Titan: the Moon that would be a planet
Carbon cycle, geology, and dynamics

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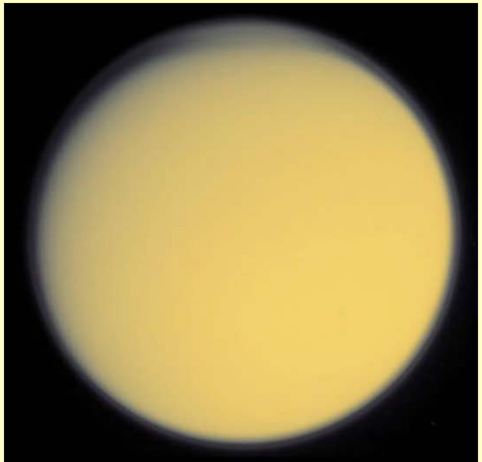
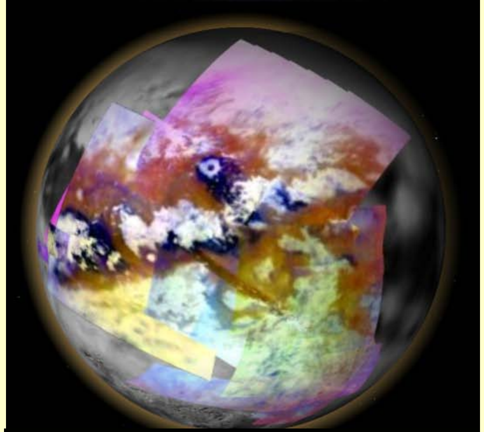
Titan is the only satellite in the solar system with a dense atmosphere and liquids at its surface

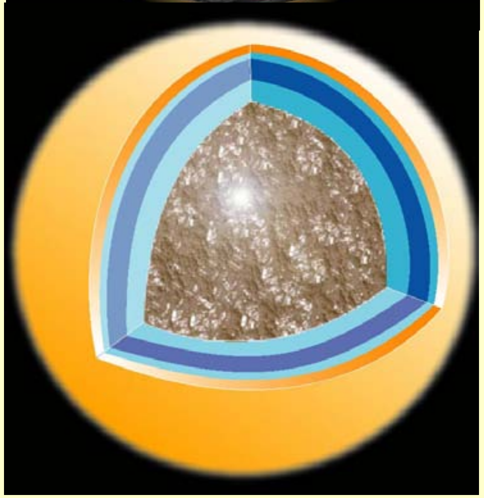
- Introduction: Titan compared to moons and planets
- Observations by the Cassini/Huygens mission
- Description of the Carbon cycle
- Surface morphology & geological implications
- Interior structure & internal dynamics
- Conclusions

References: Lorenz, R. and C. Sotin (2010) The Moon that would be a planet, R., Scientific American, 302, 20-27. Brown R.H. et al. (2009) Titan from Cassini-Huygens, Springer, 535 pp.

JPL

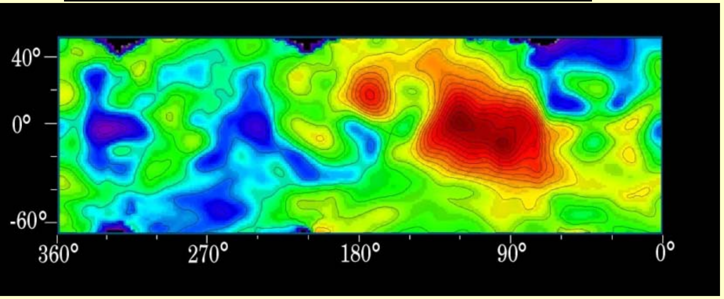




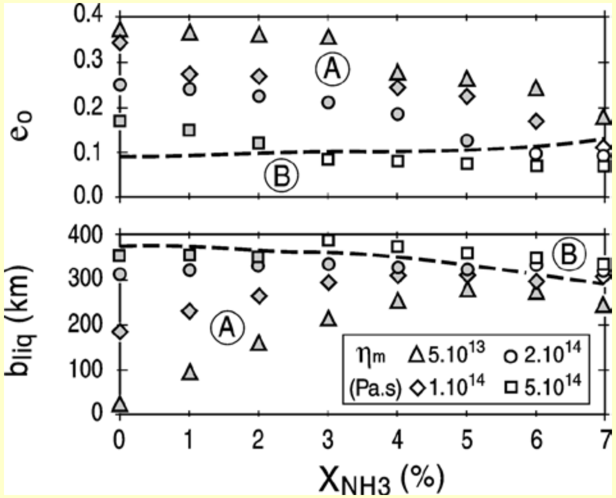


Titan before the Cassini - Huygens mission

- Mass, radius, map @ 2 µm (Meier, 2000), CH_4, N_2
- Eccentricity (interpretation by Tobie et al., 2005)
- Comparison with the Jovian icy satellites



$$\frac{de}{dt}\frac{e}{1-e^2} = -\frac{a}{GM_S M_T}\frac{dE}{dt}$$



e = 2.9 %
R= 2575 km
M = 0.1345 10^{24} kg
ρ = 1881 kg/m^3
Ice and silicates
800 GW

Titan compared to Mars and the Earth

Diameter	: 1
Mass	: 1
Pressure (surf.)	: 1 bar
Temp. (sur.)	: 15°C
Density	: 5.52
Composition	: silicates

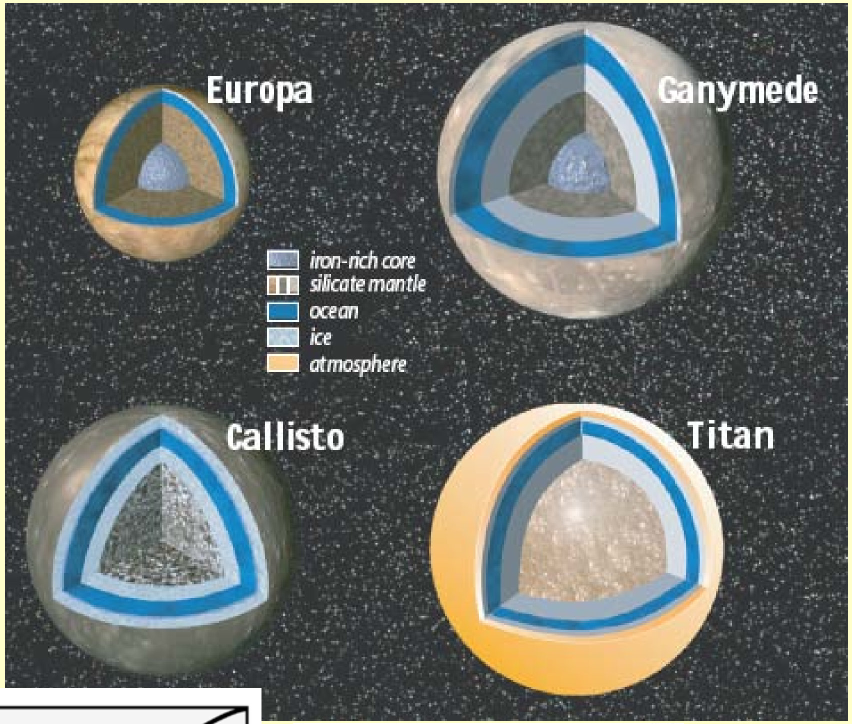
Diameter	: ~ 0.53
Mass	: ~ 1/10
Pressure (sur.)	: 0.007 bar
Temp. (sur.)	: -63°C
Density	: 3.94
Composition	: silicates

Diameter	: ~ 0,4
Mass	: ~ 1/45
Pressure (sur.)	: 1.5 bar
Temp. (sur.)	: -170°C
Density	: 1.88
Composition	: ices and silicates

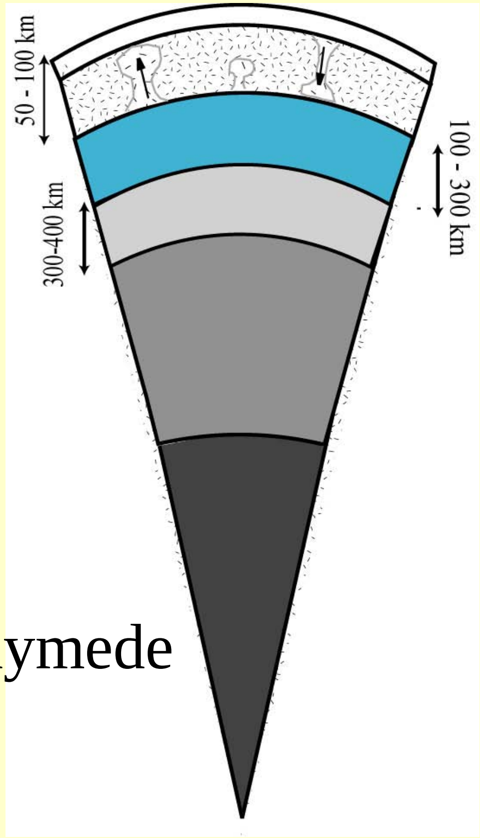
Titan compared to the Galilean icy satellites

