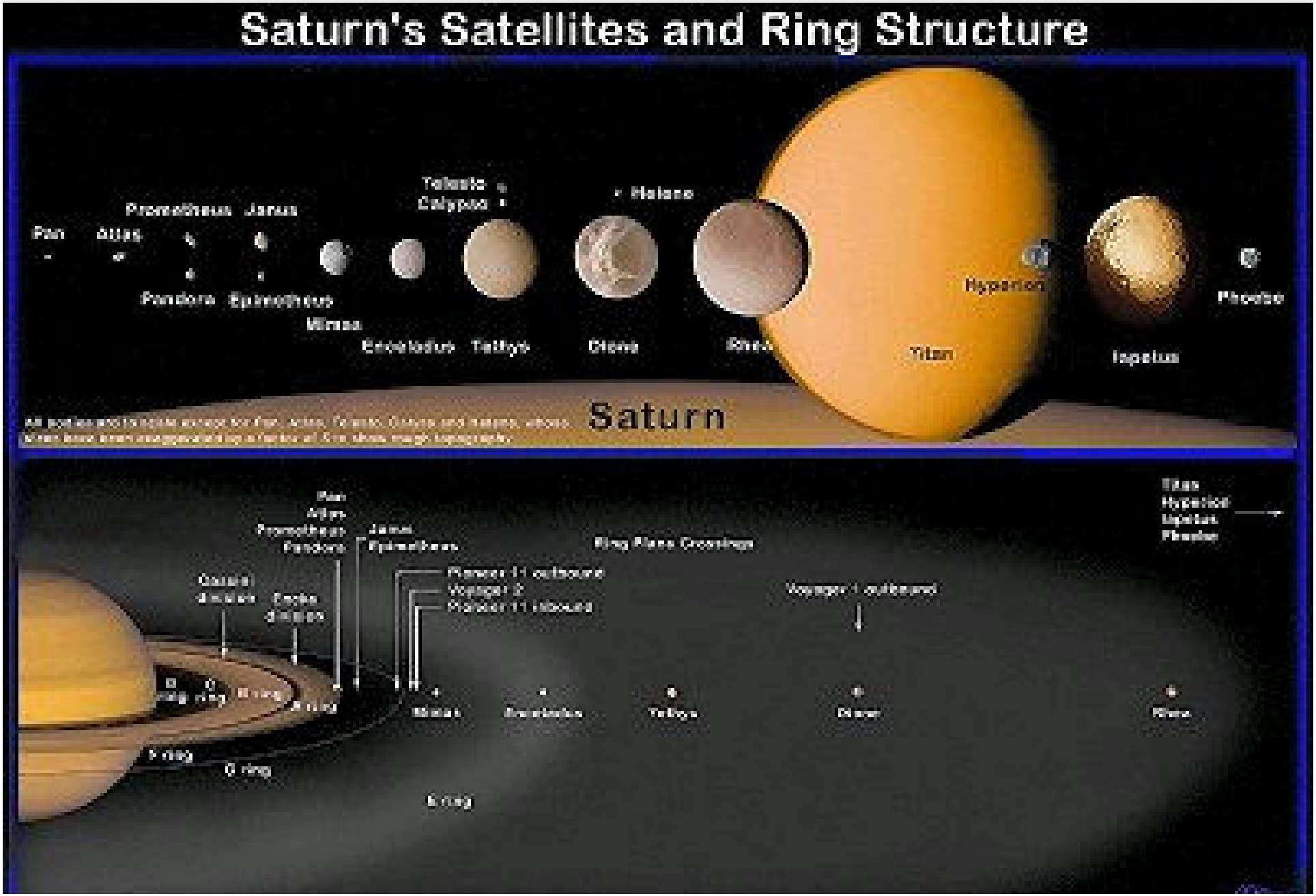
Titan: The moon with an atmosphere

The Saturnian System



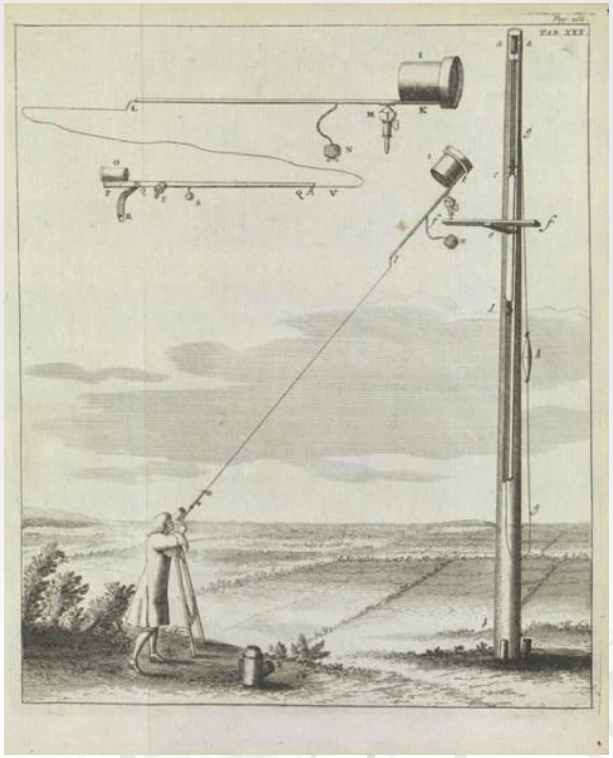
The story of Titan's discovery

- Discovered in 1655 by Dutch scientist Christiaan Huygens

- Referred to it as *Luna Saturni*

  (Saturn's moon)

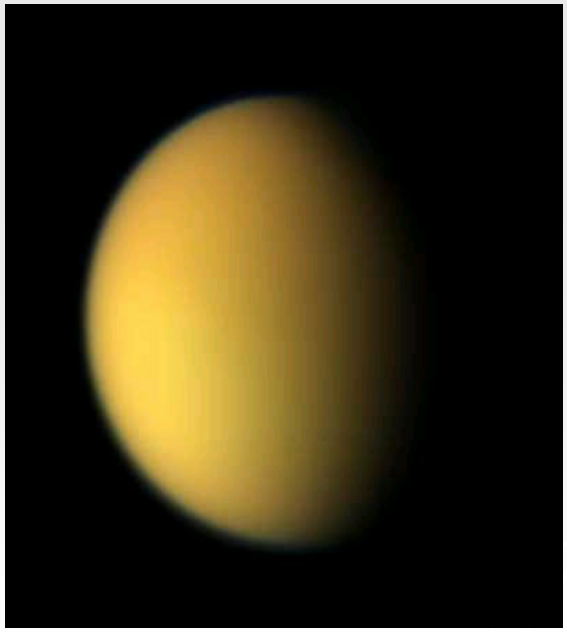
- Named 'Titan' in 1847 by the English astronomer John Herschel



Aerial telescope

Possibility of atmosphere suggested by Comas Solas in 1903 , after observing limb darkening

Existence of atmosphere confirmed by Kuiper in 1944, methane identified in Titan spectrum



Ground-based telescopic observations

Voyager1 (1980-81) saw featureless surface

Cassini-Huygens mission (1997-present)

Comparison with other solar system objects

- Largest satellite of Saturn
- Larger than Mercury and Pluto
- Second largest natural satellite in the solar system after Ganymede
- Similar in size, mass to Ganymede ,Callisto
- Why does Titan have an atmosphere , while its Jovian cousins don't?

Table 1. Global Parameters of Titan

Parameter	Value	References[a]
Mean surface radius R_p, km	2575	1,2,3,4
Global mass M_p, kg	1.346×10^{23}	2,3,4
Planetocentric constant, GM_p, $km^3\ s^{-2}$	8978.2	1
Surface gravity g_p, $m\ s^{-2}$	1.35	3,4
Mean density $\bar{\rho}$, $kg\ m^{-3}$	1881	2,3,4
Rock to ice ratio (by mass)	~55:45	5
Orbital semimajor axis a, km	1.2218×10^6	2
Free orbital eccentricity e	0.0292	2
Mean orbital motion n, s^{-1}	4.56×10^{-6}	
Period of revolution τ_{rev}, d	15.945	2,6
Period of rotation τ_{rot}, d	15.945	2,6
Surface pressure p_S, Pa	1.496×10^5	3
Surface temperature T_s, K	94	3,6

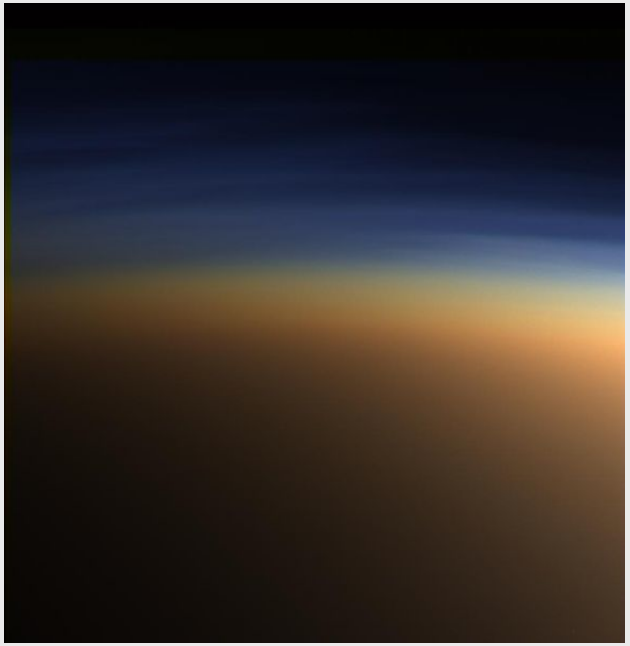
[a]References: 1, *Thomas* [1991]; 2, *Burns* [1986]; 3, *Morrison et al.* [1986]; 4, *Schubert et al.* [1986]; 5, *Stevenson* [1992]; 6, *Lorenz and Mitton* [2002].

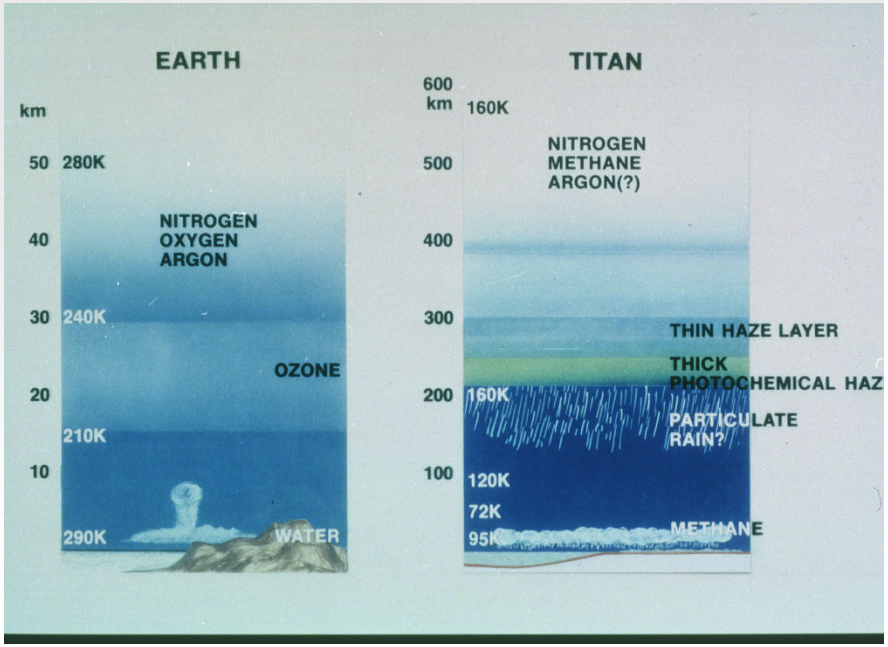
Titan's atmosphere

- Only moon in the solar system to possess a dense atmosphere
- 10 times thicker than Earth's atmosphere
- Presence of huge atmosphere unexplained
- N_2 : Major constituent of both Earth's and Titan's atmosphere (~98.4% N_2, ~1.6% CH_4)
- Unique atmospheric organic chemistry

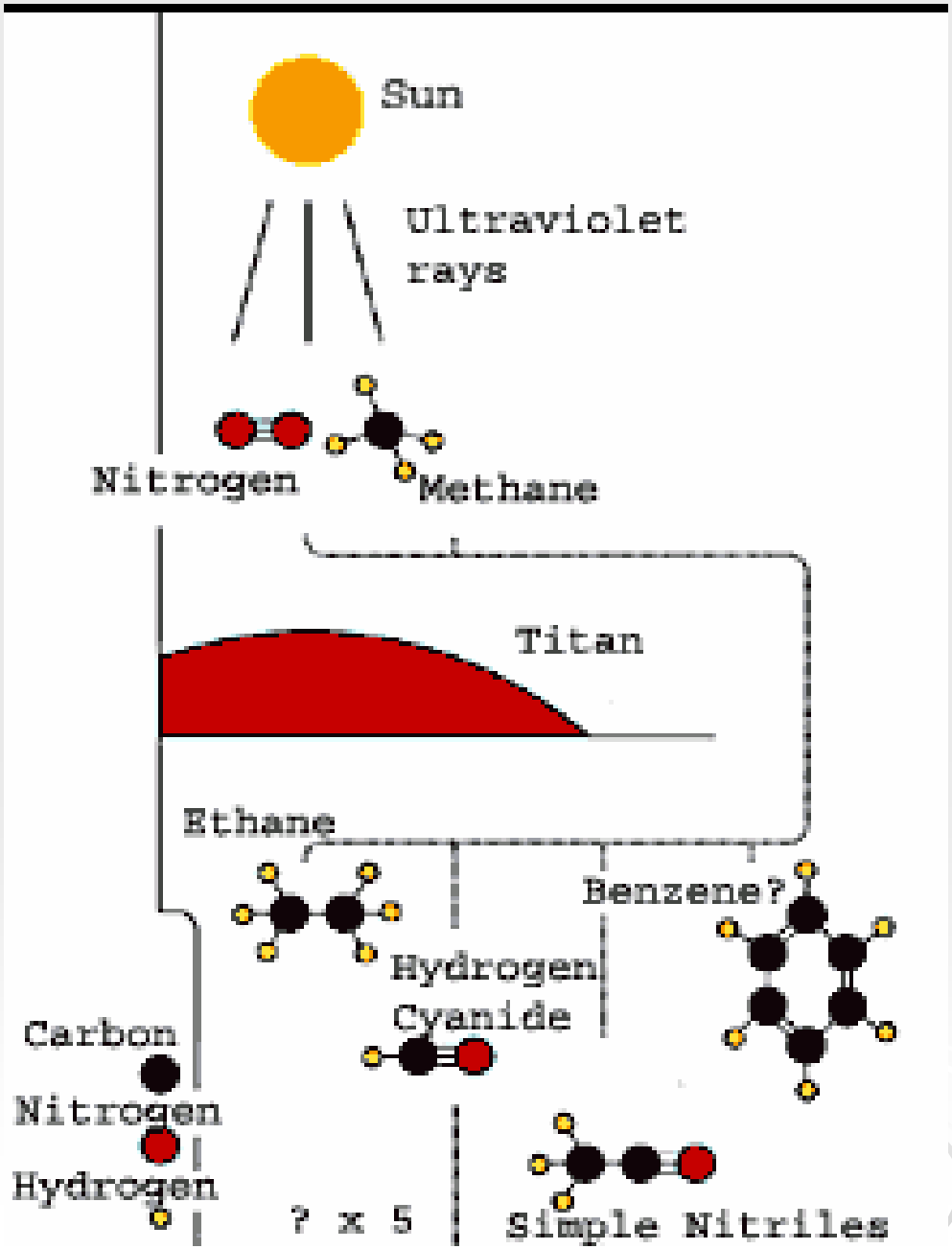
→ forms thick haze which envelopes the moon; prevents from seeing the surface

