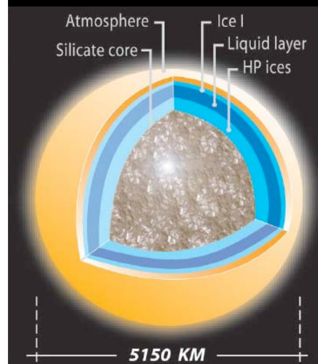
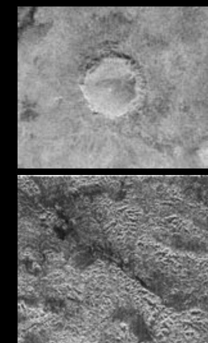
Titan Mission Study

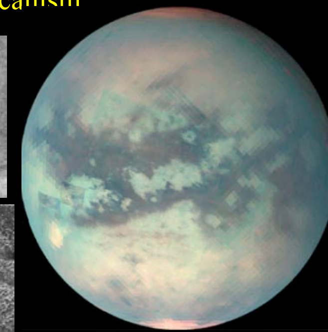
Titan is the 2nd-largest satellite in the solar system, larger than planet Mercury and is unique in having a thick nitrogen atmosphere. Like other large icy satellites, it likely has a silicate core, and a layer of liquid water (preserved by ammonia acting as an antifreeze) a few tens of km beneath its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



Model of Titan’s Interior

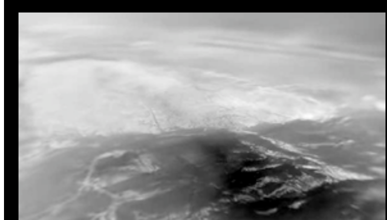


Cassini RADAR images of impact crater and tectonic mountains

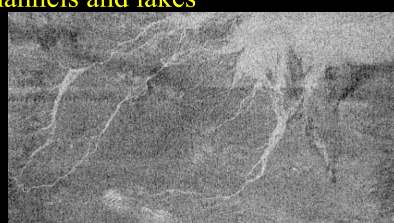


Cassini VIMS (Near-IR) maps show a spectrally-diverse surface

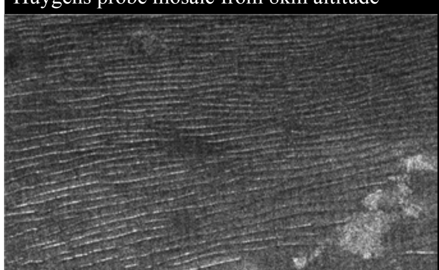
Titan’s Landscape is being actively modified by Earth-like processes, forming sand dunes, river channels and lakes