- Mass and radius are the same than those of Ganymede and Callisto
- Ganymede is differentiated, has a liquid iron core where a dipole-like magnetic field is produced and an internal ocean that gives an induced signal
- Callisto is thought to be partly undifferentiated with an internal ocean (induced magnetic field)

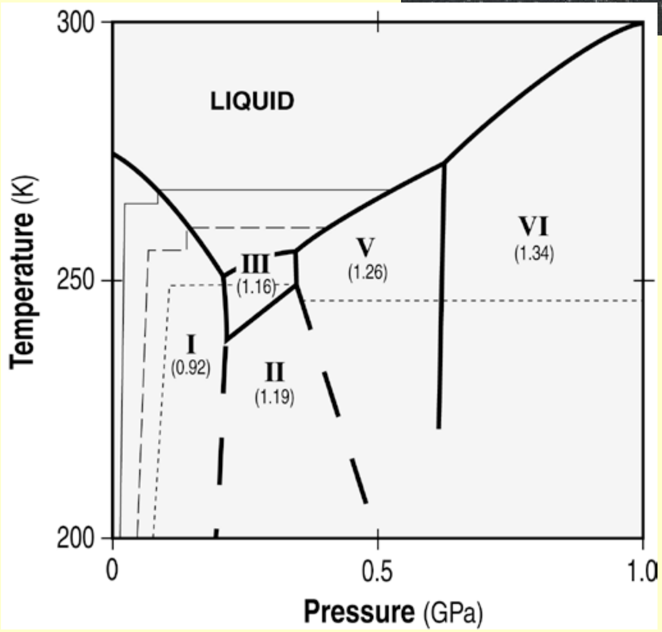
Titan compared to the Galilean icy satellites

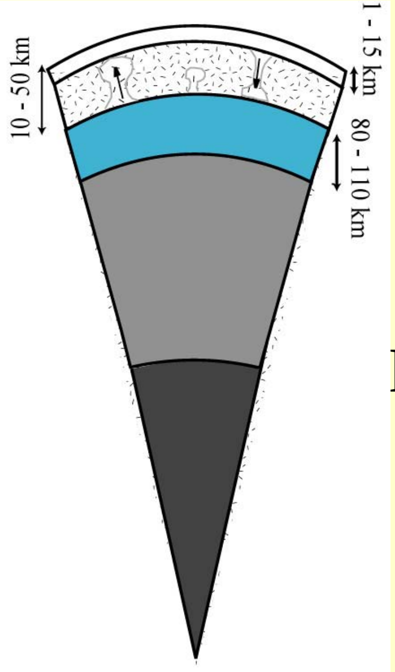


Values of the moment of inertia suggest that the galilean satellites are differentiated. Magnetic data suggest the presence of a liquid layer.



Ganymede

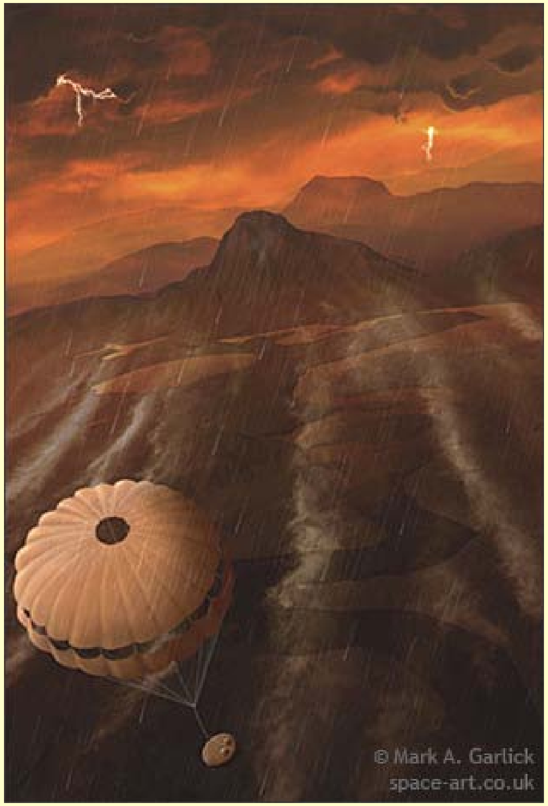


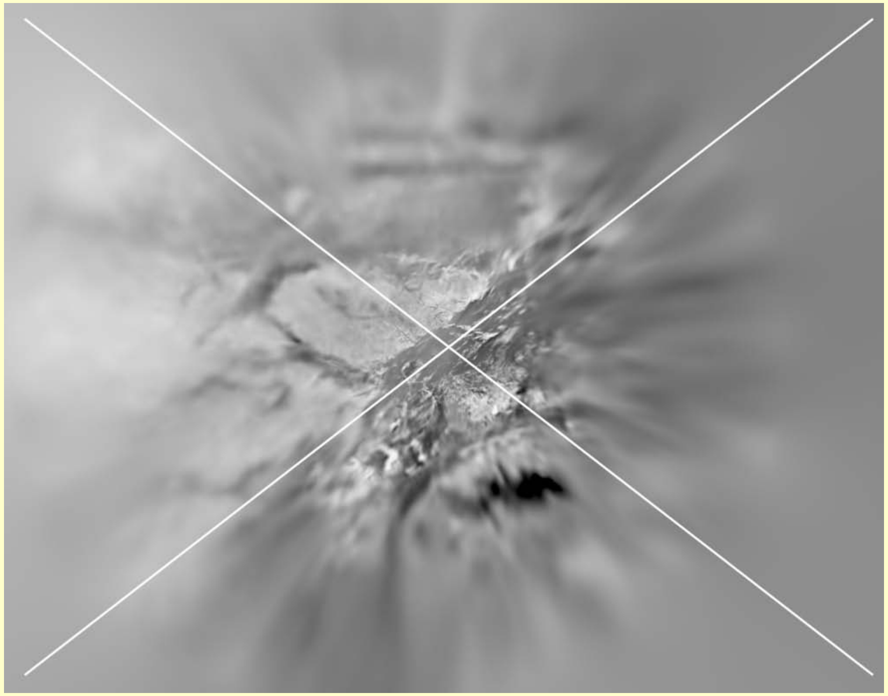


Europa

The Huygens probe – 01/14/2004

Gas Chromatograph-Mass Spectrometer (GC-MS)
Aerosol Collector & Pyrolyser (ACP)
Huygens Atmospheric Structure Instrument (HASI)
Descent Imager & Spectral Radiometer (DISR)
Doppler Wind Experiment (DWE)
Surface Science Package (SSP)