- Early Earth/Pre-biotic Earth in deep freeze





Titan's atmospheric chemistry



$$2CH_4 \rightarrow C_2H_6 + H_2\ (\uparrow)$$

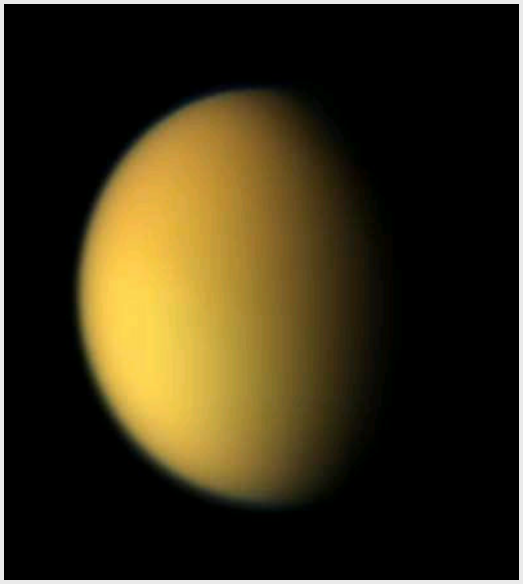
Methane → Ethane + Hydrogen

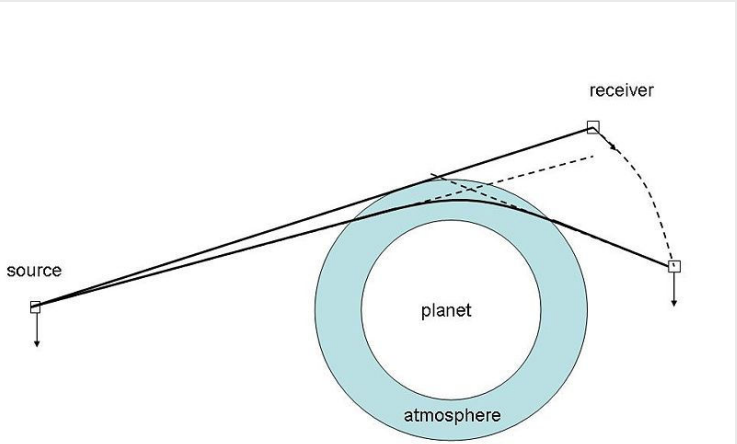
Tholins

- Term first proposed by Carl Sagan et al.
- Haze made of long chain molecules- ‘tholins’
- Solid end products of photolysis and electronic discharge experiments simulating other planetary atmospheres
- Complex reddish or brownish organic compounds
- Not precise qualification of the compounds constituting Titan’s haze

Results from Voyager

- Saw an orange, featureless ball

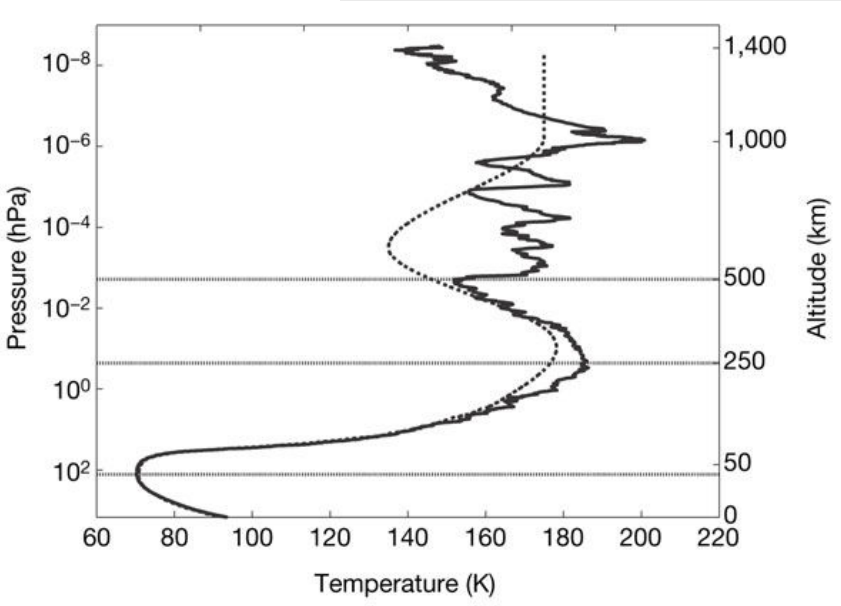




- Radio occultation used to determine Titan's radius

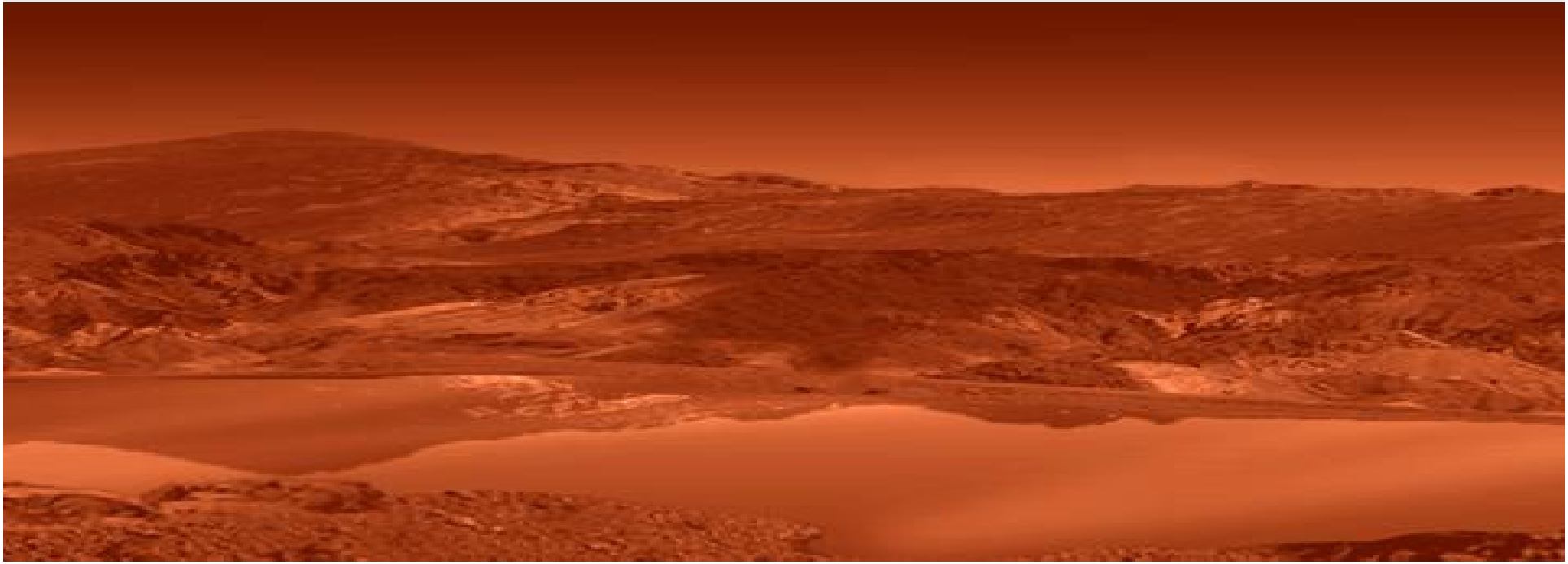
- Atmospheric structure, composition

- Pressure-temperature profile through the atmosphere



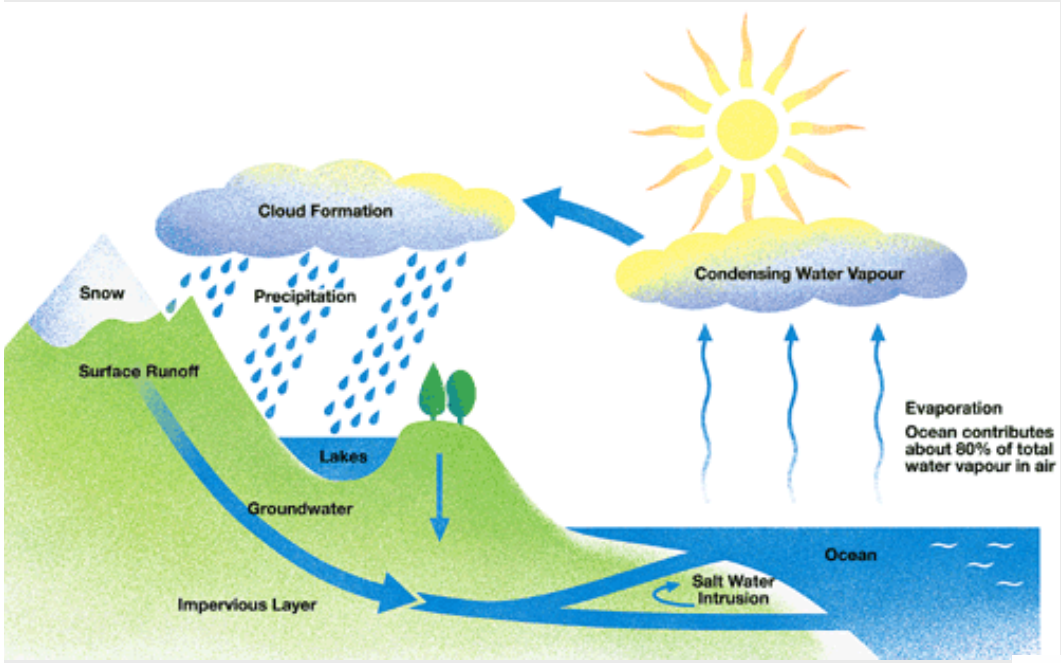
Surface composition

- No conclusive results yet
- However, surface has to be made mainly of water ice (ground-based/spacecraft observations)
- Expected to be coated with hydrocarbons that rain down from above (ethane, benzene, propane, etc.)



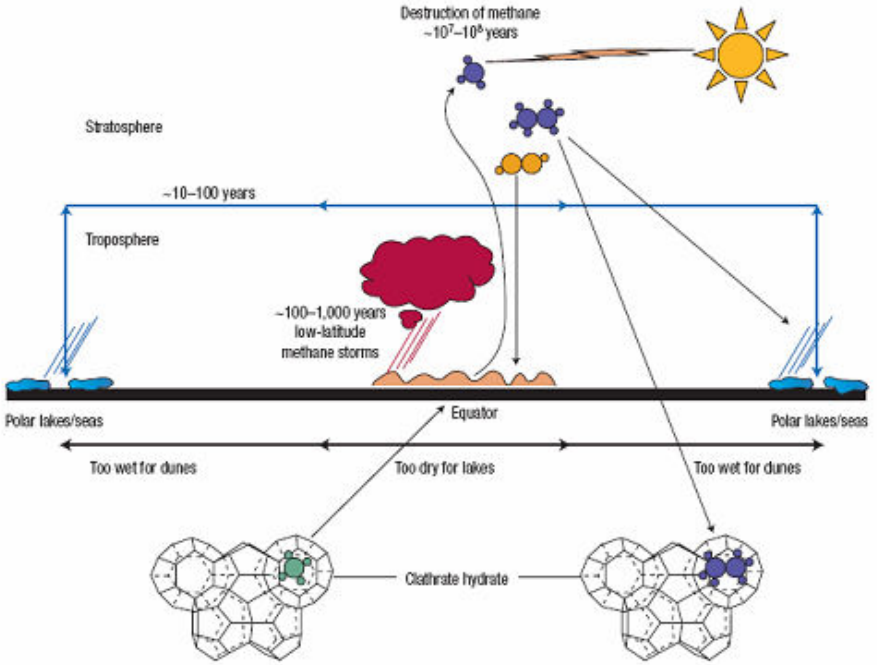
Comparison of surface materials

	Earth	Titan
Bedrock	Silica	Water ice
Working fluid	Water	Methane
Sediment/Soil	Quartz	Water ice/organic materials (tholins)



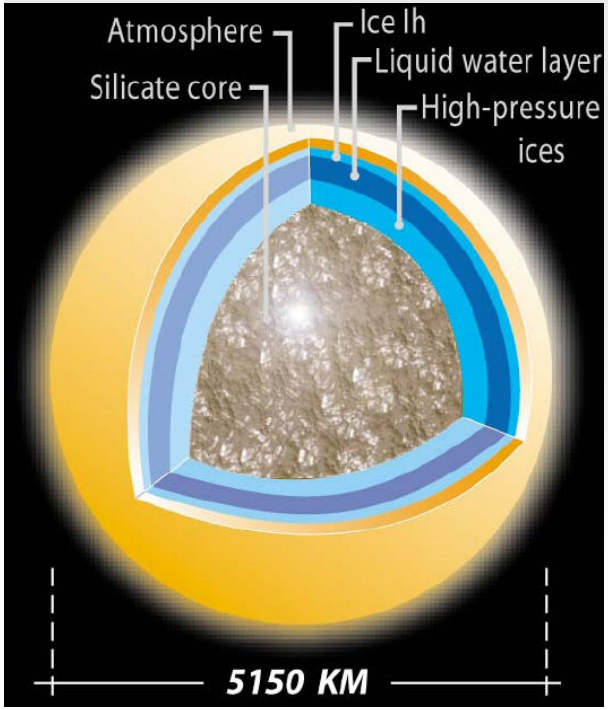
Water cycle on Earth

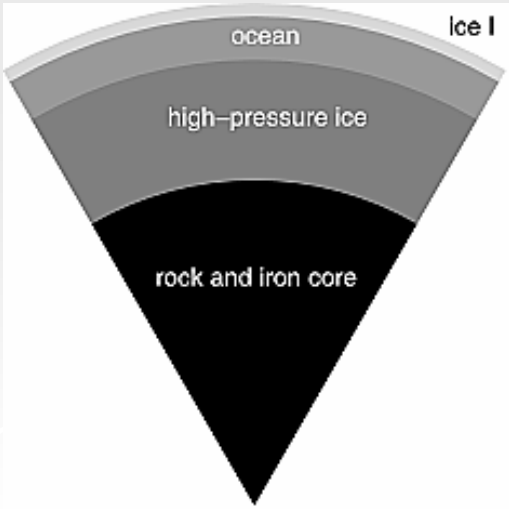
Methane cycle on Titan

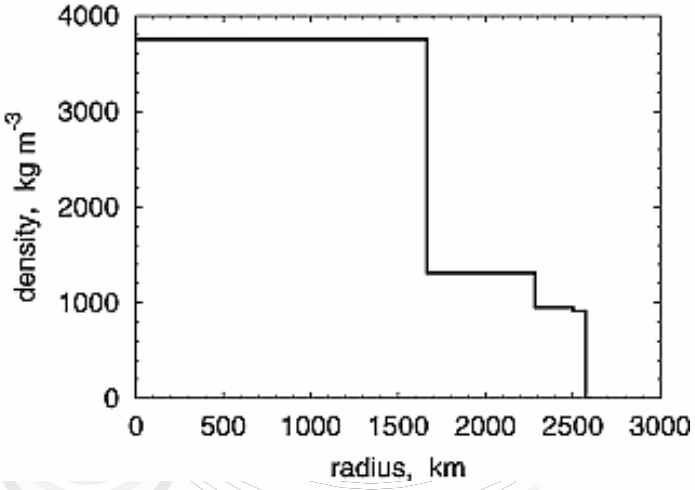


Internal structure

- Mean density of ~1880 kg m^{-3}
  - Implies a 50-50 mixture of rock and ice (like Ganymede)
- Sub-surface ocean ?(suggested by Cassini mission results)