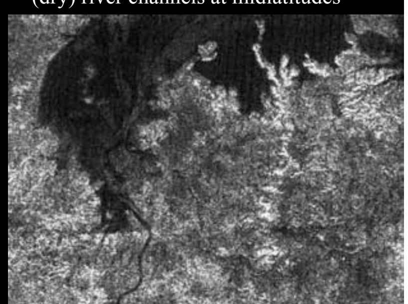
Huygens probe mosaic from 8km altitude



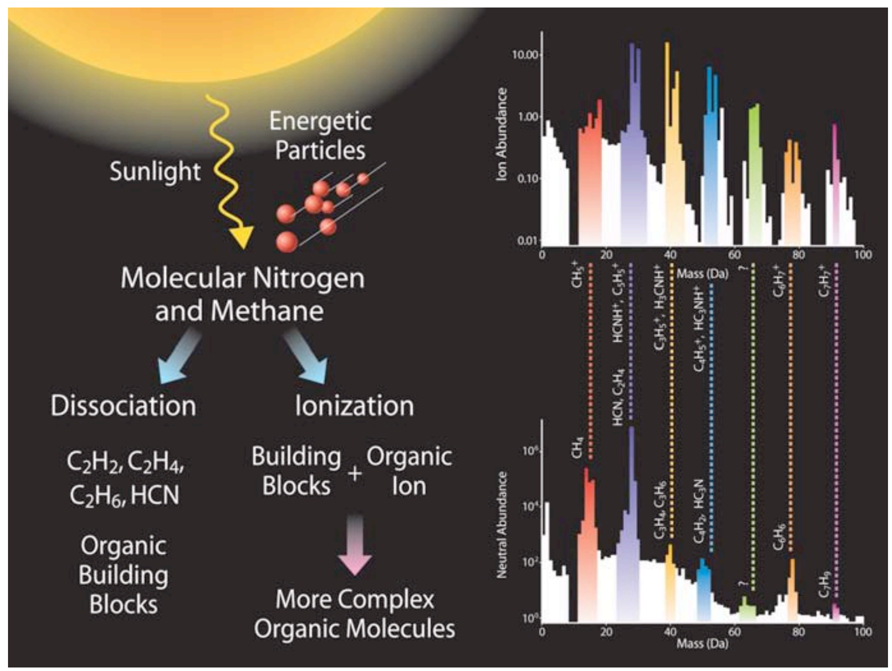
(dry) river channels at midlatitudes



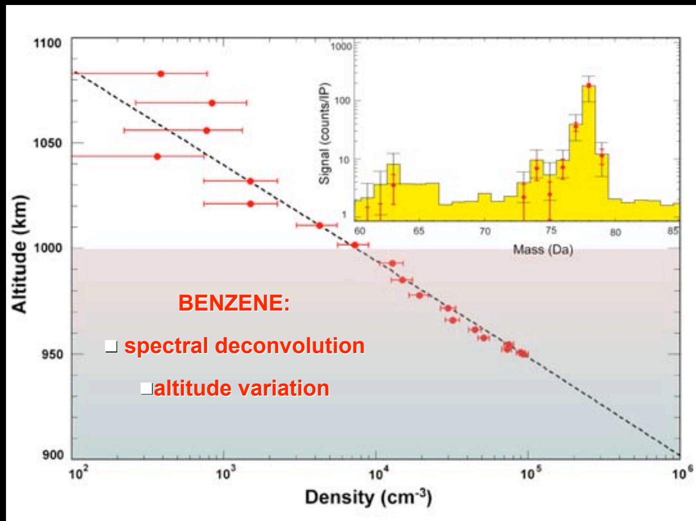
Giant organic sand dunes, 10’s km long, 150m high, near Titan’s Equator (Cassini RADAR)