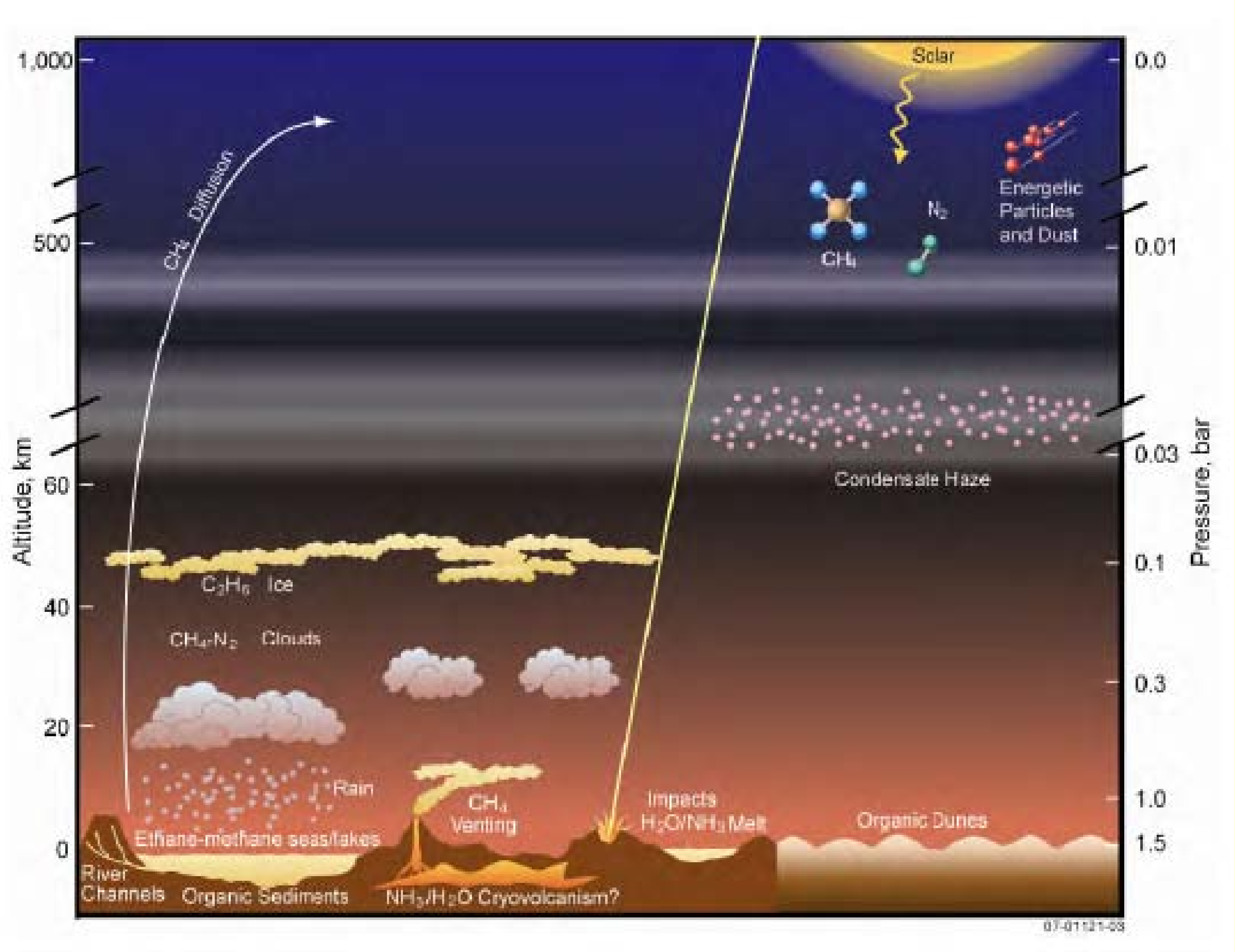




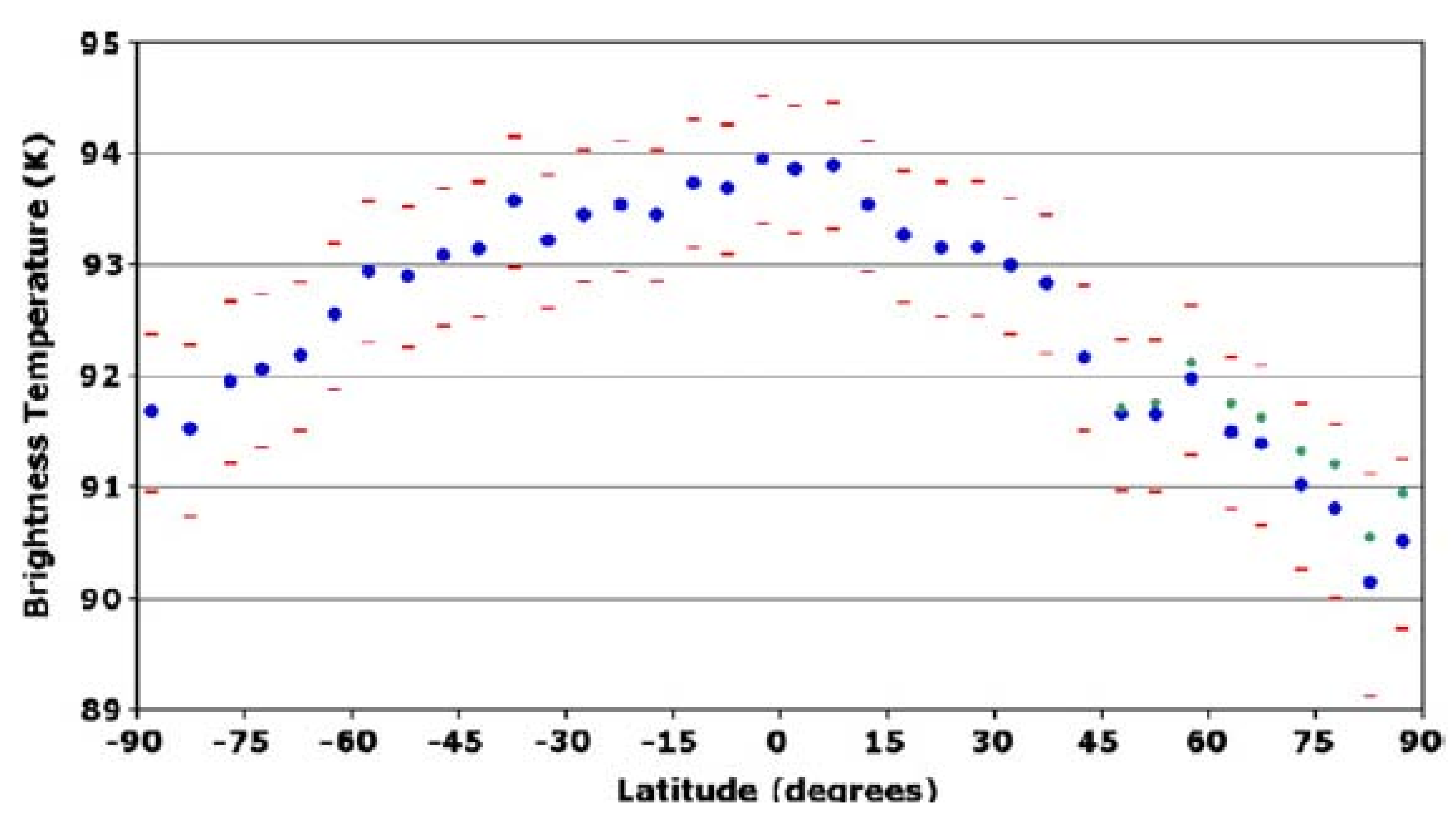
Constraints from the atmospheric composition

- CH_4 has a short lifetime (10 to 100 Ma) according to the H_2 escape rate. $2\ CH_4 \rightarrow C_2H_6 + H_2$
- Gradient in concentration from 1.67% at high altitude to 5% at the surface.
- ^{40}Ar is present – it implies exchange processes between the interior where silicates are leached and released the Argon produced by the decay of ^{40}K. And there is very little ^{36}Ar.
- The isotopic ratio $^{15}N/^{14}N$ is higher than the terrestrial value and suggests that nitrogen is primordial.
- Heavy organic molecules are being synthesized in the upper atmosphere.

Carbon cycle: transformation of methane (CH_4)