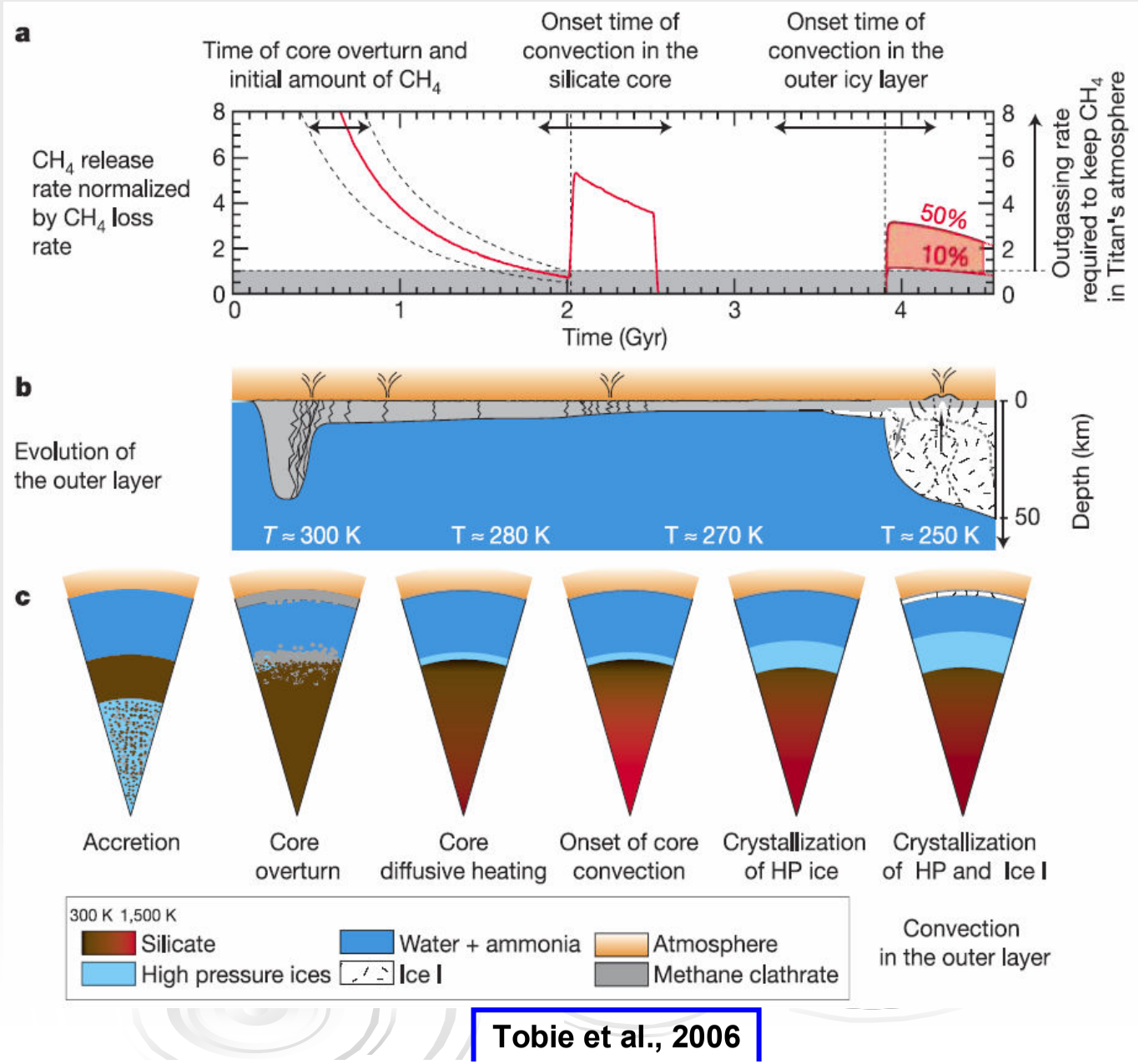






Titan's Formation Sequence

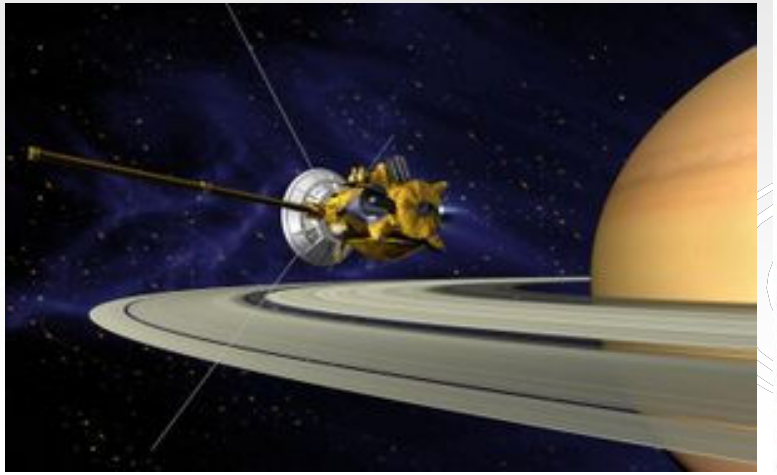
- Titan accretes
- Core overturn occurs
- Three episodes of CH_4 outgassing
- High pressure ices form at core-mantle boundary
- Ice I shell forms under methane clathrate layer



Tobie et al., 2006

Cassini-Huygens mission

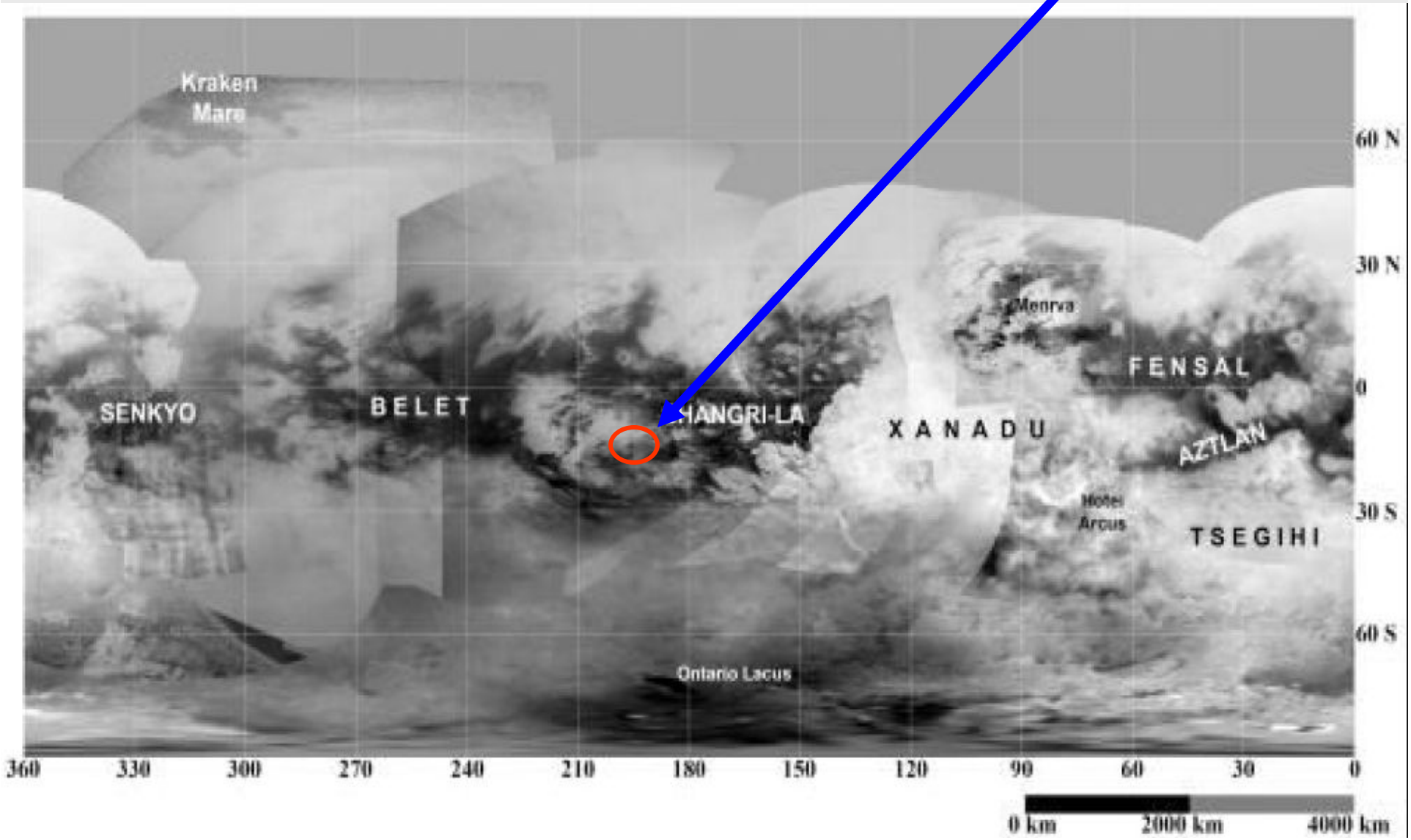
- International collaboration between three space agencies : NASA, ESA, Italian Space Agency
- 2 main elements: Cassini orbiter and Huygens probe
- Launched in 97’; Entered into Saturn orbit on July1, 04; Huygens probe landed on Titan on January 14, 05



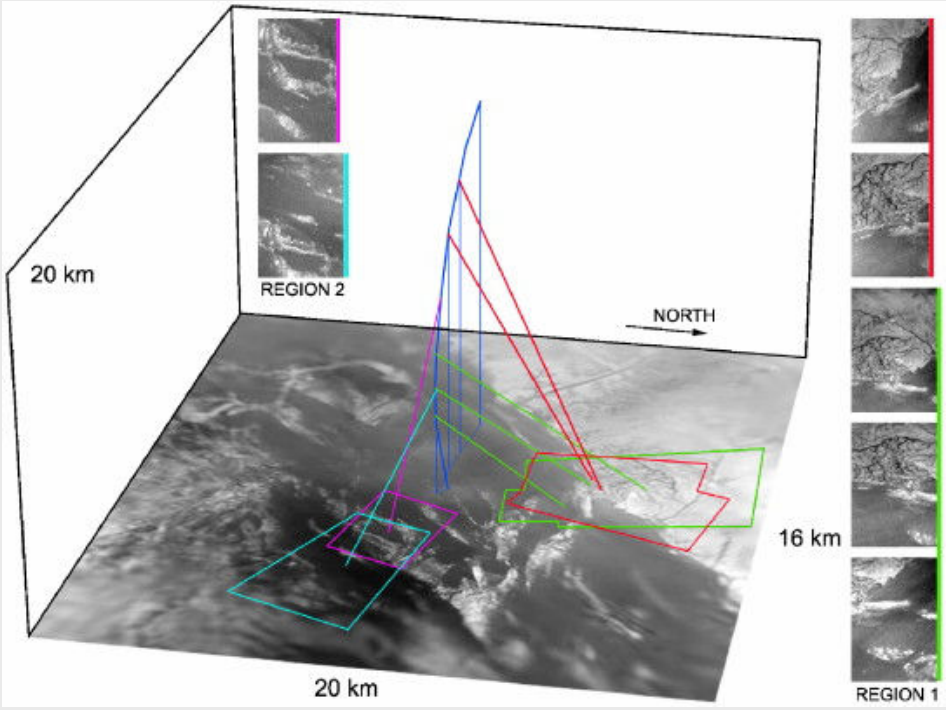
Surface map of Titan

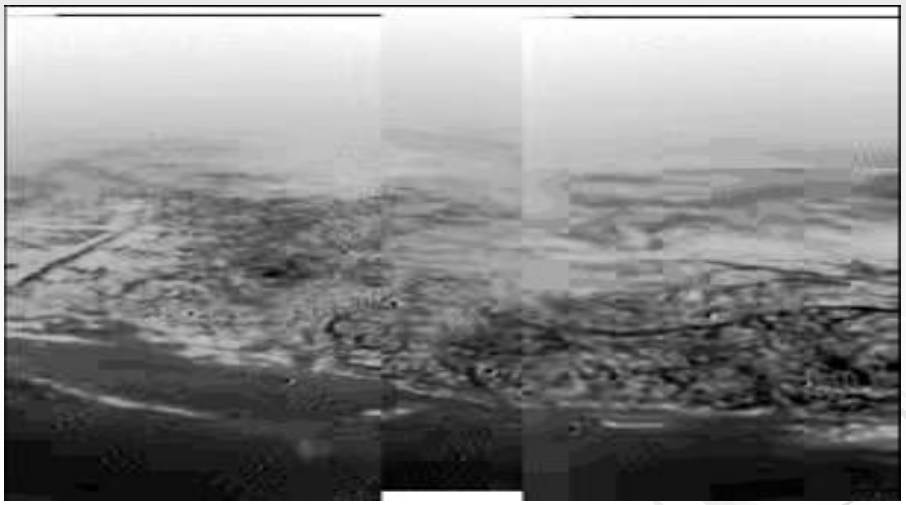
Facula – bright spot, Macula – dark spot

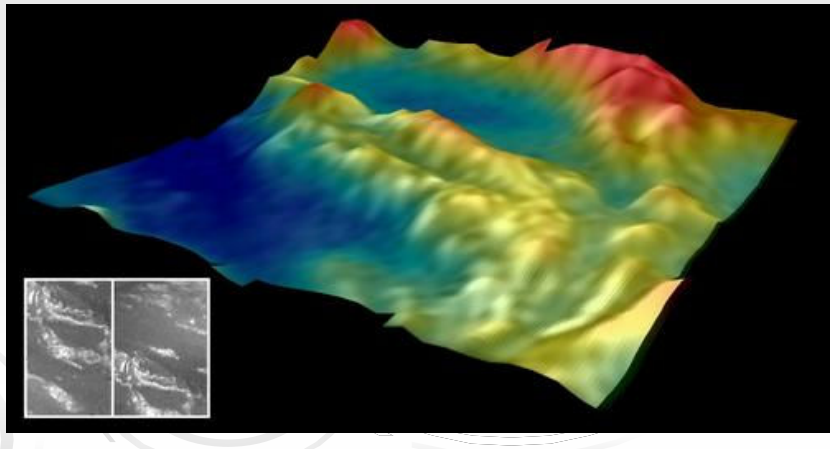
HLS (10°S, 192°W)



- Huygens probe landed in dark area
  - 10 S, 192 W
  - Dried-up river bed?
  - Descent images showed shoreline
  - Dendritic features, channels
  - East-west ridges of bright material



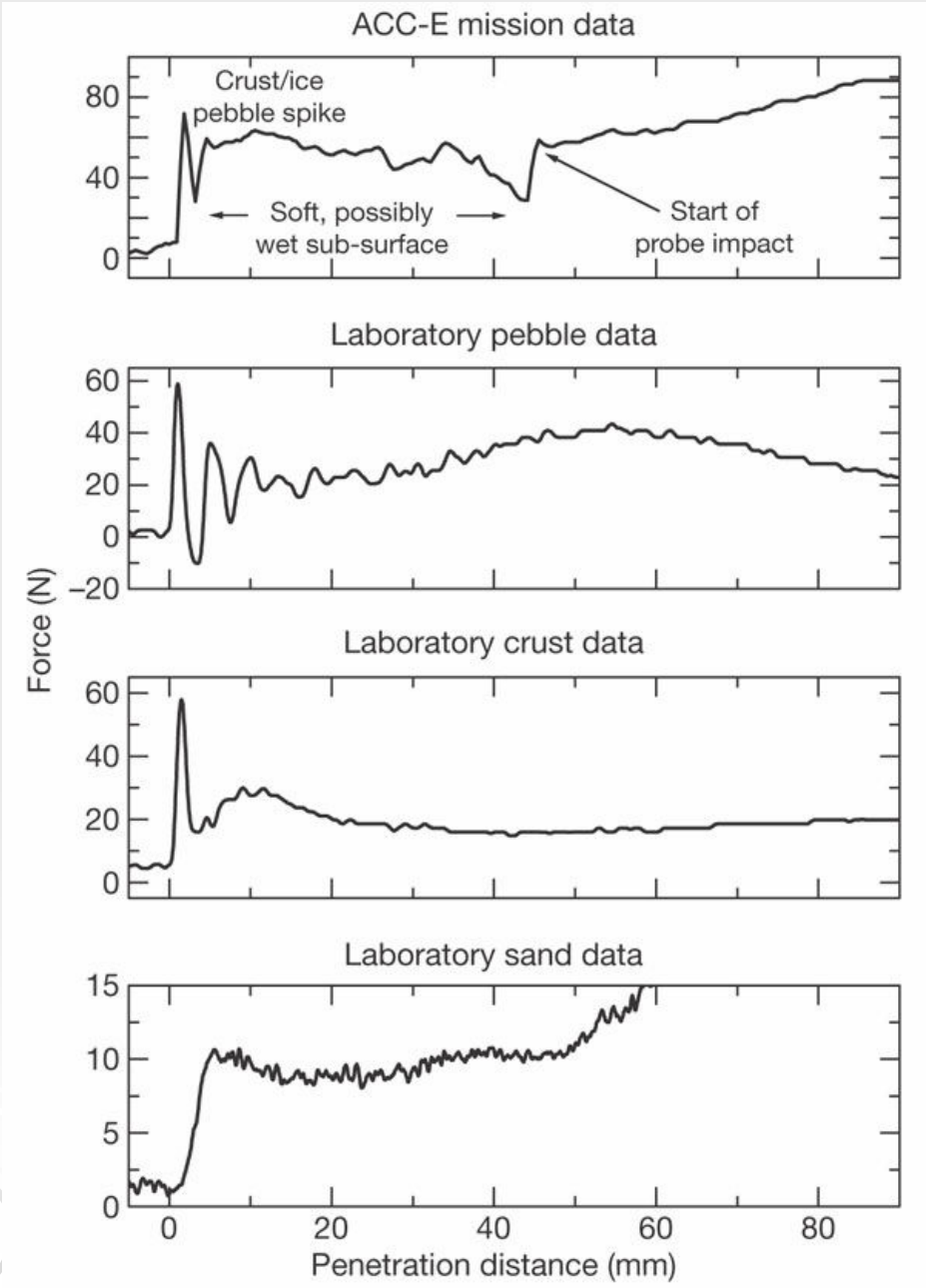




- In the dark areas
  - Low albedo organic compounds
  - Some water ice visible
  - Littered with 15cm cobbles
    - Bright icy composition
    - Rounded appearance suggests fluvial transport
  - Channel bed apparent a few meters away
  - Very subdued topography