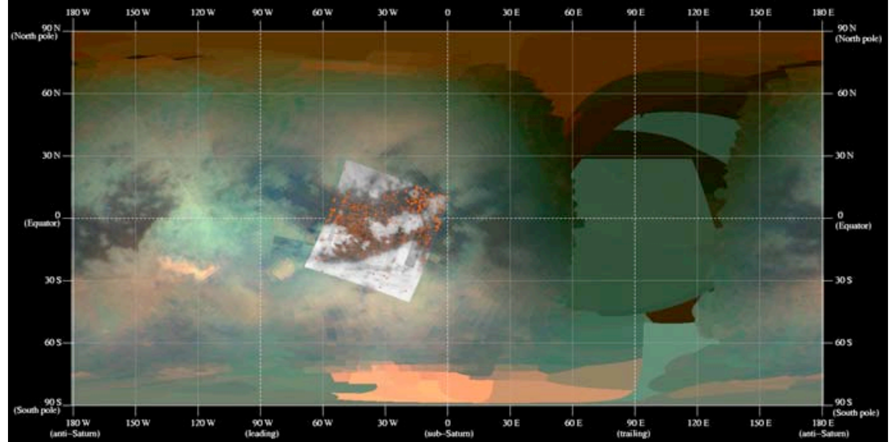
Lake and river channel near North

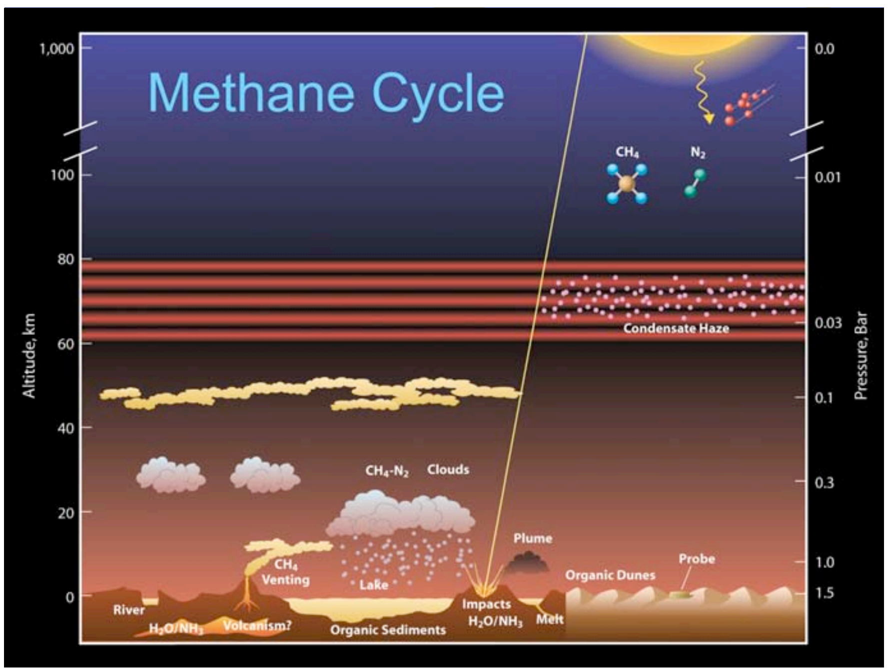


INMS Mass Spectral Analysis



VIMS Detection of Benzene on Titan's Surface

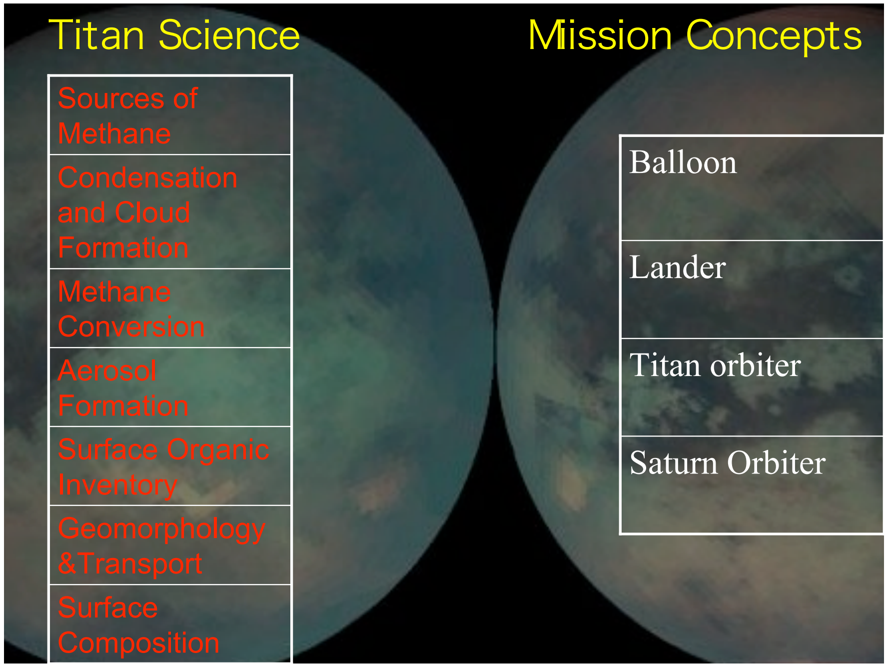




Titan goals

- 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



	Balloon			
	Imager	Met Package	Subsurface Radar	IR? Spectrometer
Sources of Methane	XXX	XX		
Condensation and Cloud Formation	X	XX		
Methane Conversion				
Aerosol Formation				
Surface Organic Inventory	XXX		XXX	XX
Geomorphology&Transport	XXX		XX	
Surface Composition	X			XXX

	Orbiter			
	2m Imager	Radar	Mass Spectrometer	Gravity/Mag
Sources of Methane	XXX	XX		XX
Condensation and Cloud Formation	XXX	X		
Methane Conversion	X		XXX	
Aerosol Formation	XX		X	
Surface Organic Inventory	XXX	XXX		
Geomorphology&Transport	XX	XXX		
Surface Composition	X	X		

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 characterise 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.

	Lander			
	Imager	Met Package	Seismometer	In-situ Chemistry
Sources of Methane		X	XX	X1
Condensation and Cloud Formation	X			
Methane Conversion				
Aerosol Formation				
Surface Organic Inventory	X			X
Geomorphology&Transport	XX			XX
Surface Composition	X			XXXX

	Flyby			
	?	?	?	?
Sources of Methane	?	?	?	?
Condensation and Cloud Formation	?	?	?	?
Methane Conversion	?	?	?	?
Aerosol Formation	?	?	?	?
Surface Organic Inventory	?	?	?	?
Geomorphology&Transport	?	?	?	?
Surface Composition	?	?	?	?

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