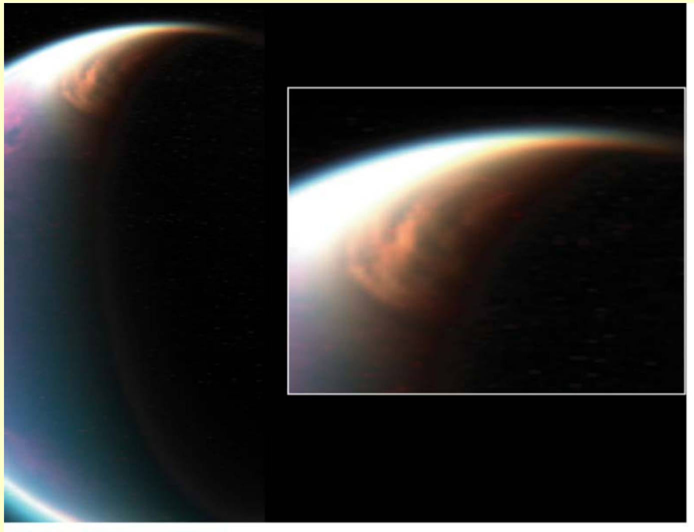
Surface temperature

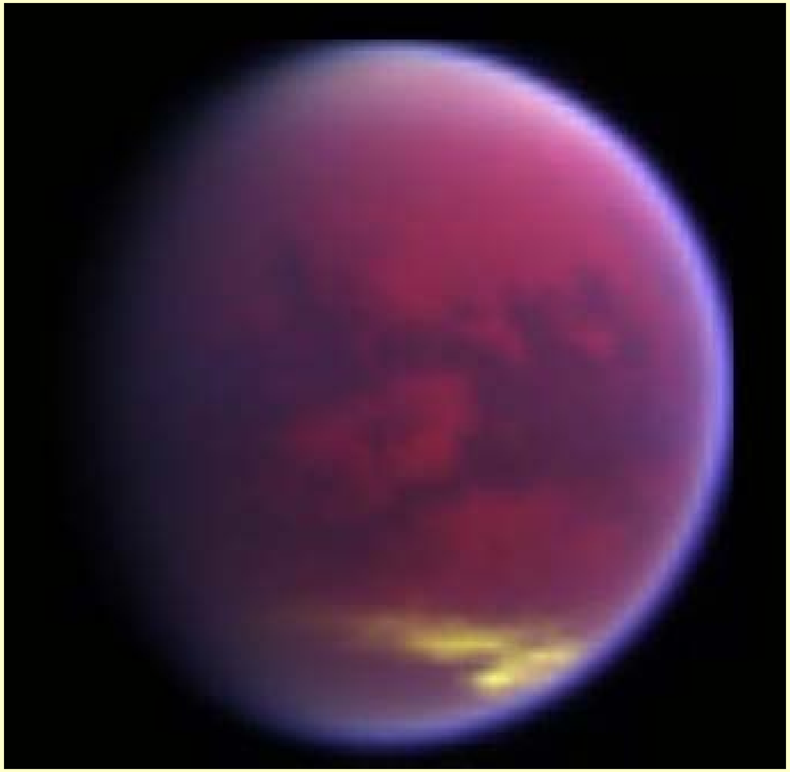


Without the greenhouse effect caused by methane, the surface temperature would be around 70 K.

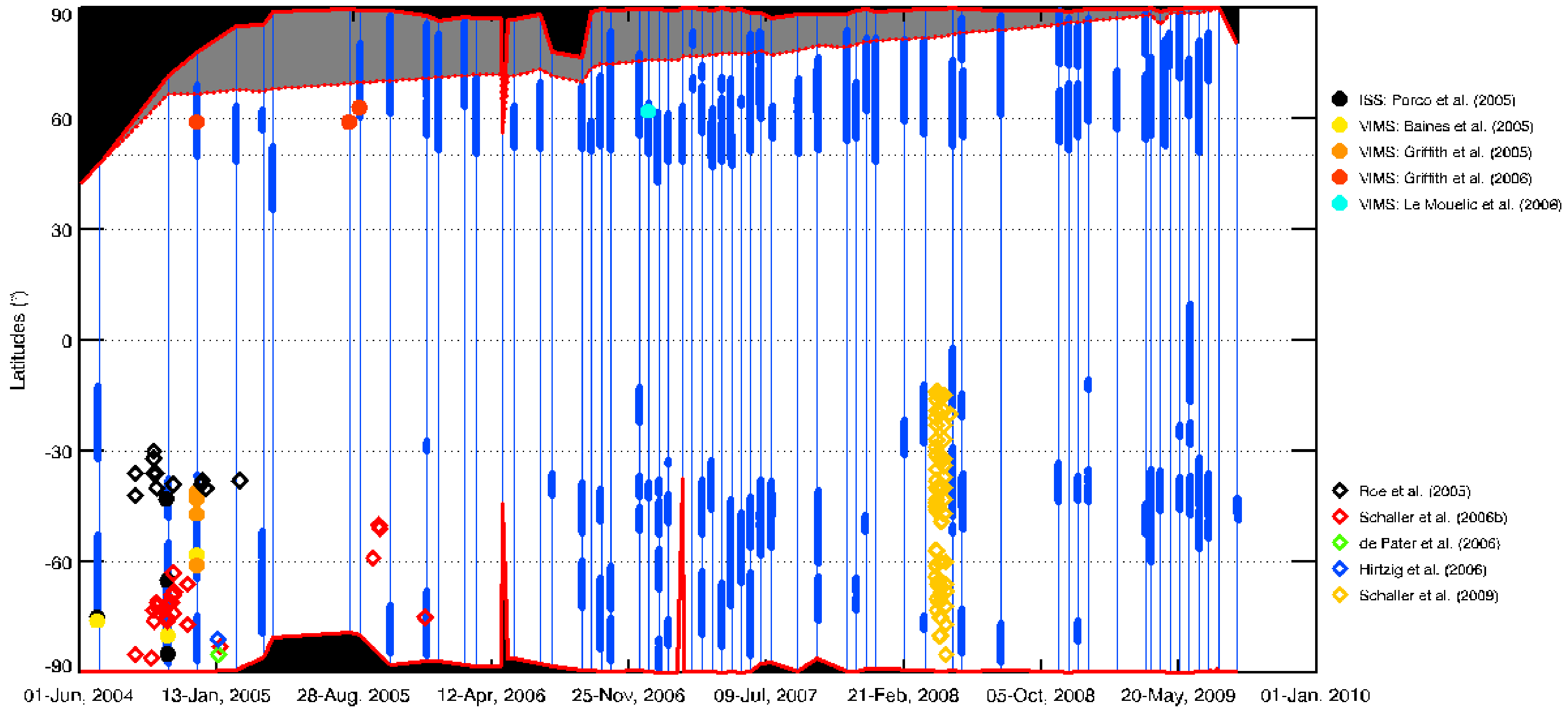
The clouds

Titan is not very cloudy compared to Earth. Ethane North polar clouds and methane mid-latitude clouds