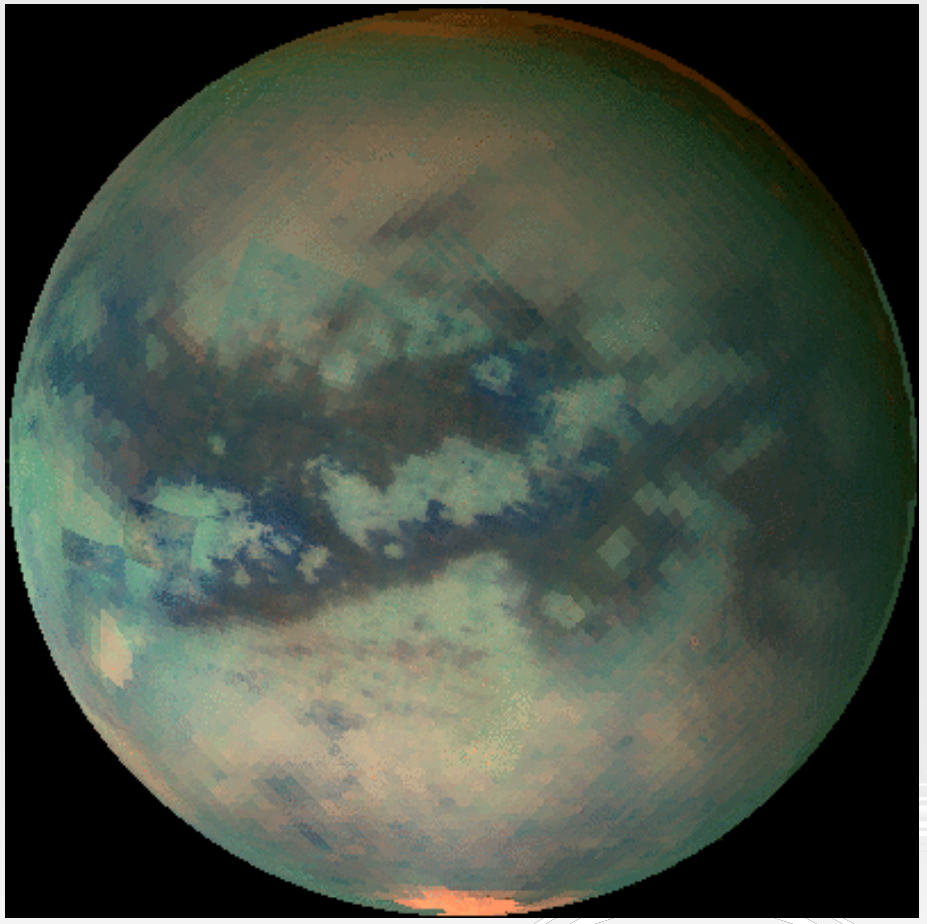
- Methane released
  - Methane concentration increased after landing

- Penetrometer
  - Probe first hit one of the icy cobbles
  - After that ground has consistency of wet clay
  - Coupled with methane release
    - Wet-ish subsurface
    - Like packed snow or wet clay

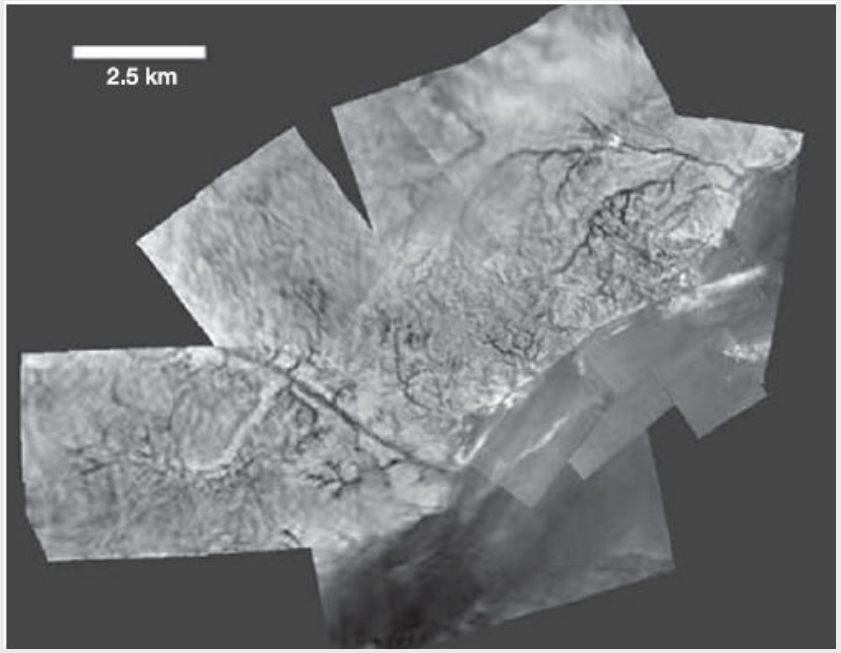


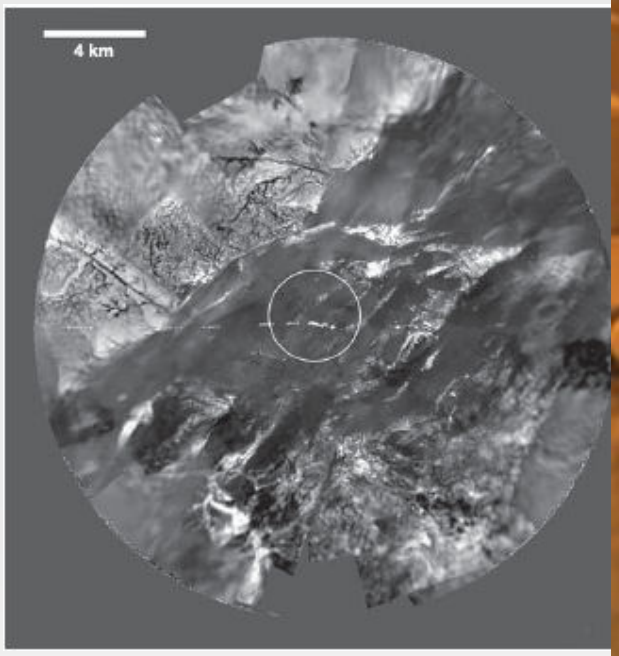
Active surface processes

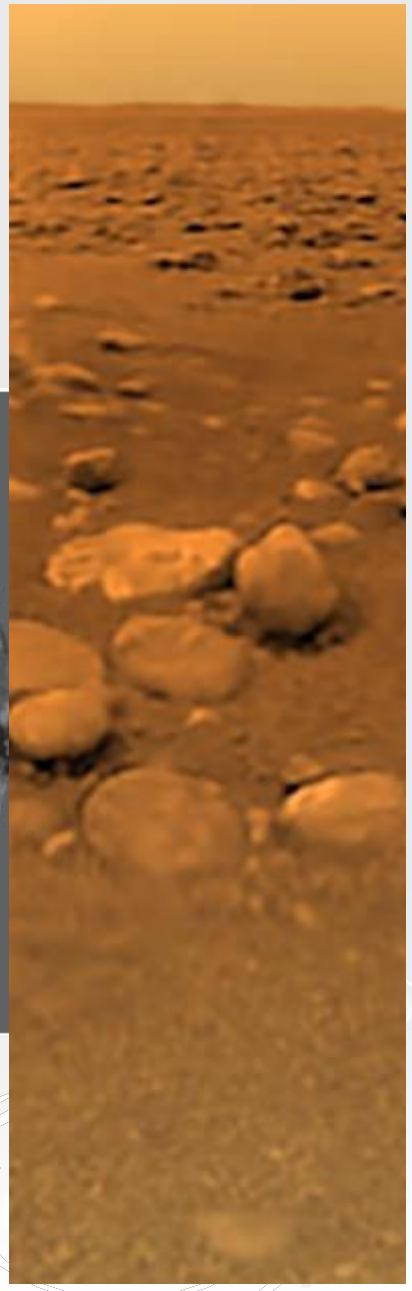
- Fluvial erosion
- Aeolian activity
- Tectonics
- Cryovolcanism
- Impact cratering
- Lacustrine processes (lakes)

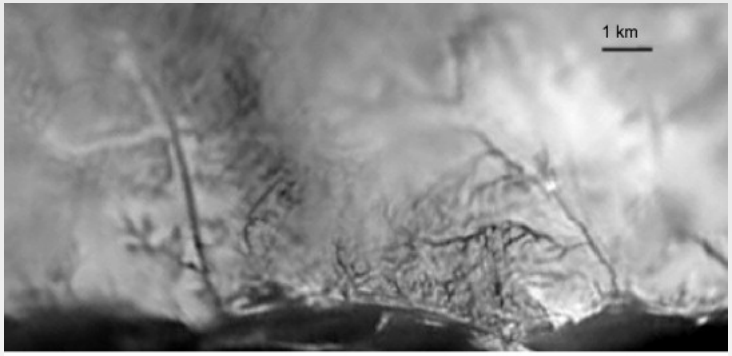


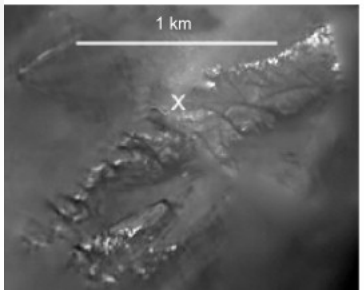
Fluvial erosion

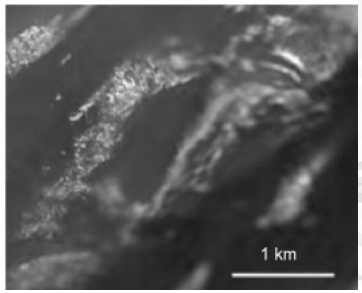








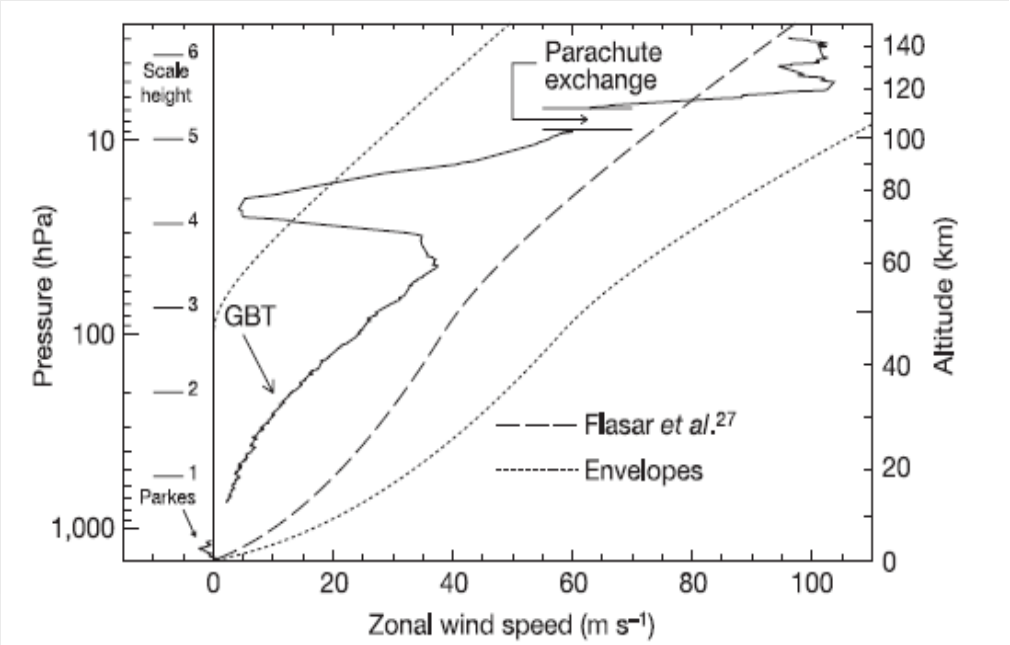




Aeolian activity

- Wind speeds on Titan were to be measured by Doppler Wind Experiment onboard Huygens

- Glitch with one of the radio links
  → earth-based radio telescopes had to be used for measuring wind speeds



- Strong prograde (eastward) zonal winds during most of descent

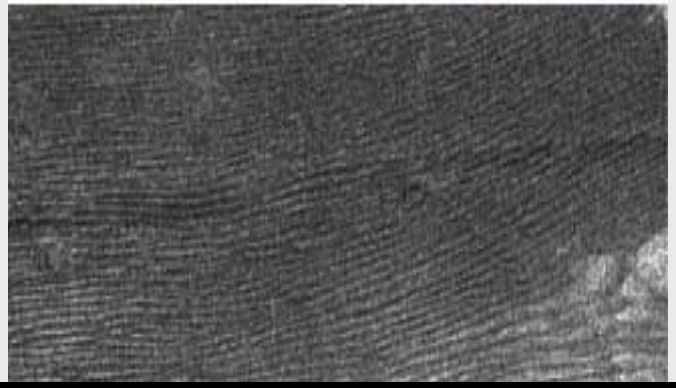
- In situ confirmation of superrotation on Titan (wind speeds of ~ 100 m/s at 120 km altitude)

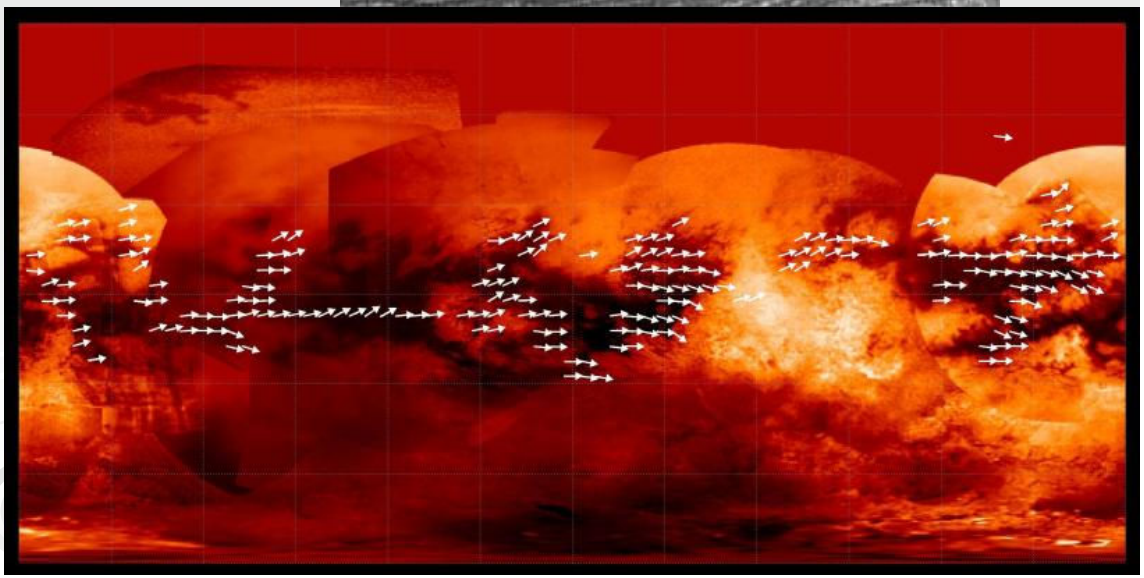
- Weak surface winds (~ 1 m/s)

Longitudinal dunes on Titan

- 3km wavelength, 100m height
- Found in equatorial regions, oriented along predominant wind-flow direction (west-east)
- Wrap around topographic obstacles
- Similar to Namibia

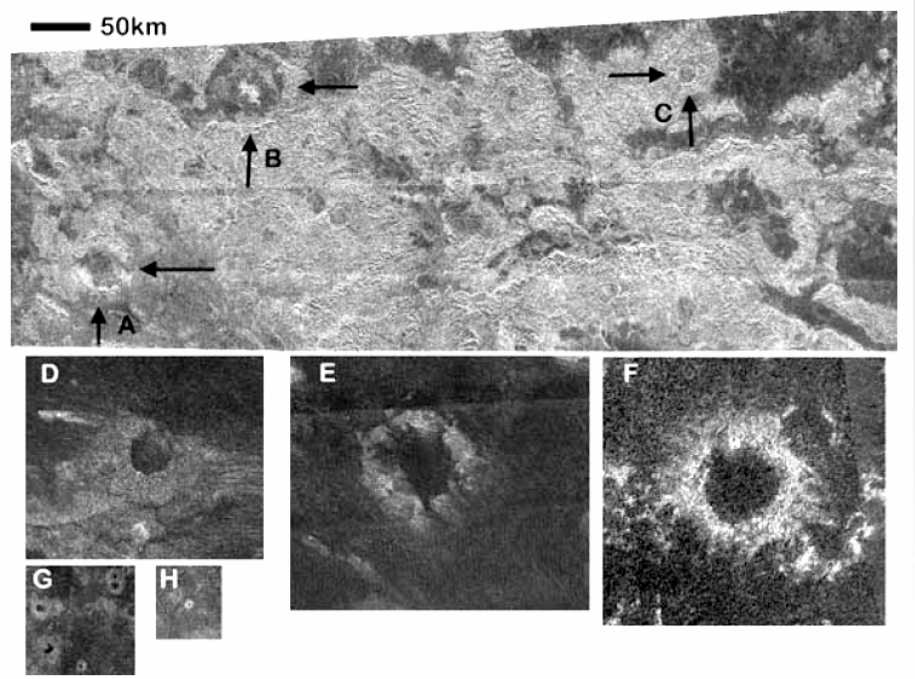
- Dunes observed to cover some craters
  - Aeolian erosion/burial might be an important process
- Spectral (UVIS) data
  - Dune areas have low water ice signature
  - Maybe solid organic (Photochemical products of methane?)

