aerocapture technology (not yet available)

Titan Balloon (RPS Power, Direct-to-Earth)
- long-duration wind-drift imaging and subsurface sounding (no altitude control or surface sampling).