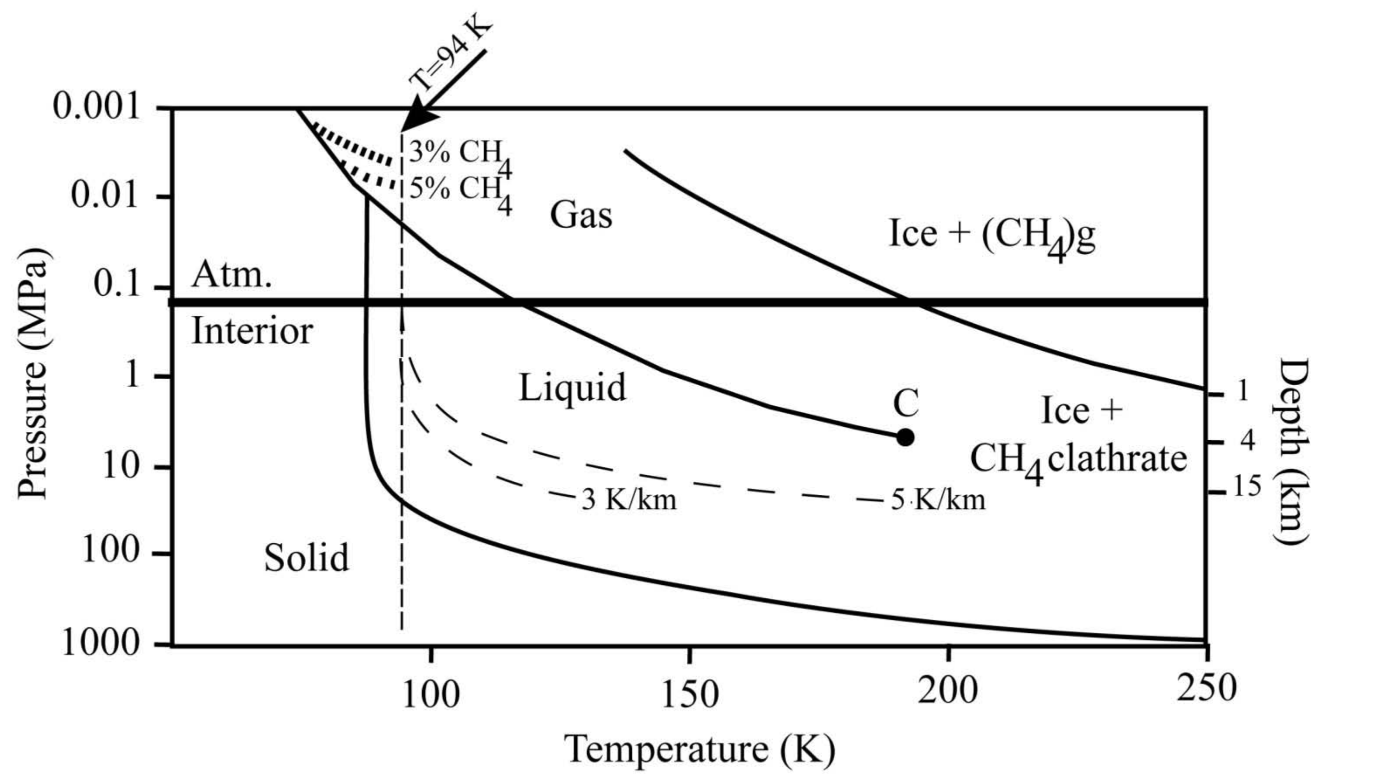


Cloud coverage

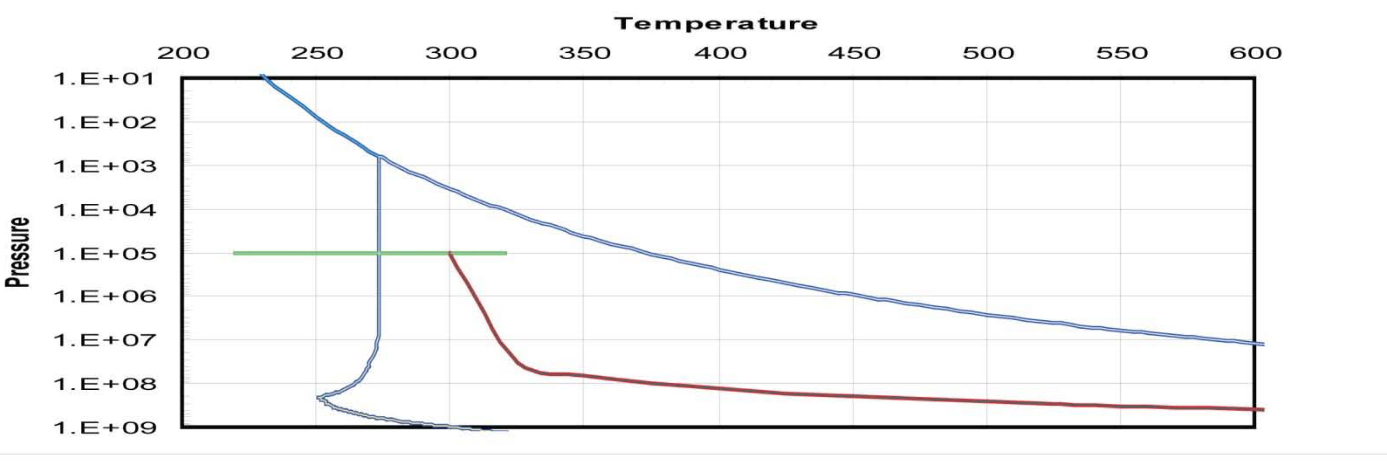


From Rodriguez et al. (2010)

CH_4 on Titan



H_2O on Earth



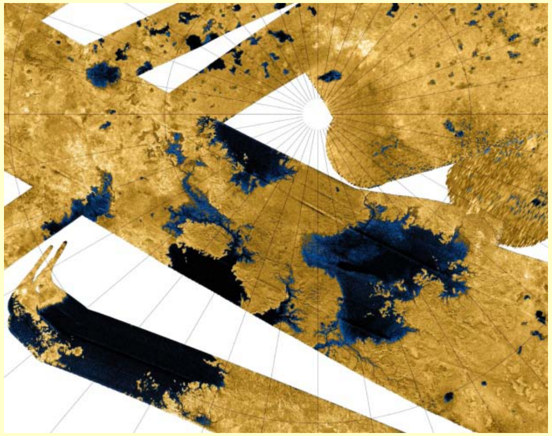
CH_4 on Titan and H_2O on Earth: similarities and differences

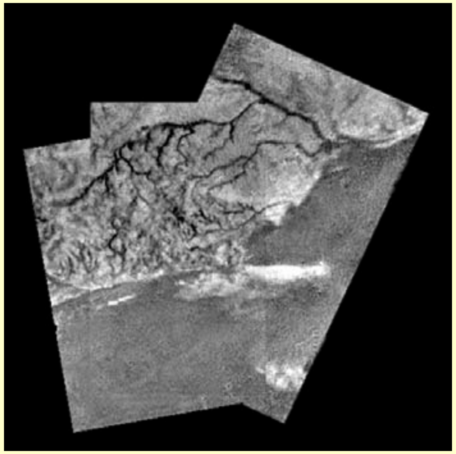
- The triple point of methane (water) is in the (Pressure, Temperature) domain of Titan (Earth)'s atmosphere.
- Methane on Titan, like water on Earth, evaporates at the surface, condenses in the atmosphere, rains, runs at the surface and fills topographic depressions.
- Methane is a very effective greenhouse gas.

BUT

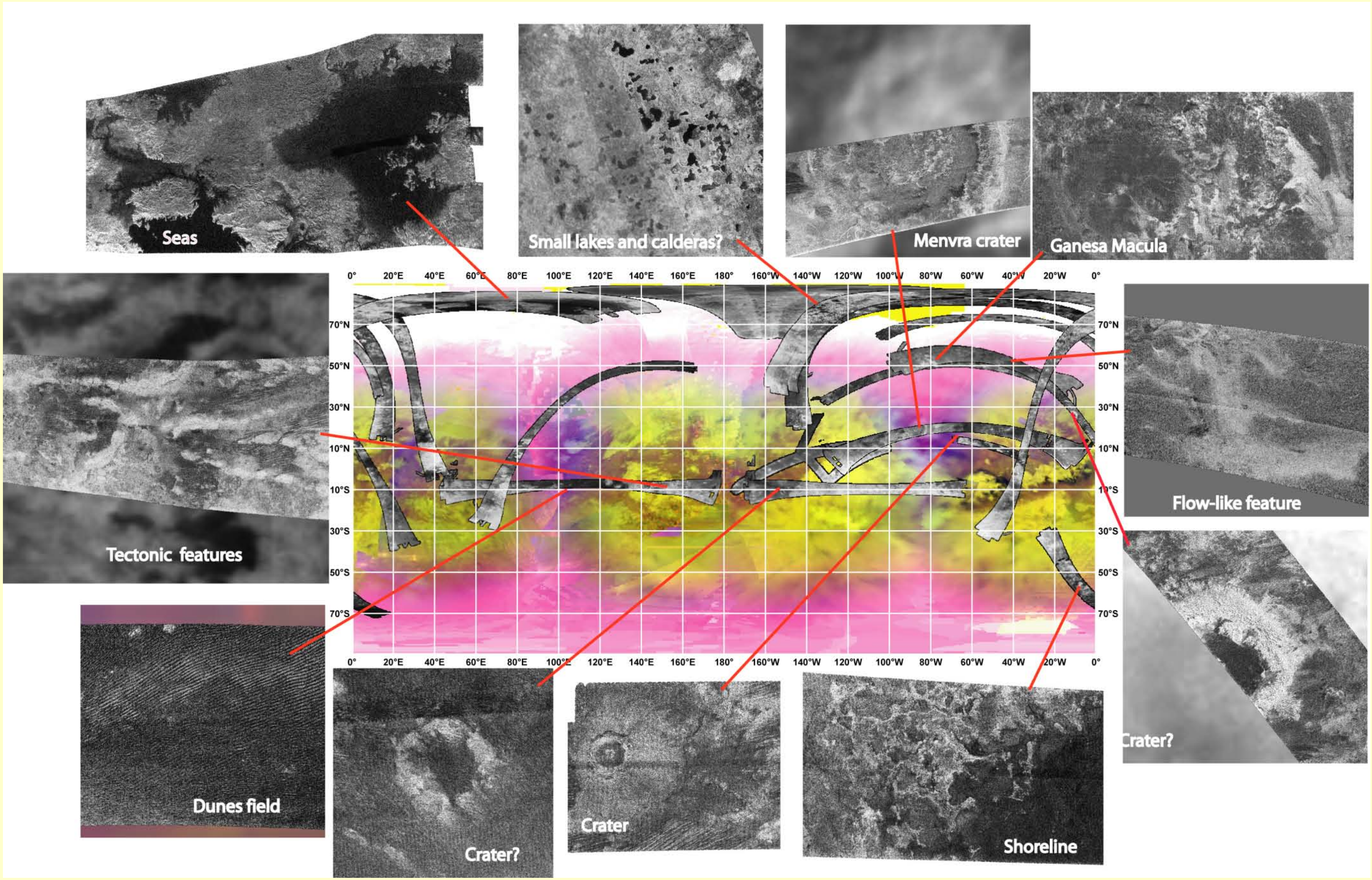
- methane irreversibly transforms into ethane
- If there is no replenishment (from the interior or from meteorites), the methane would disappear, the greenhouse effect would vanish, the surface temperature would drop, and nitrogen would freeze. All this would happen in less than 100 Myrs (likely 30 Myrs). Titan would become Triton like.

WHAT IS THE SOURCE OF METHANE ?