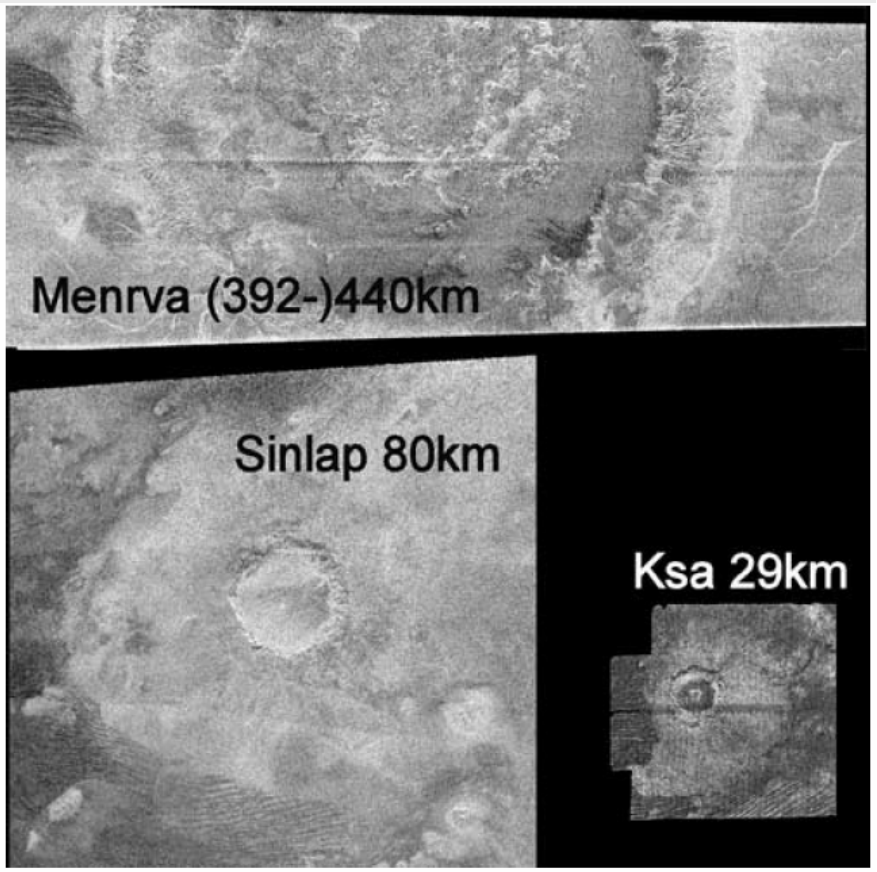


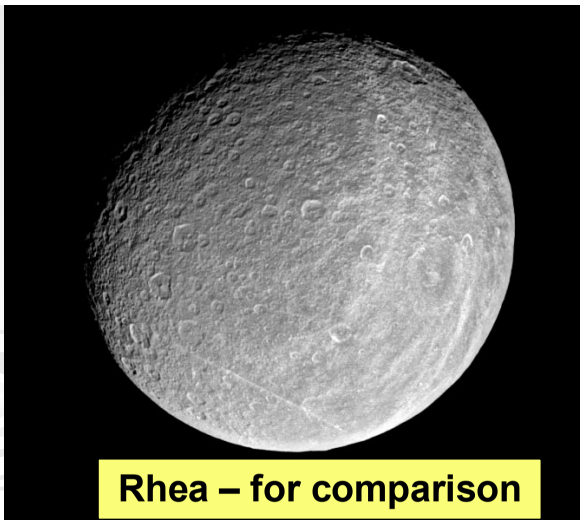


Impact cratering

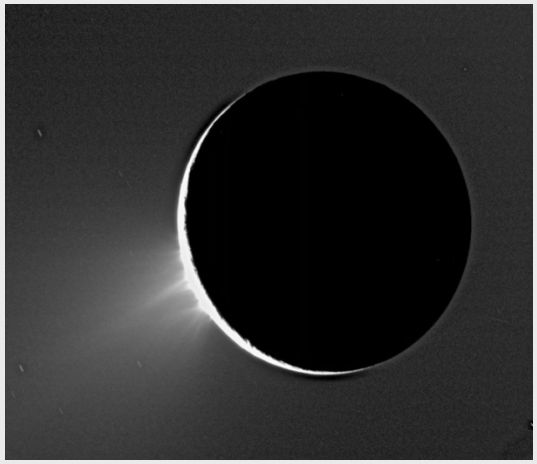
- Titan has a dearth of craters
  - Several *suspiciously* circular features
  - Radar has imaged ~30% of surface
  - Geomorphologically very active; young surface







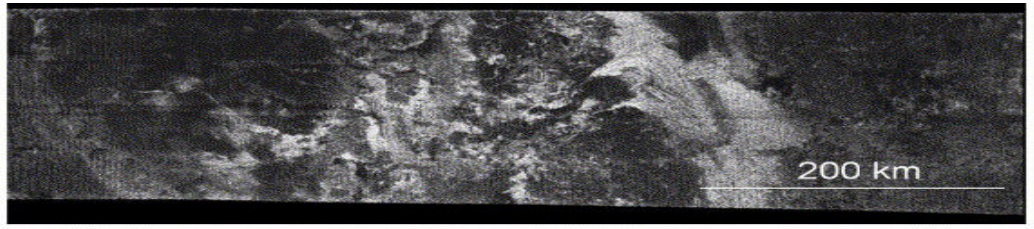
Cryovolcanism



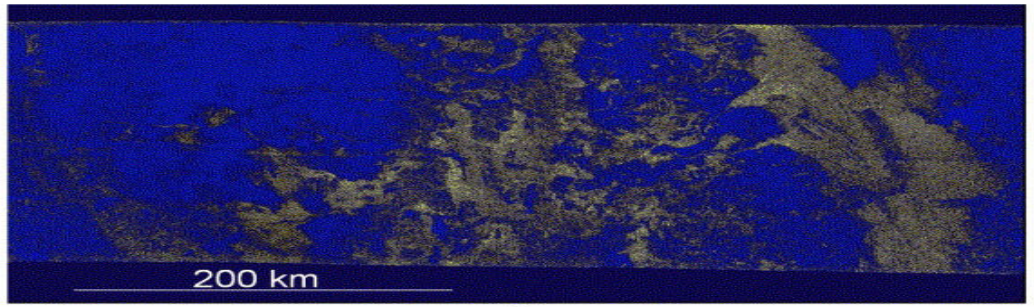
- Ice-rich volcanism
- Cryovolcanoes erupt volatiles like water, methane, ammonia instead of molten rock
- Erupted substances → usually liquids, form plumes, can also be in vapour form
- Contribution to replenishment of methane in Titan's methanological cycle (Yung et al. 1984)
- Important resurfacing process
- Might explain clustering of clouds near 40°S, 350°W (Roe et al. 2005)
- Astrobiological implications : Potential habitats for life

Cryovolcanism

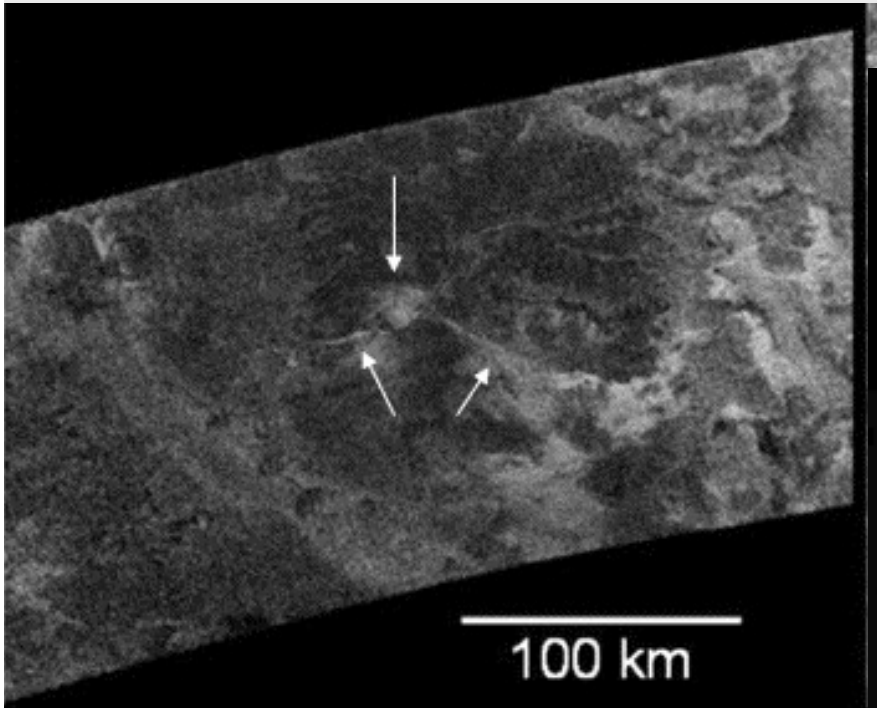
- Ganesa Macula
  - Circular feature, 180 km dia
- Flow features
- Cryolvolcanic/alluvial fans

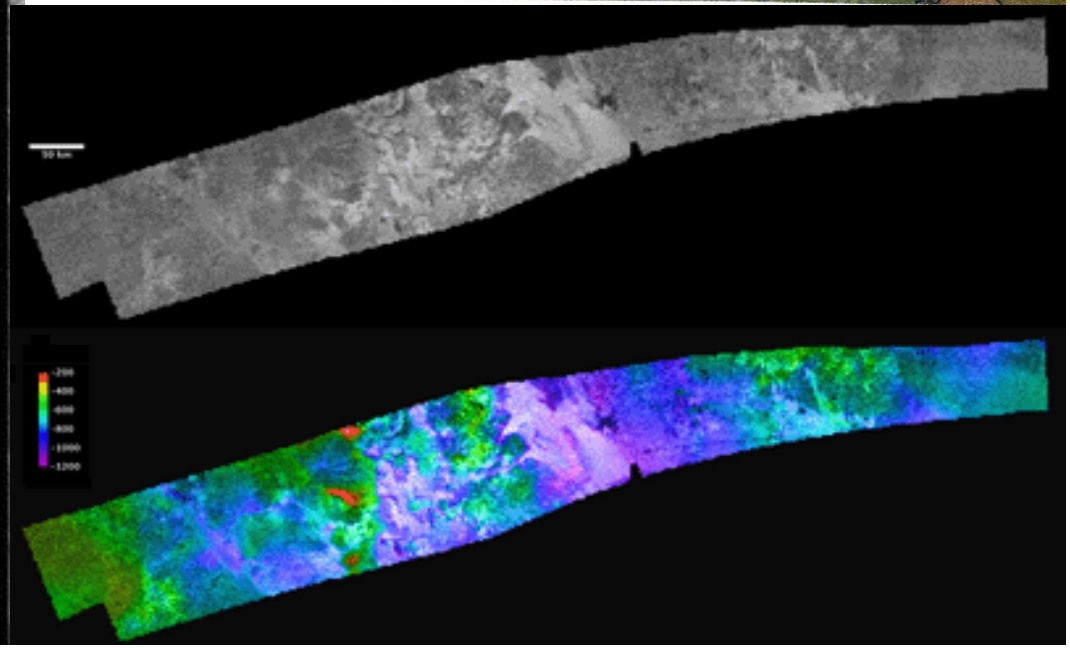


(a)

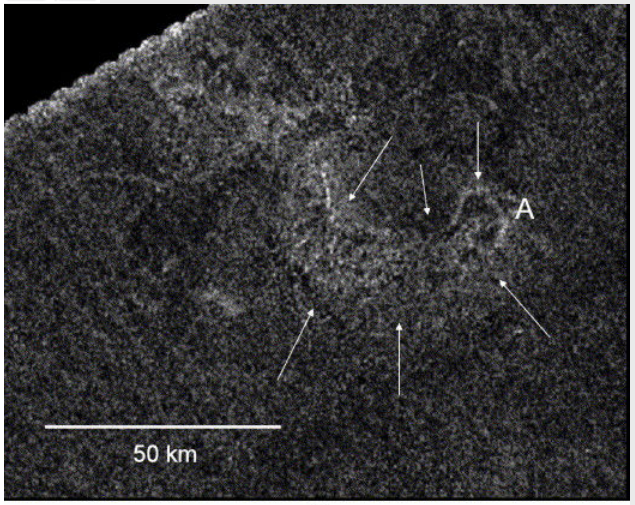


(b)

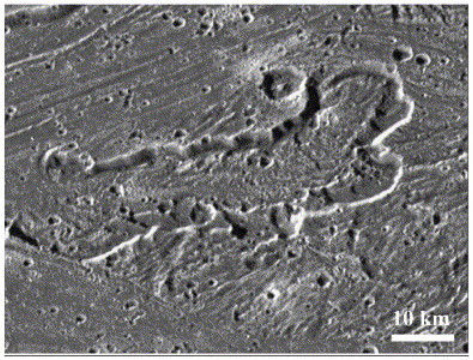


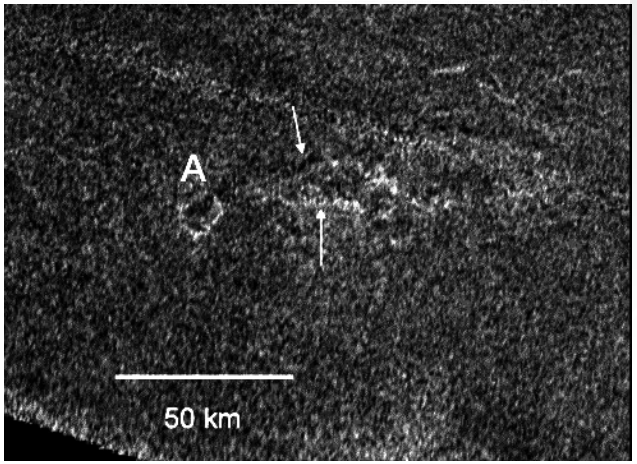


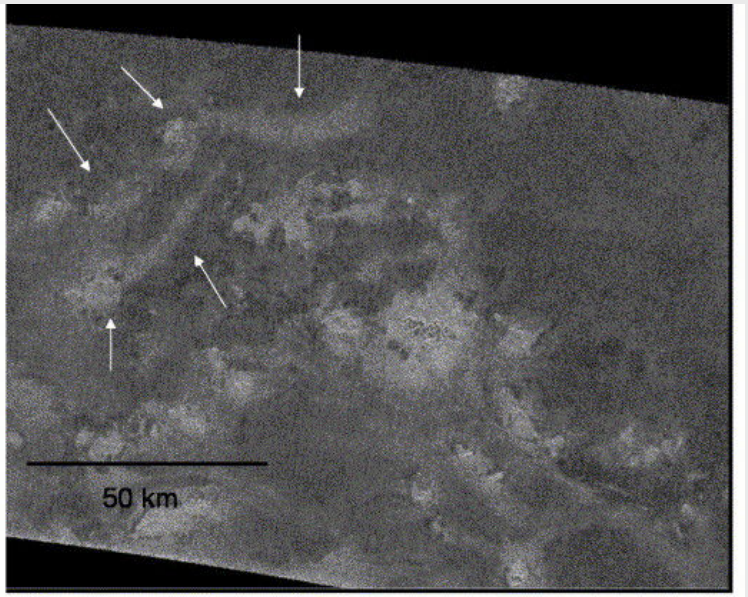
- More ‘calderas’ and ‘flows’



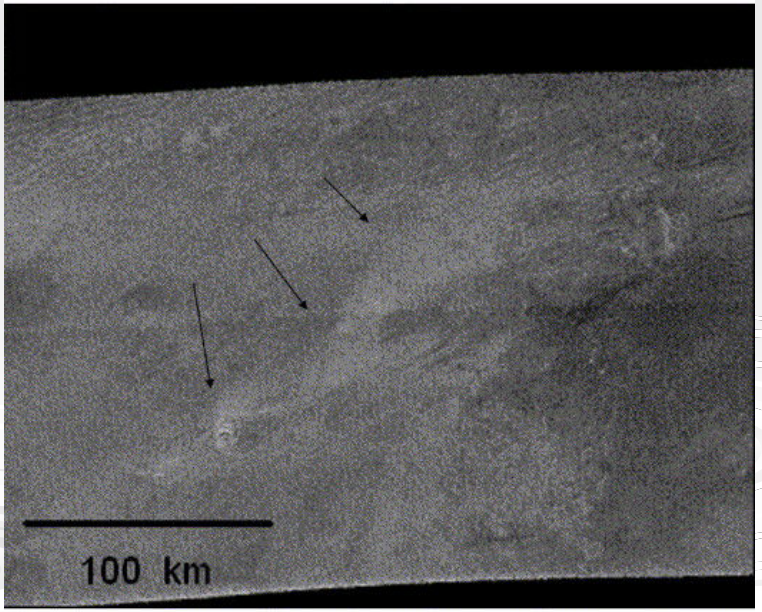
(a)