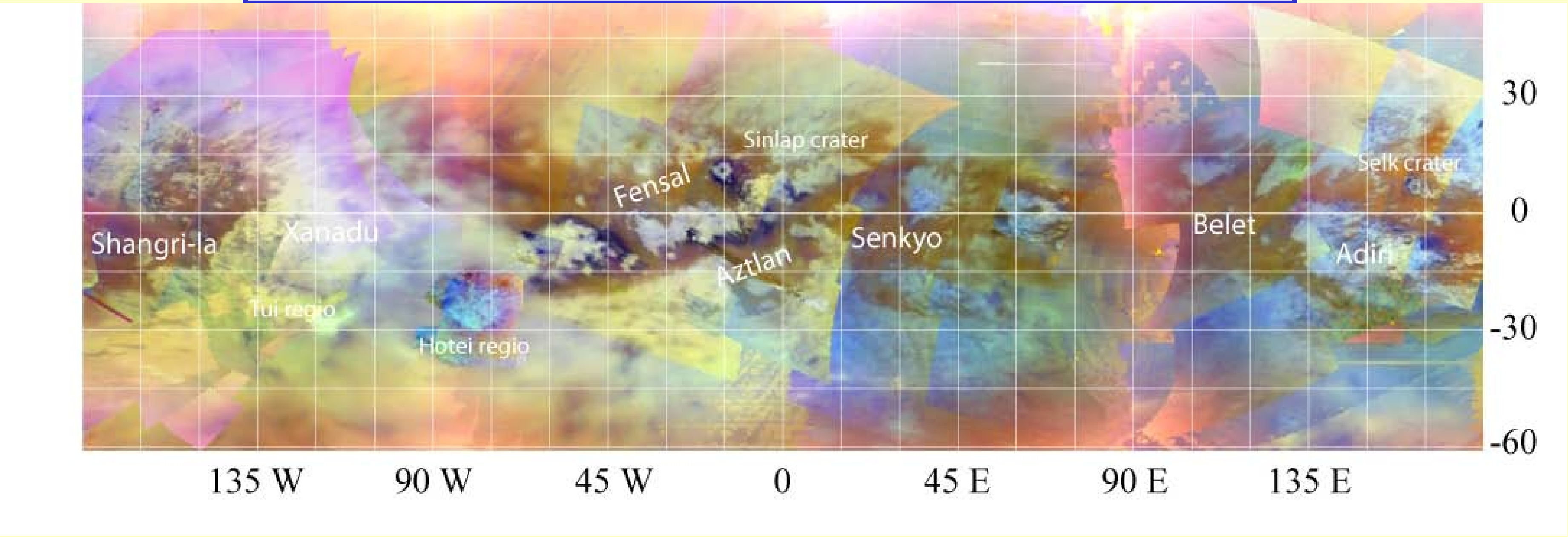




Geology – Radar observations

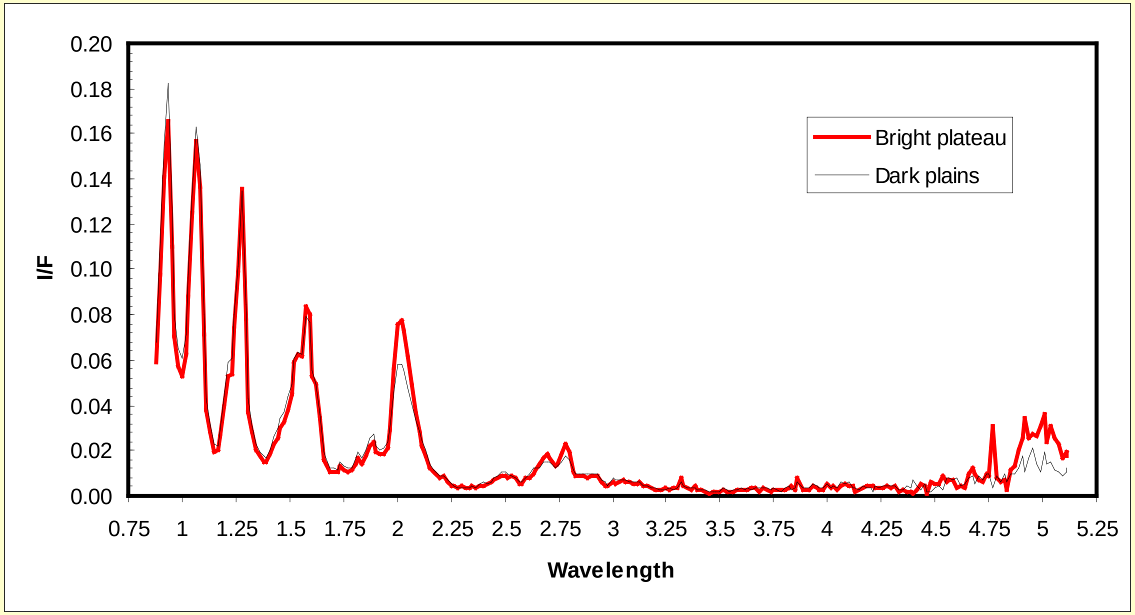


Geology: infrared observations

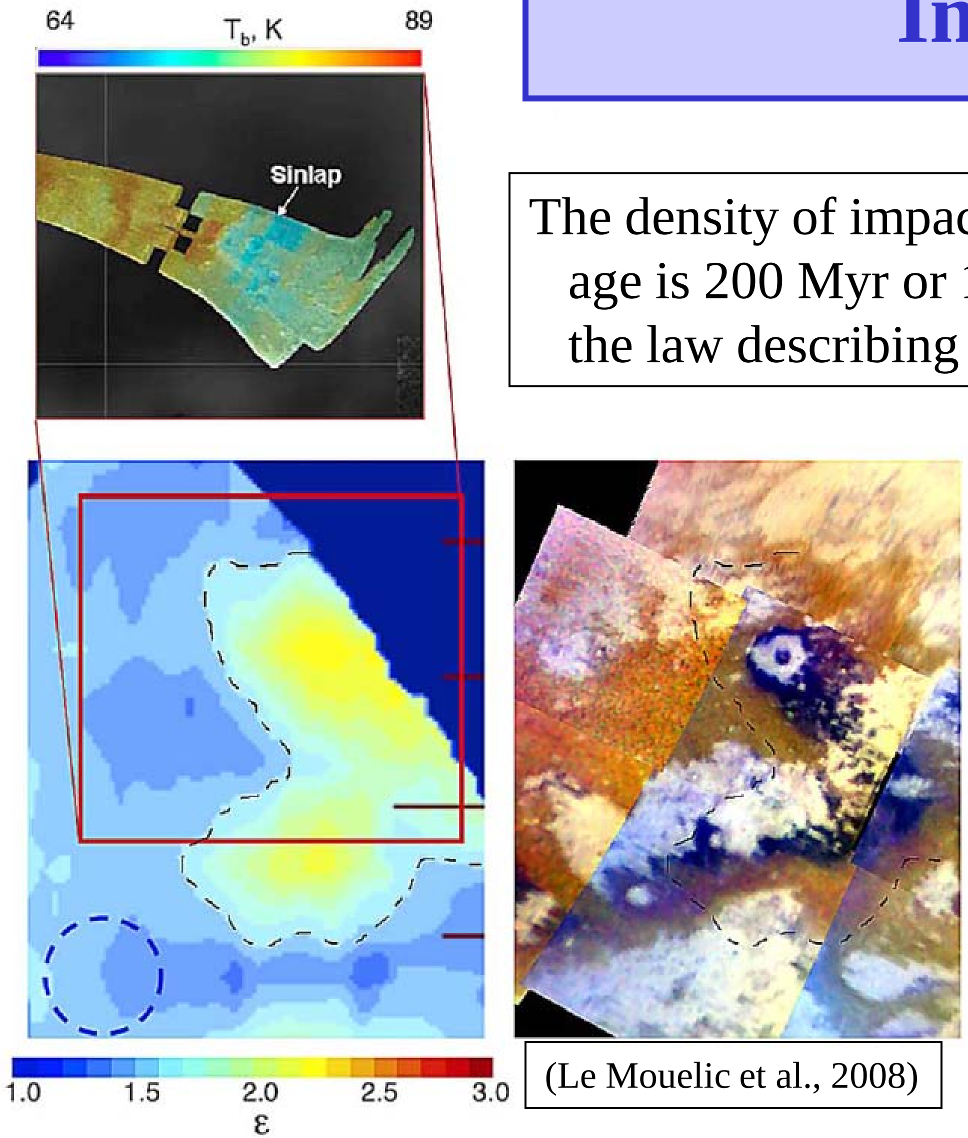


There are several infrared windows which allow us to observe Titan's surface: 0.94, 1.08, 1.28, 1.55, 2, 2.7, and 5 μm)