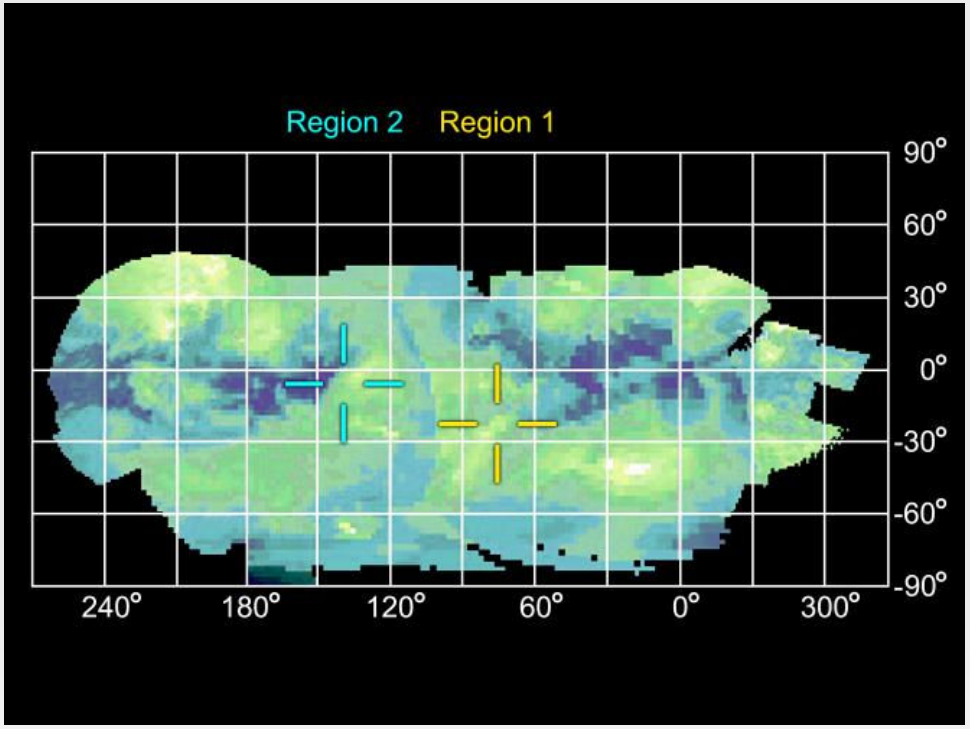
(a)

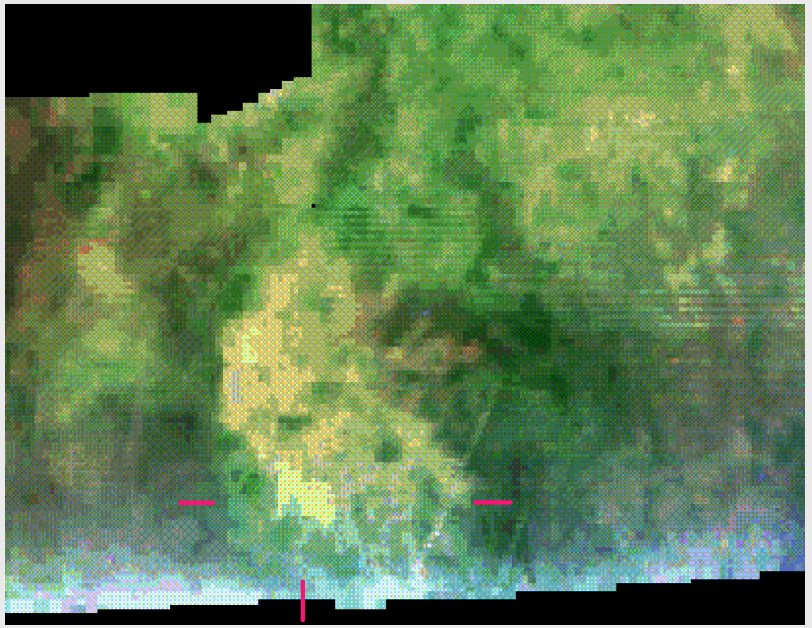


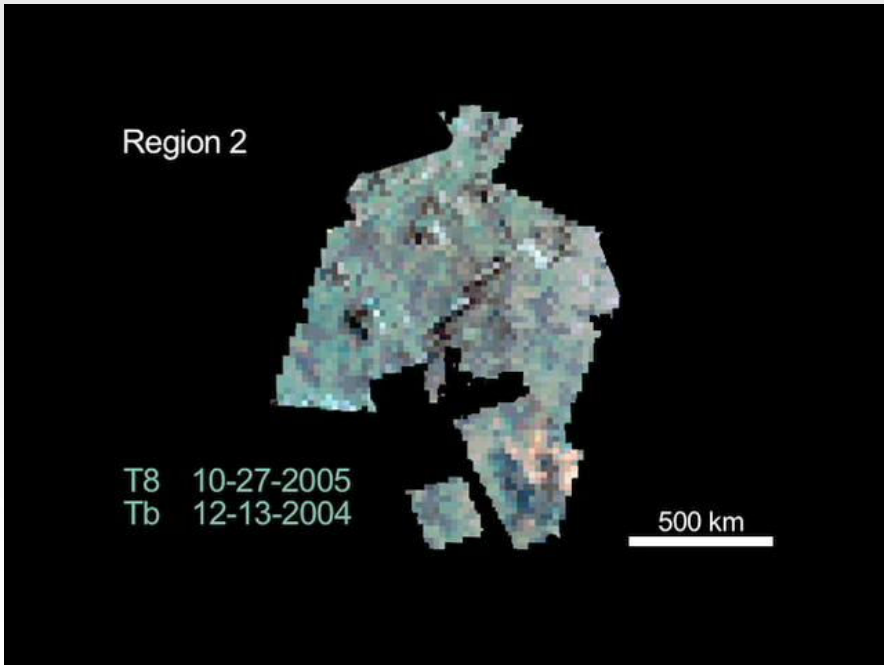
(b)

Probable cryovolcanic sites

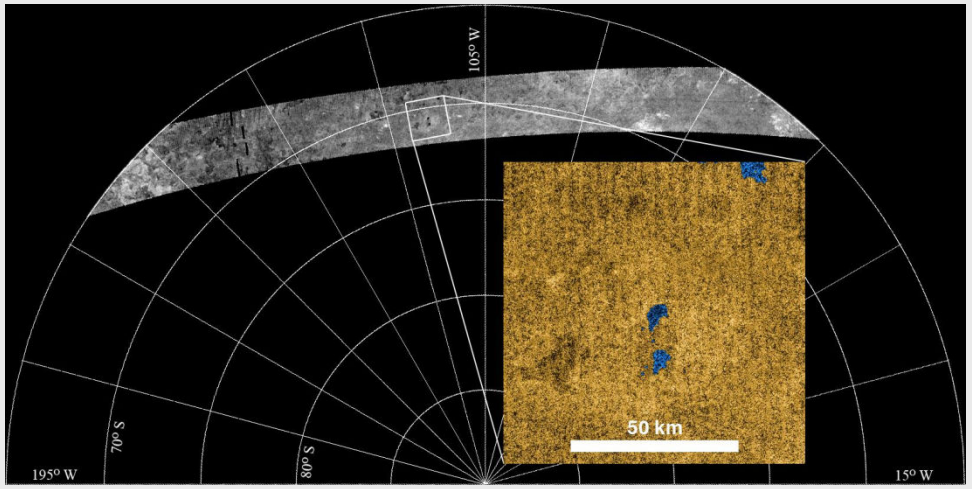
Hotei Arcus

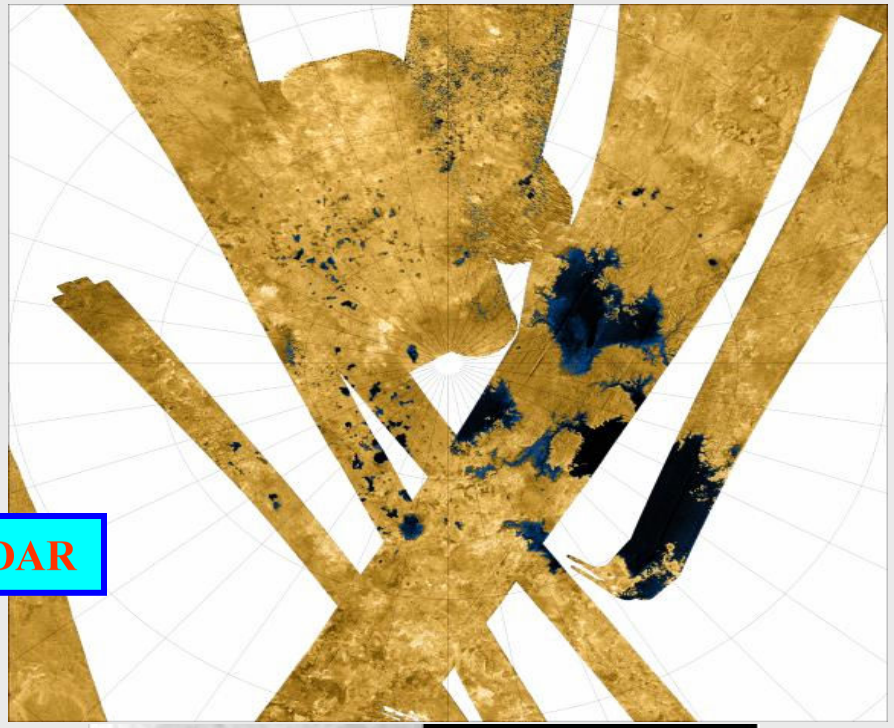






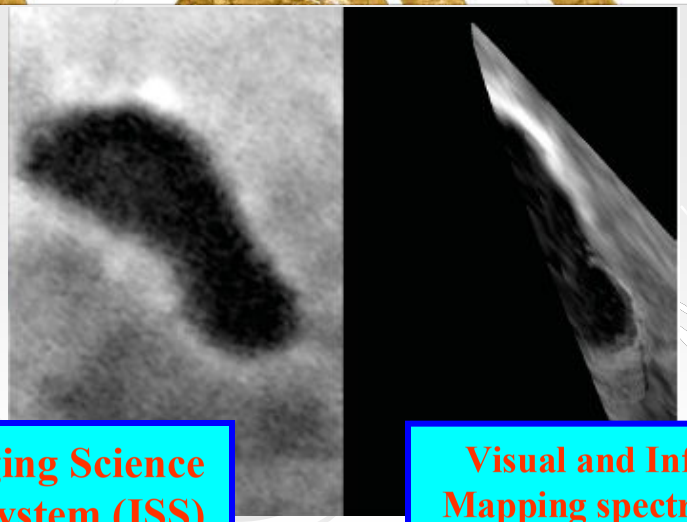
Titan's Land-o-Lakes!





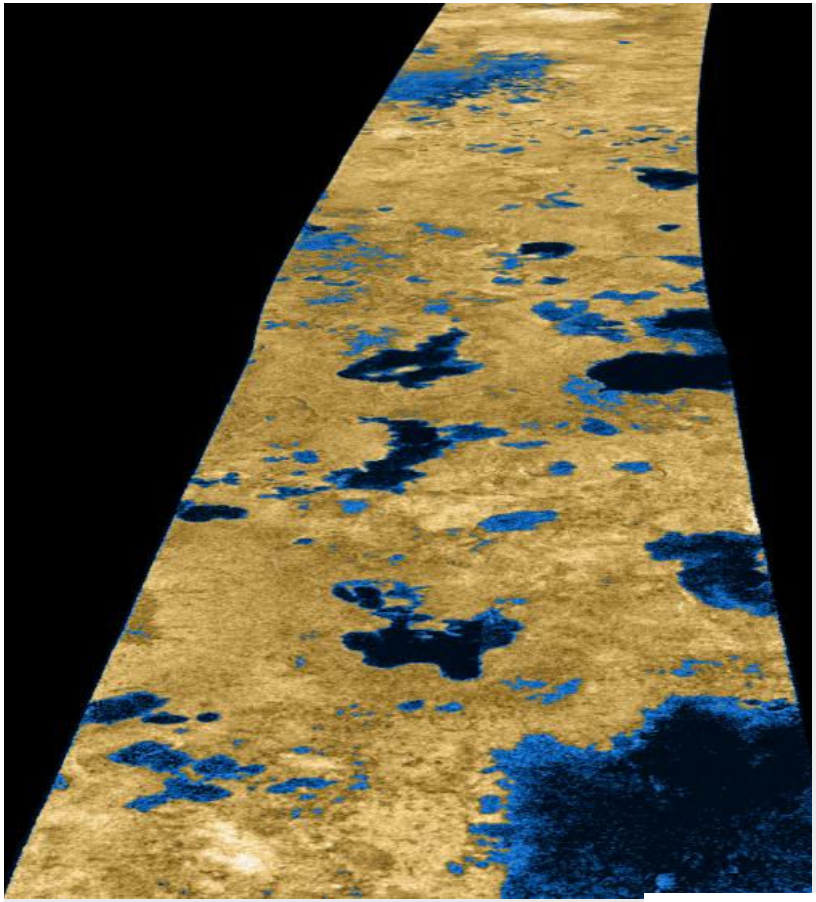
RADAR

- Lakes discovered at North (Stofan *et al.* 2007) and South Pole
- Liquid ethane determined to be one of the components (Brown *et al.* 2008)
- Only known active lake system on any solar system object apart from Earth



Imaging Science Subsystem (ISS)

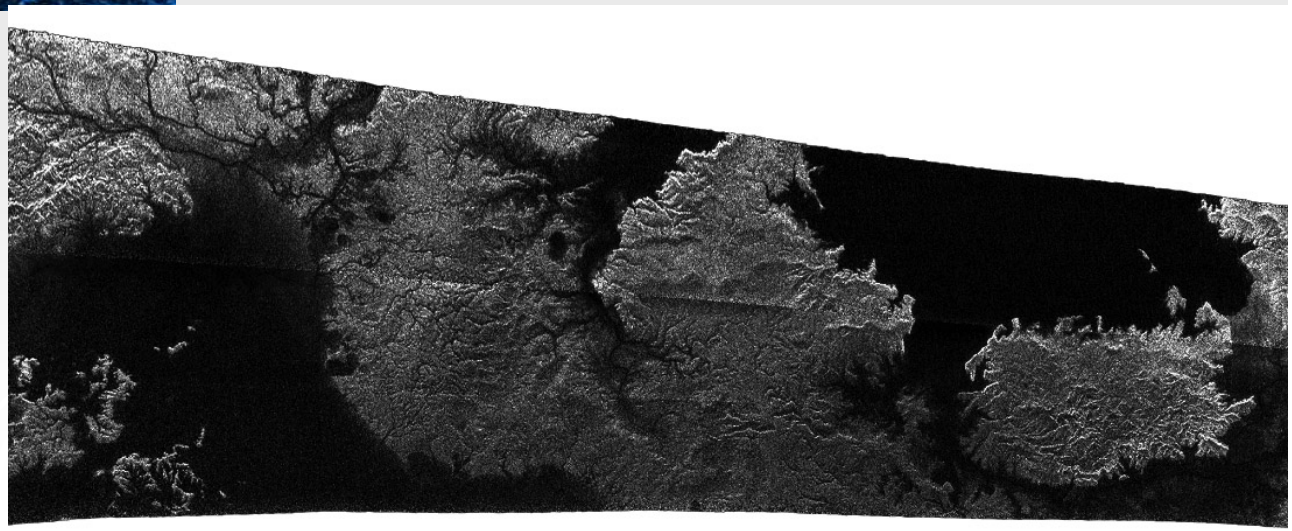
Visual and Infrared Mapping spectrometer (VIMS)

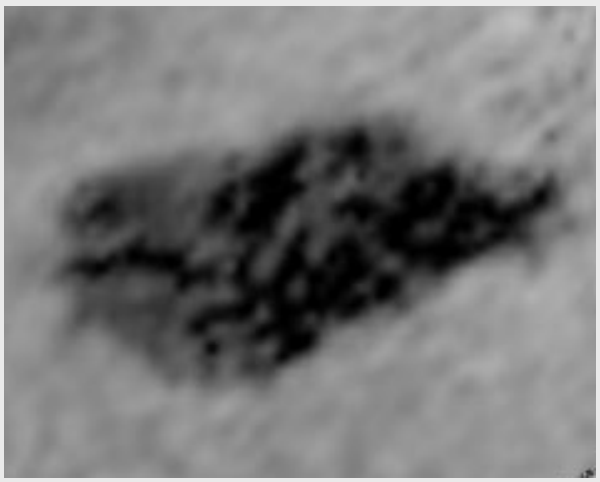


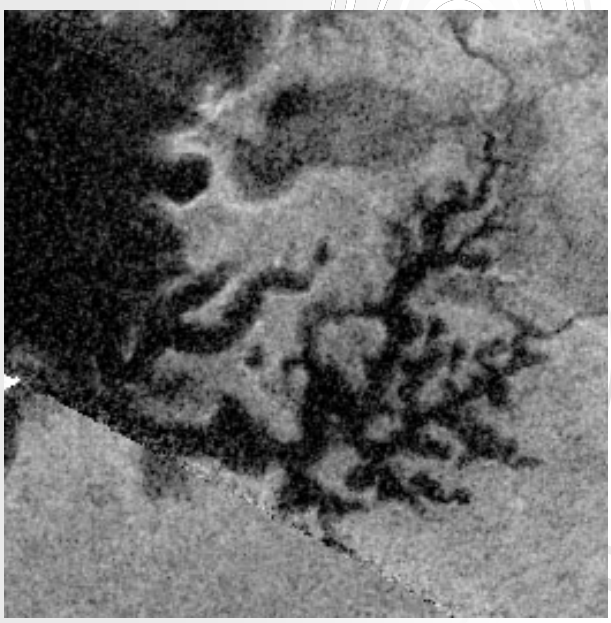
Evidences in support of lake interpretation

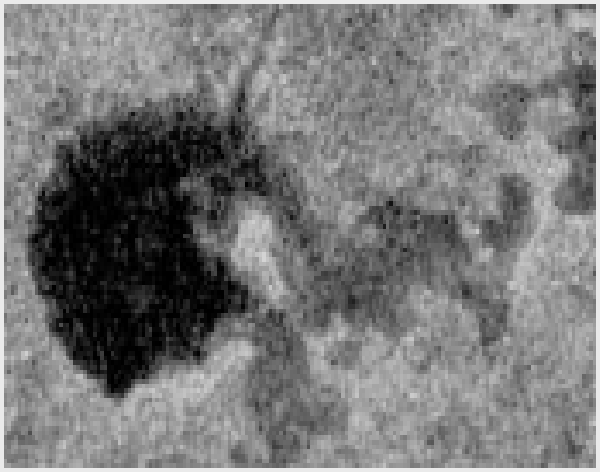
- Noise-floor level backscatter
- Higher brightness temperatures over the features compared to the surrounding region
- Presence of channels going in and coming out of the dark features
- Liquid ethane composition

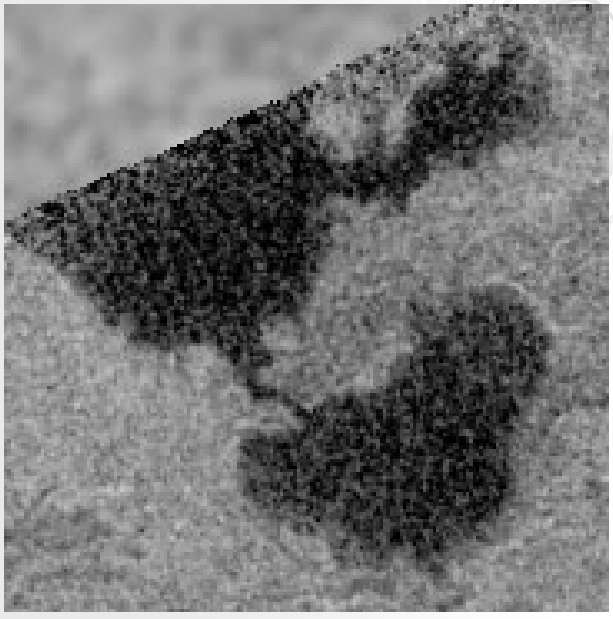
(VIMS discovery)

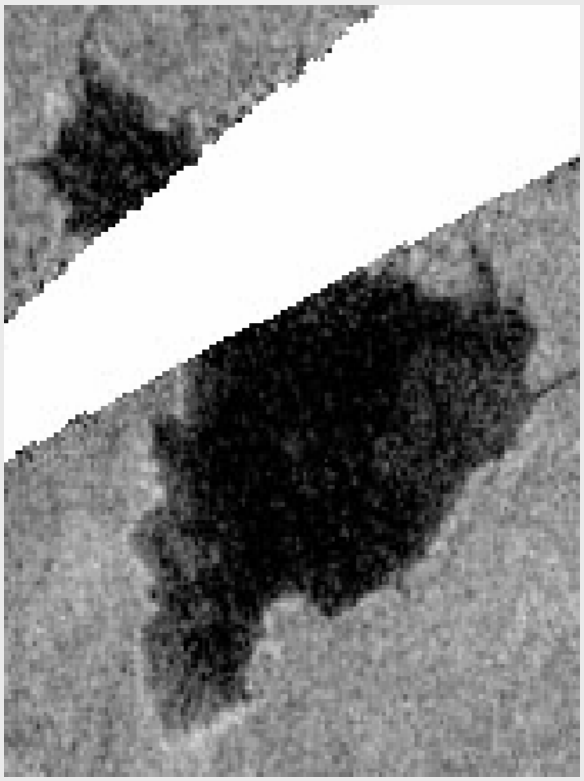






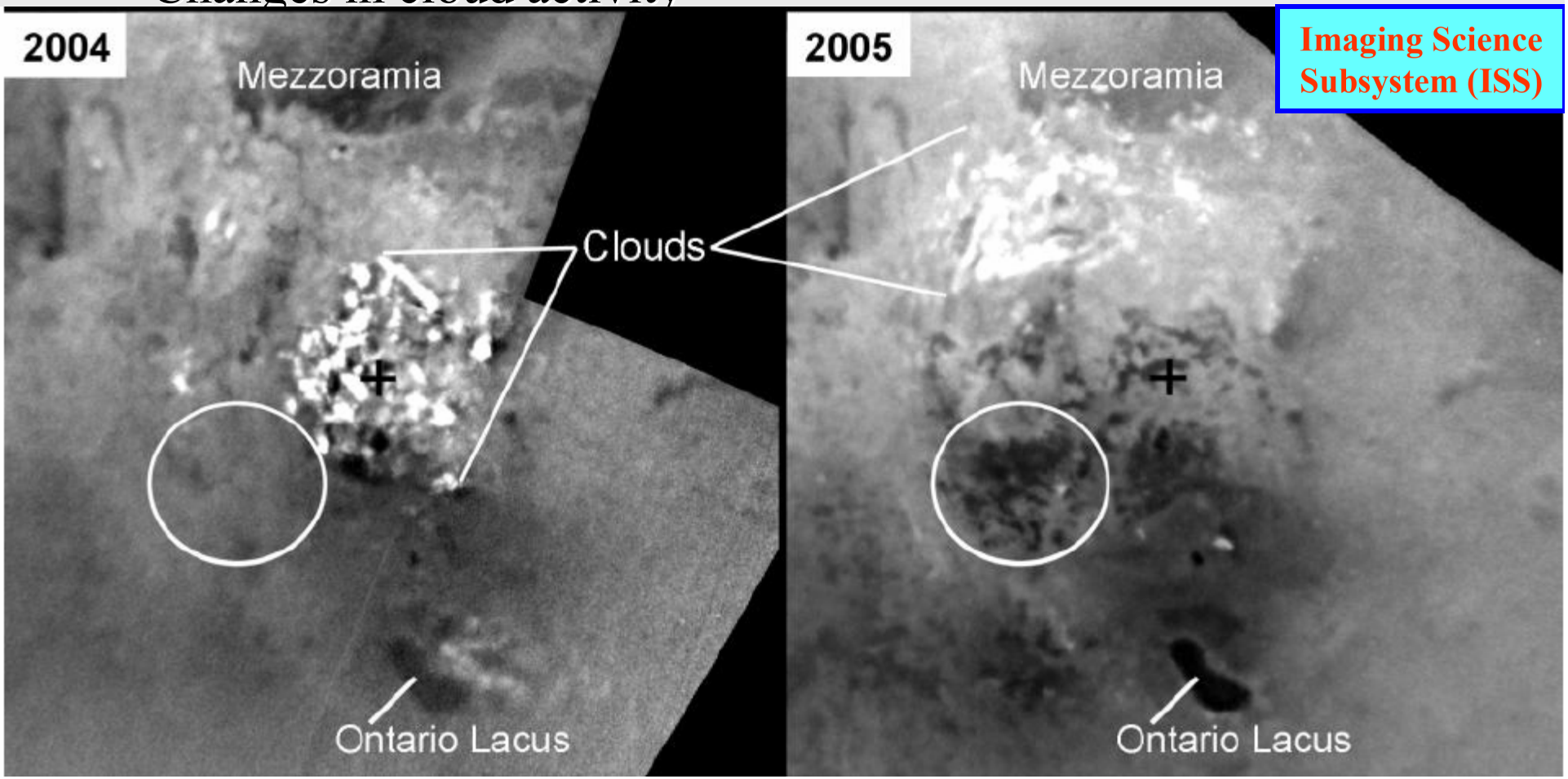




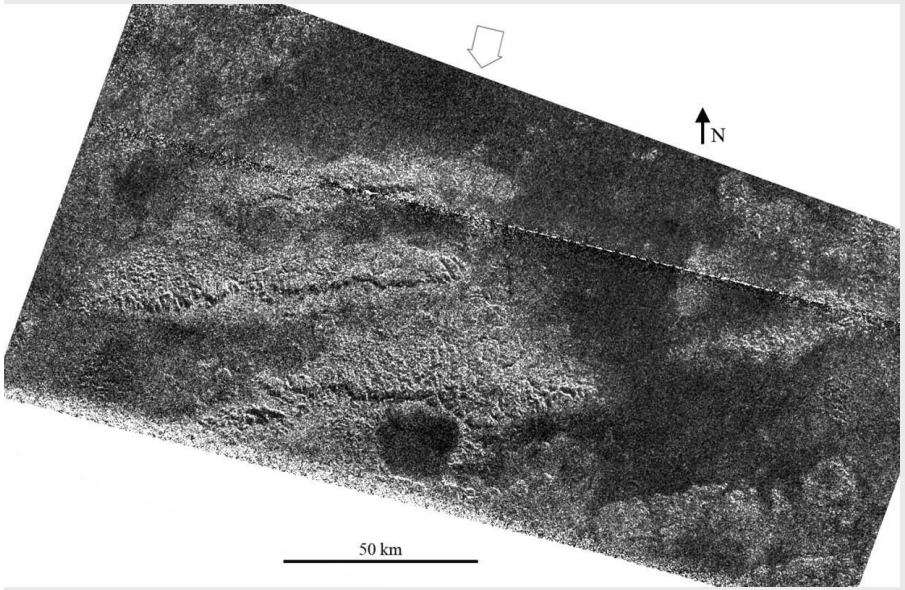


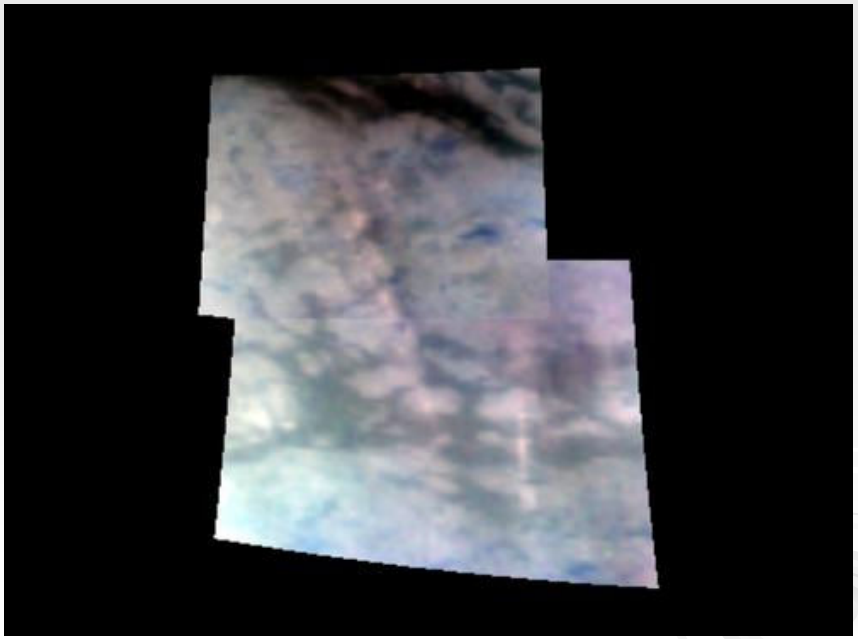
Temporal evolution of lakes at South Pole

- Changes in brightness over the course of a year
- New dark areas visible over South Pole
- Rain from large storm?
- Changes in cloud activity

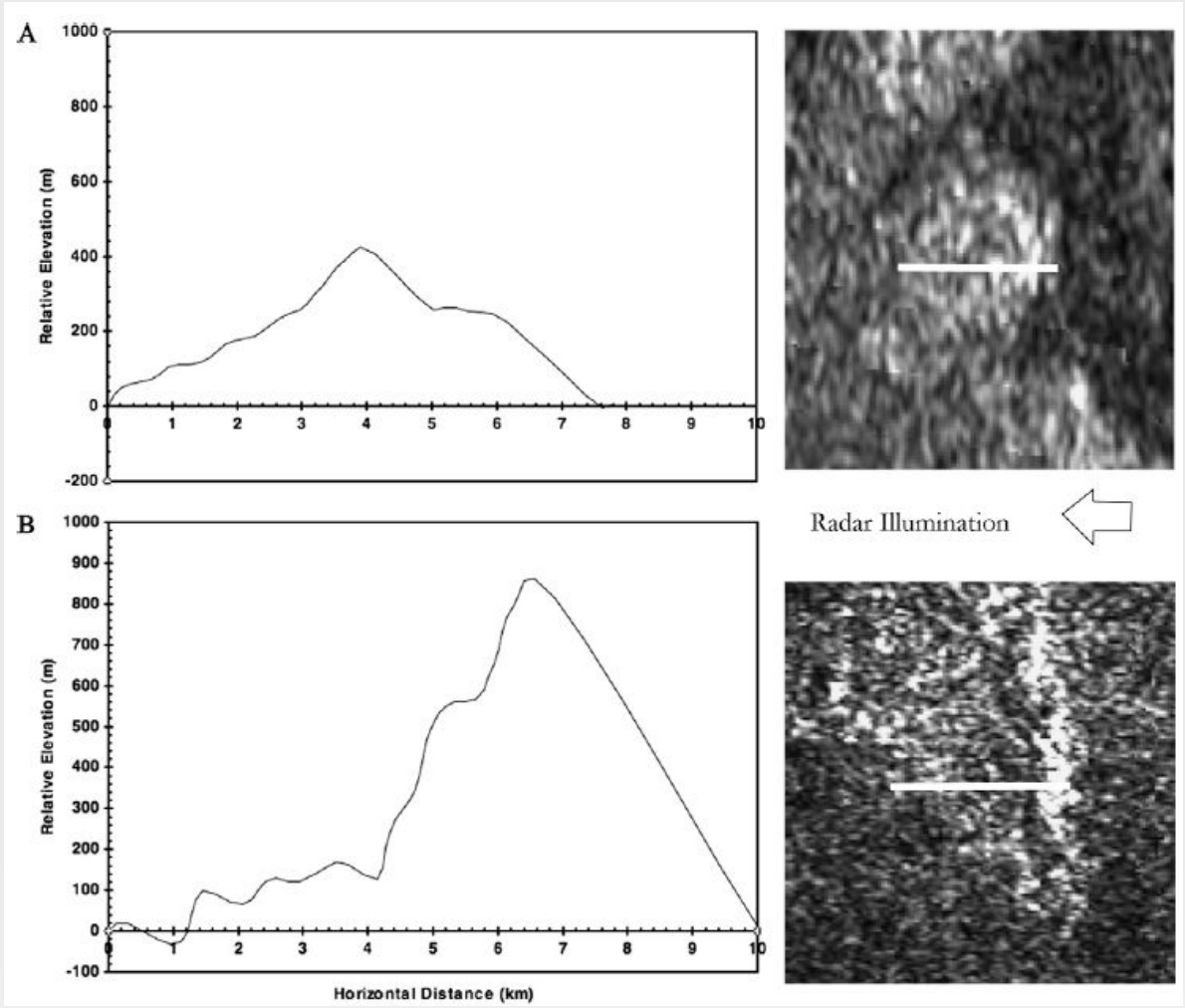


Tectonics on Titan





- Mountain ranges imaged both by VIMS and RADAR
- Possible formation mechanisms:
  - Crustal compressional tectonism and upthrusting of blocks
  - Extensional tectonism and formation of horst-and-graben
  - Deposition as blocks of impact ejecta
  - Dissection and erosion of a preexisting layer of material