Infrared and radar images can be compared



Impact craters

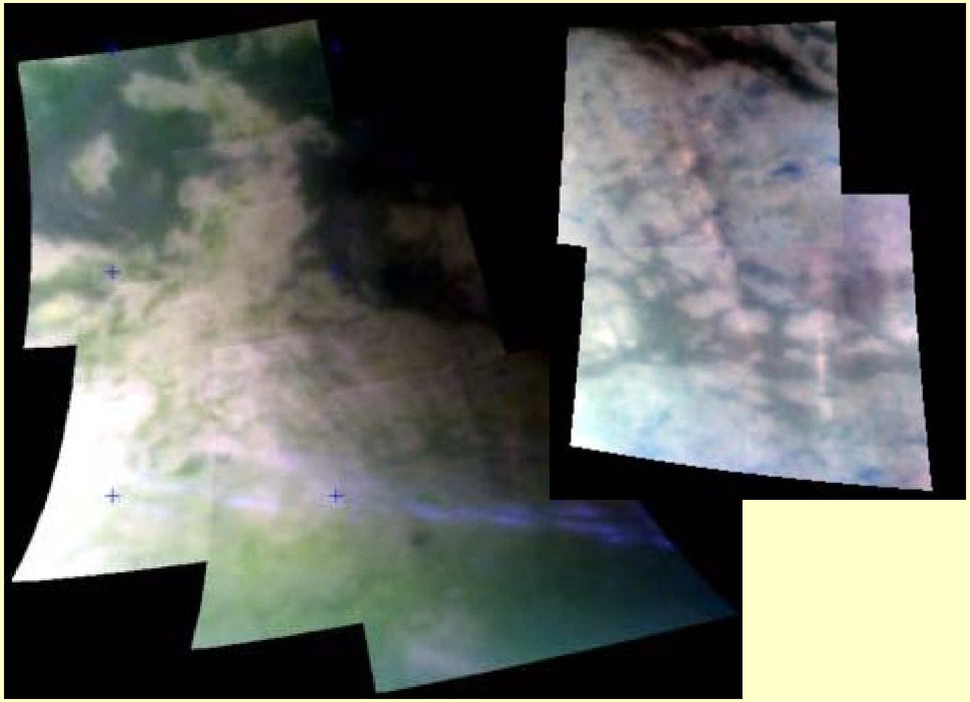


(Le Mouelic et al., 2008)

The density of impact craters is low. On average, the age is 200 Myr or 1 Byr depending on the choice of the law describing impact flux (Wood et al., 2010).

Sinlap crater is one (only) place on Titan where dielectric constant and IR spectra are correlated and suggest enrichment in H2O ice.

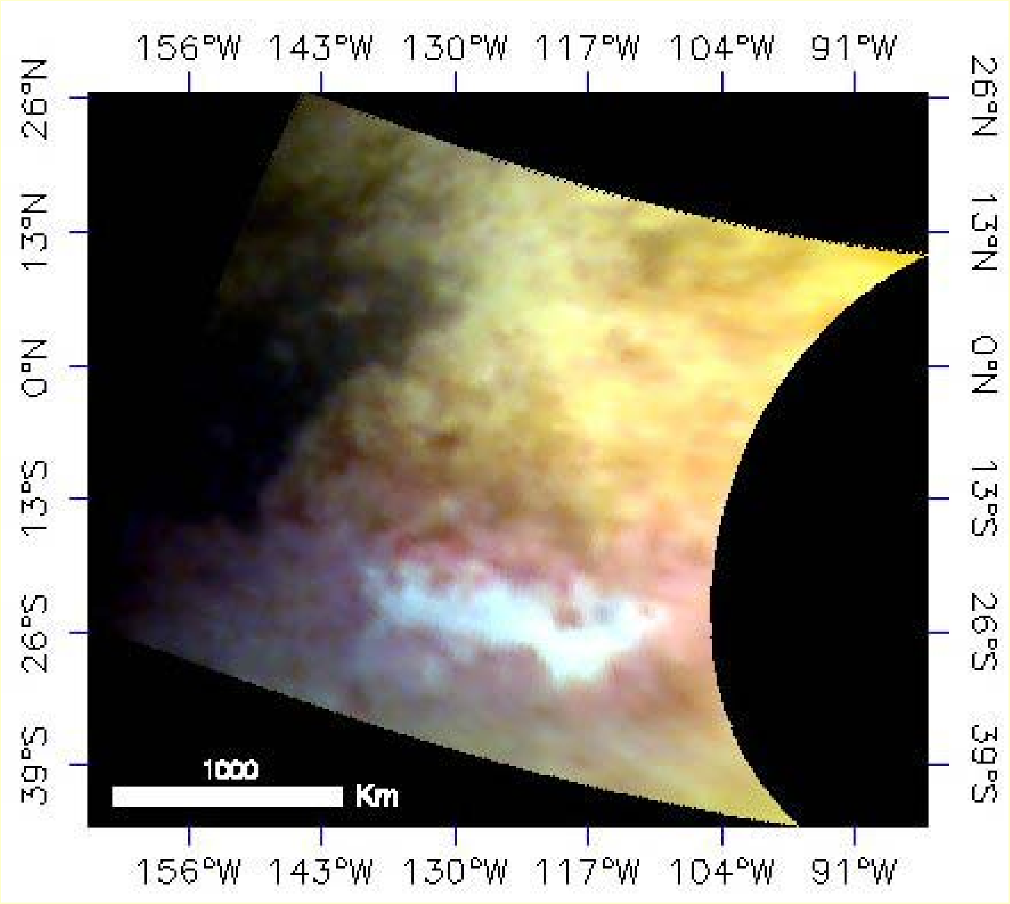
Everywhere else, the dielectric constant is much smaller than the value for water ice (Janssen et al., 2009)

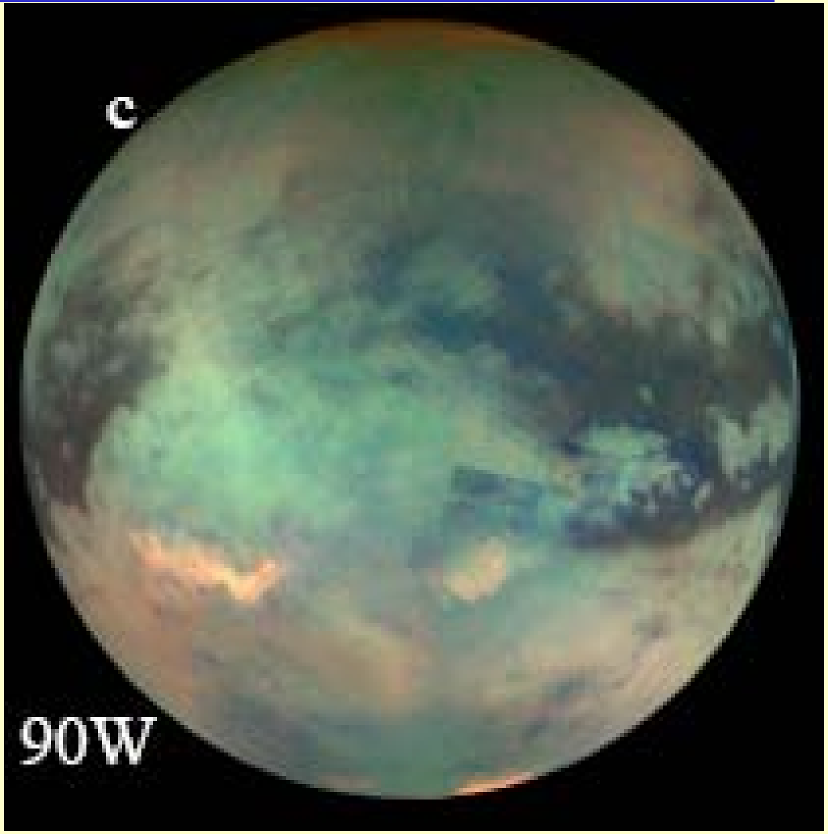


Mountains ?

Linear features observed by radar and VIMS (Visual & Infrared Mapping Spectrometer) at different locations. Same origin?