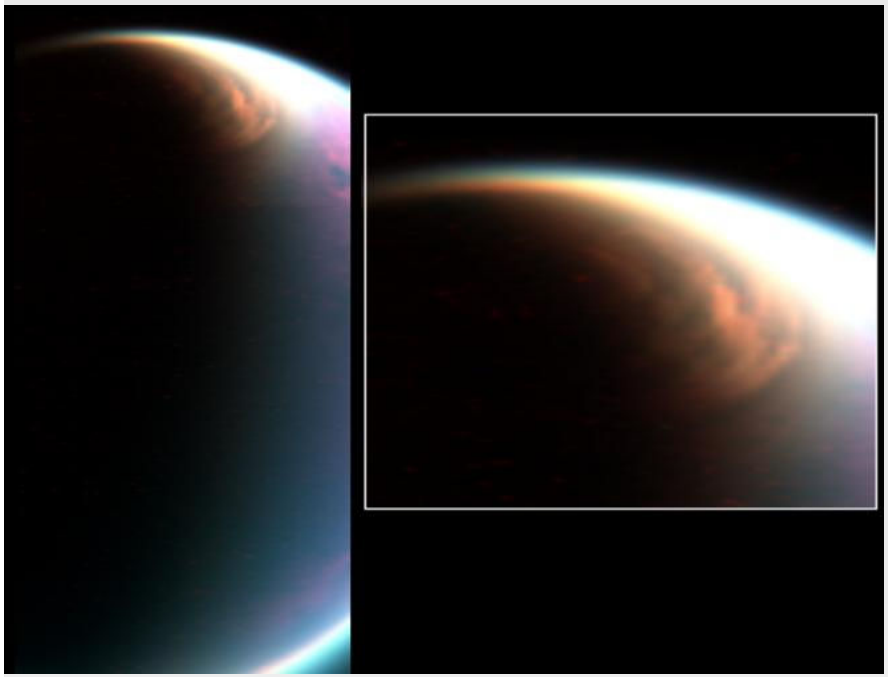


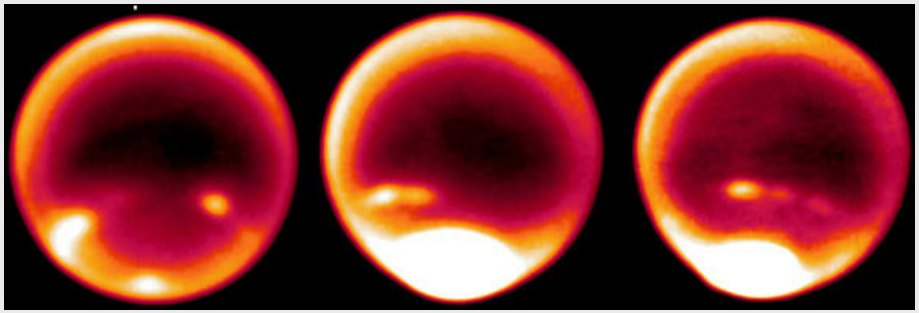
- Radarclinometry (shape-from-shading) used to infer mountain heights and slopes

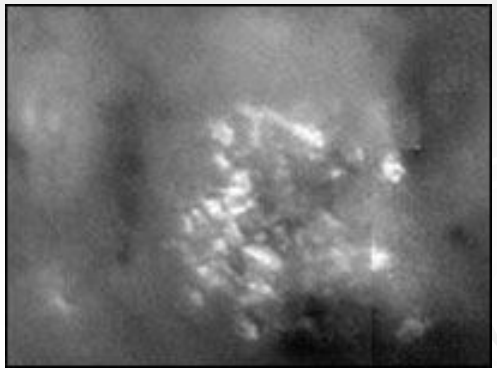
- Mean slope ~37°, max elevations ~ 1930m

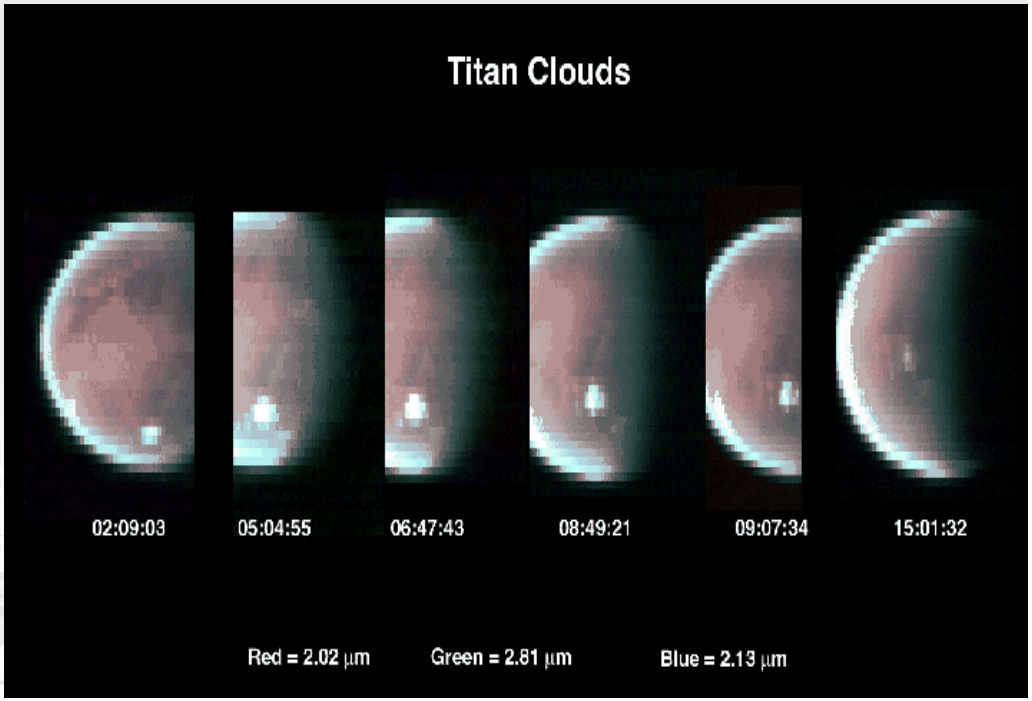
Clouds on Titan

- Mainly observed at the poles and at 40°S
- Dynamic systems; disappear in few hours









Possibility of life on Titan

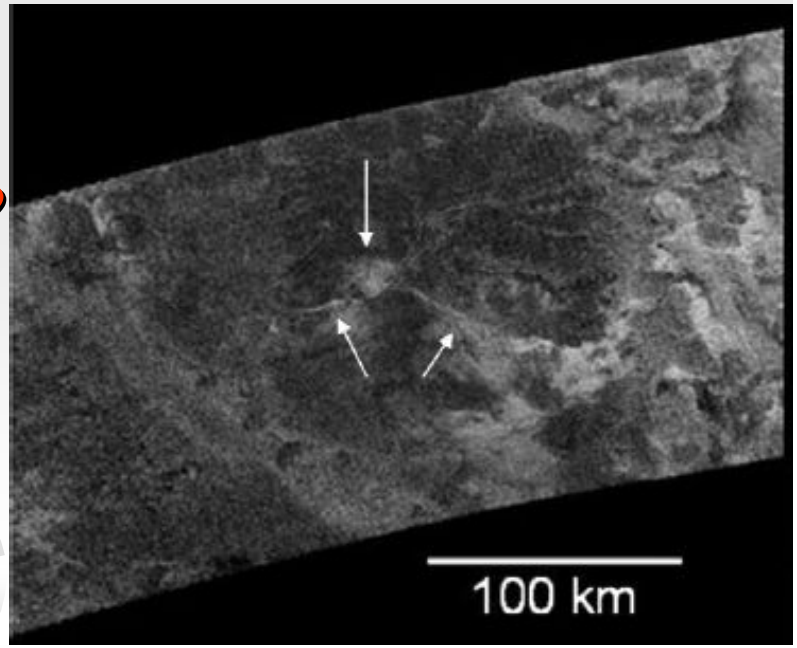
+

→ Biological molecules like amino acids

Hydrolysis of tholins

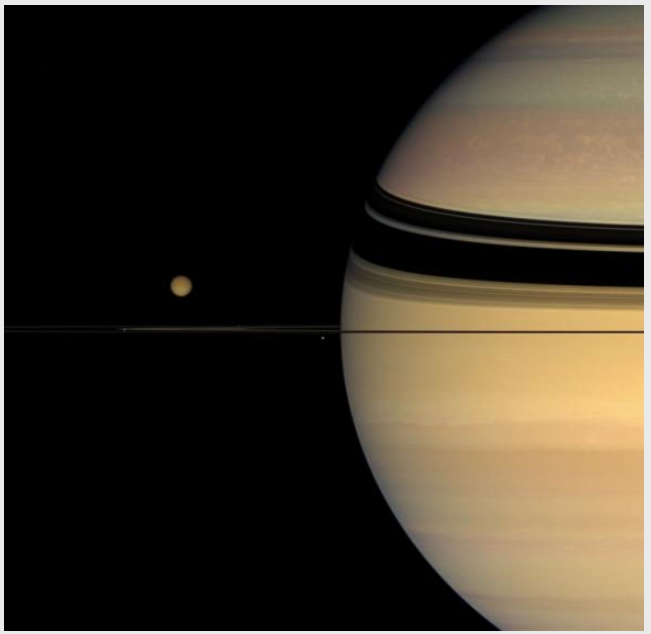
But where will the water come from?

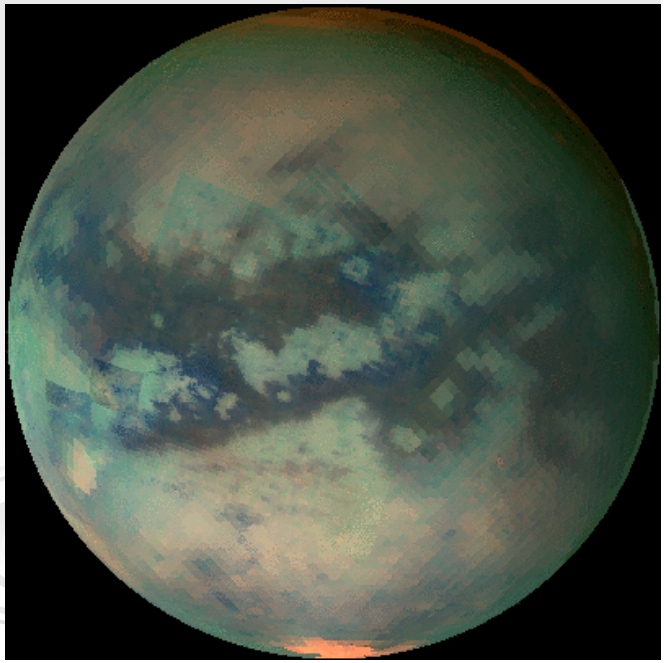
- Cryovolcanism →
- Impacts



Unanswered questions about Titan

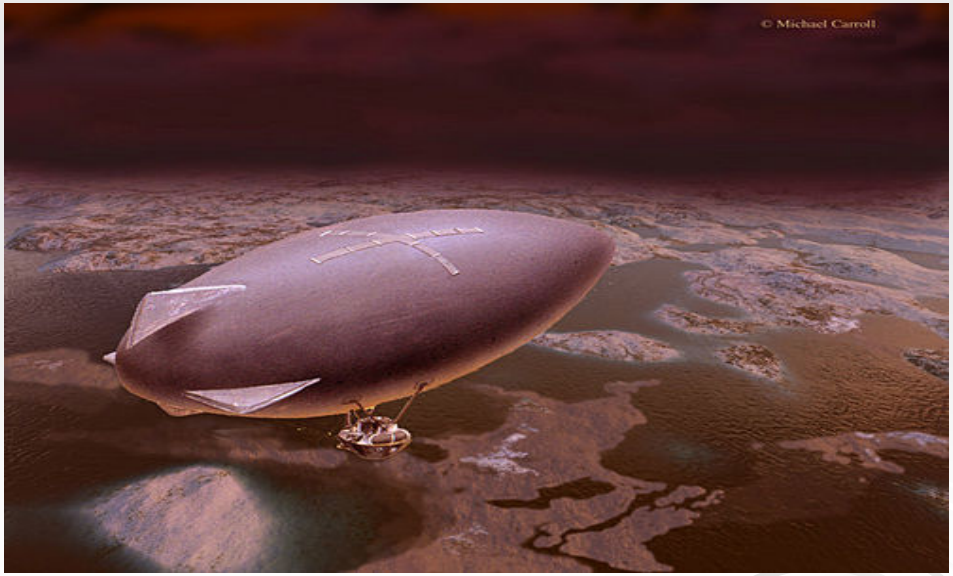
- How did Titan get its atmosphere?
- What is the source of all the methane? Why hasn't it exhausted by now?
- Where is all the ethane?
- How can the localization of clouds at 40° S be explained?
- What is the surface composition of Titan?
- Which surface processes are dominant on Titan?
- Could biological molecules be synthesized on Titan?

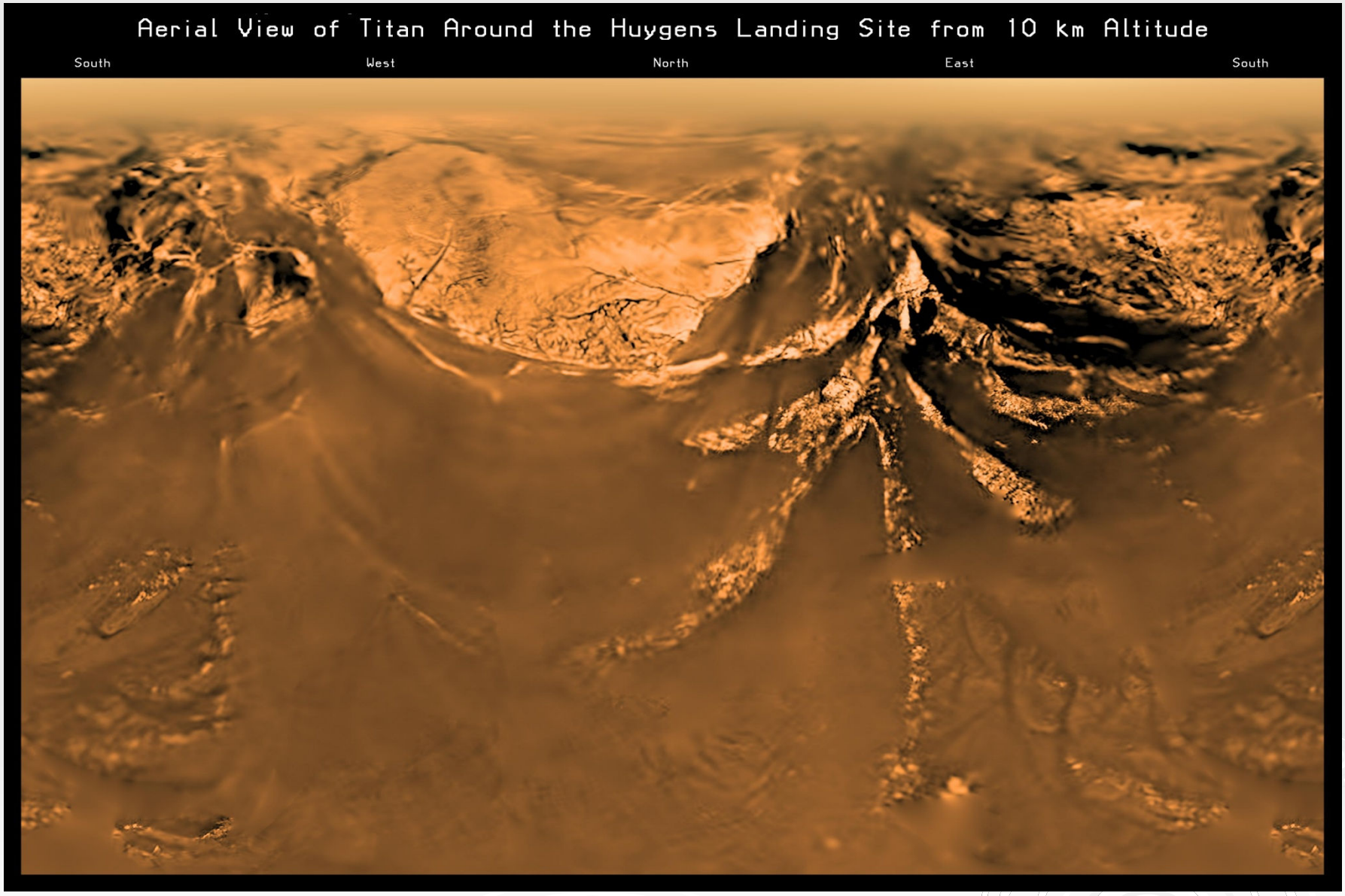




Future Missions

- Airborne platform
- Cover vast distances
- Balloons can take advantage of blowing winds
- Sample Acquisition Devices




Aerial View of Titan Around the Huygens Landing Site from 10 km Altitude
South
West
North
East
South

The End