Bright 5 microns areas





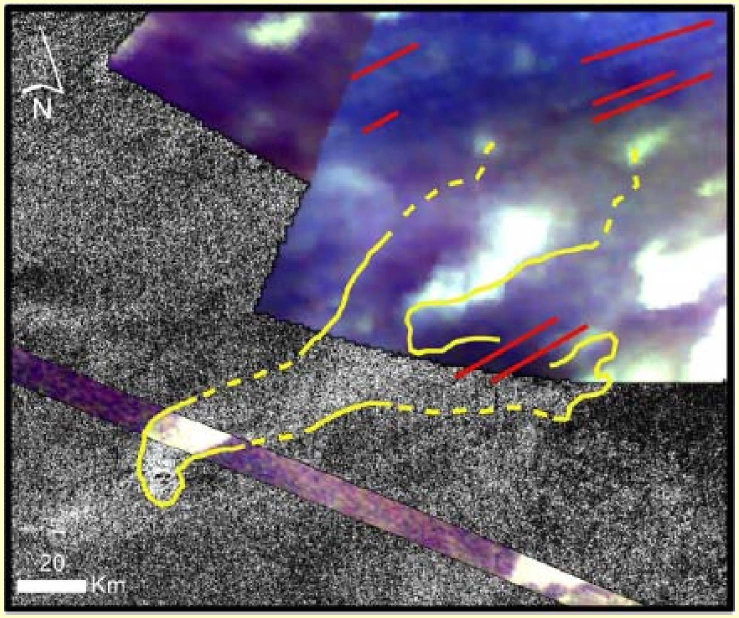
Barnes et al., 2006

Tui Regio - red = 1.55 µm, green = 2.69 µm, blue = 5µm. Data cube from T12 flyby at a distance of 75 000 km from Titan. The Tui region covers about 4,18 10^5 km².

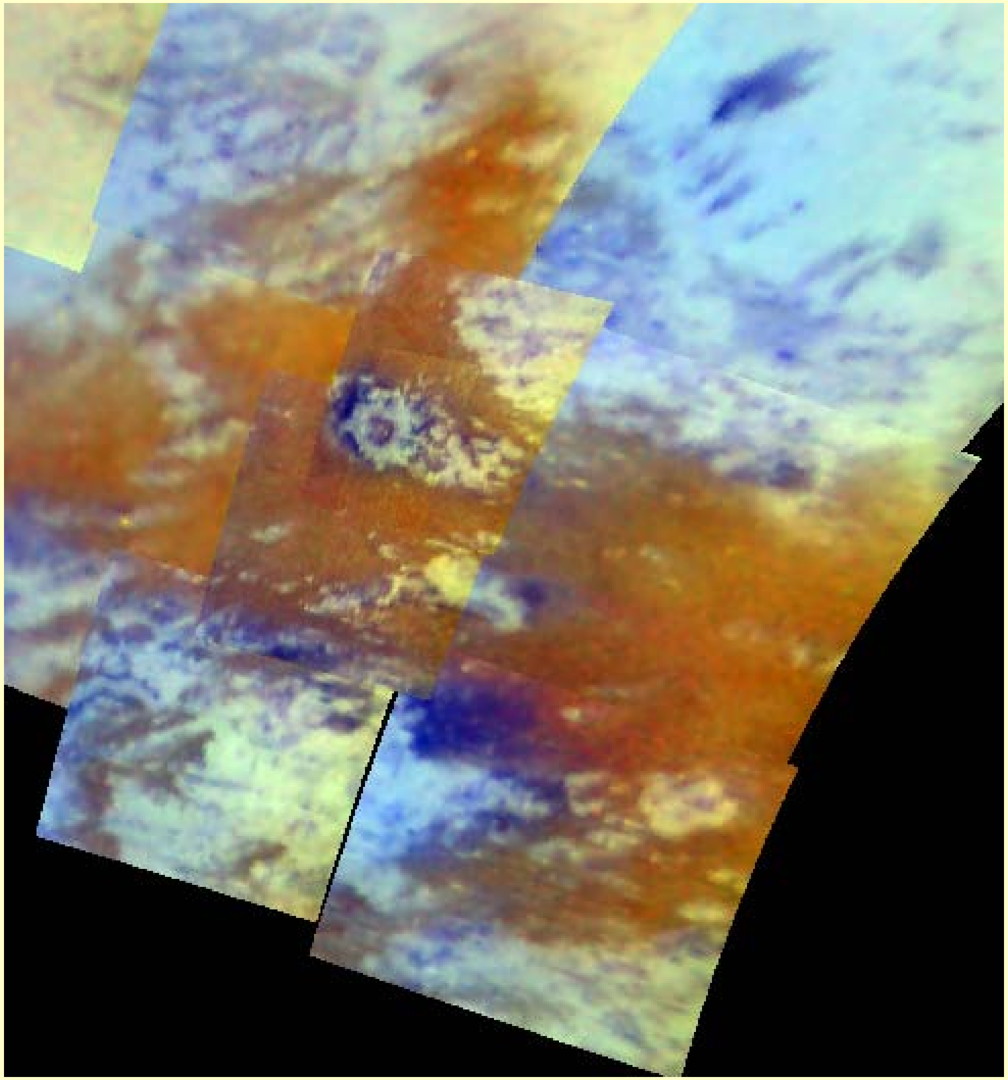
Cryovolcanic features ?

Wall et al. (2009): images obtained by the Cassini Titan Radar Mapper (RADAR) reveal lobate, flowlike features in the Hotei Arcus region that embay and cover surrounding terrains. A sedimentary alternative cannot be rejected. Nelson et al. (2009) observed variations in the albedo

Lopes et al. (2007) and Le Corre et al. (2009): small vent with deposits to the East of the crater.



Location of the Huygens Landing site

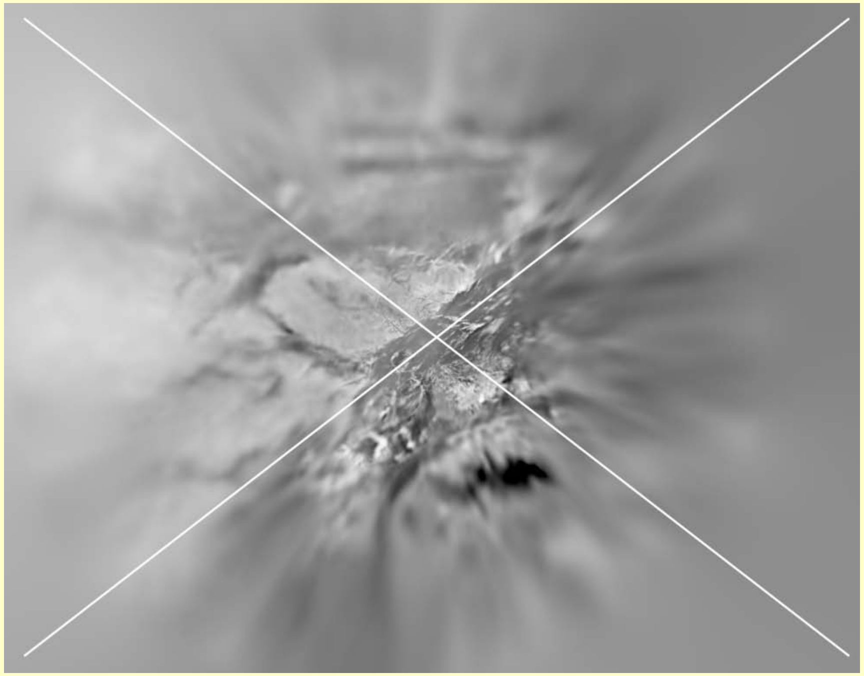


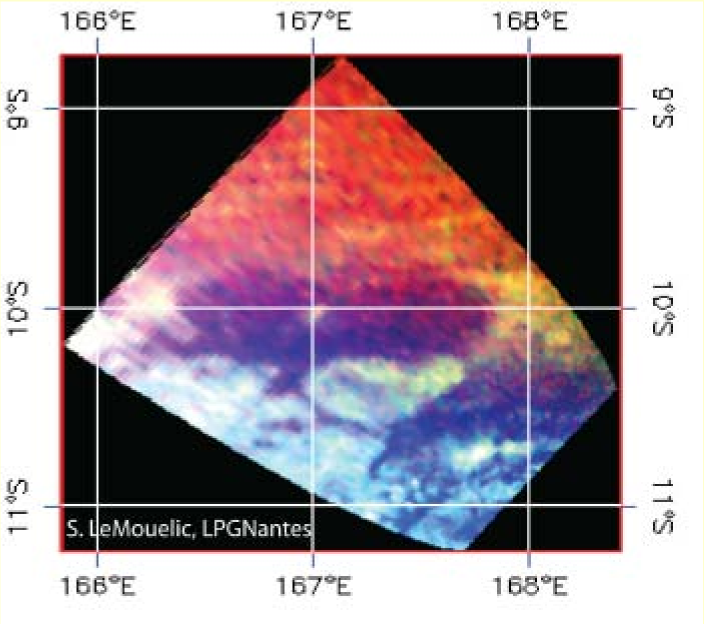
High resolution mosaic obtained at T38 showing the western tip of Adiri, the dark blue unit at the North and the dune terrains in brown.

Note also Selk crater.

Comparison DISR - VIMS

1 - The location of the Huygens landing site is at the center of the DISR image (Eric Karkoschka). The bright area in the center coincides very nicely with the VIMS observation.



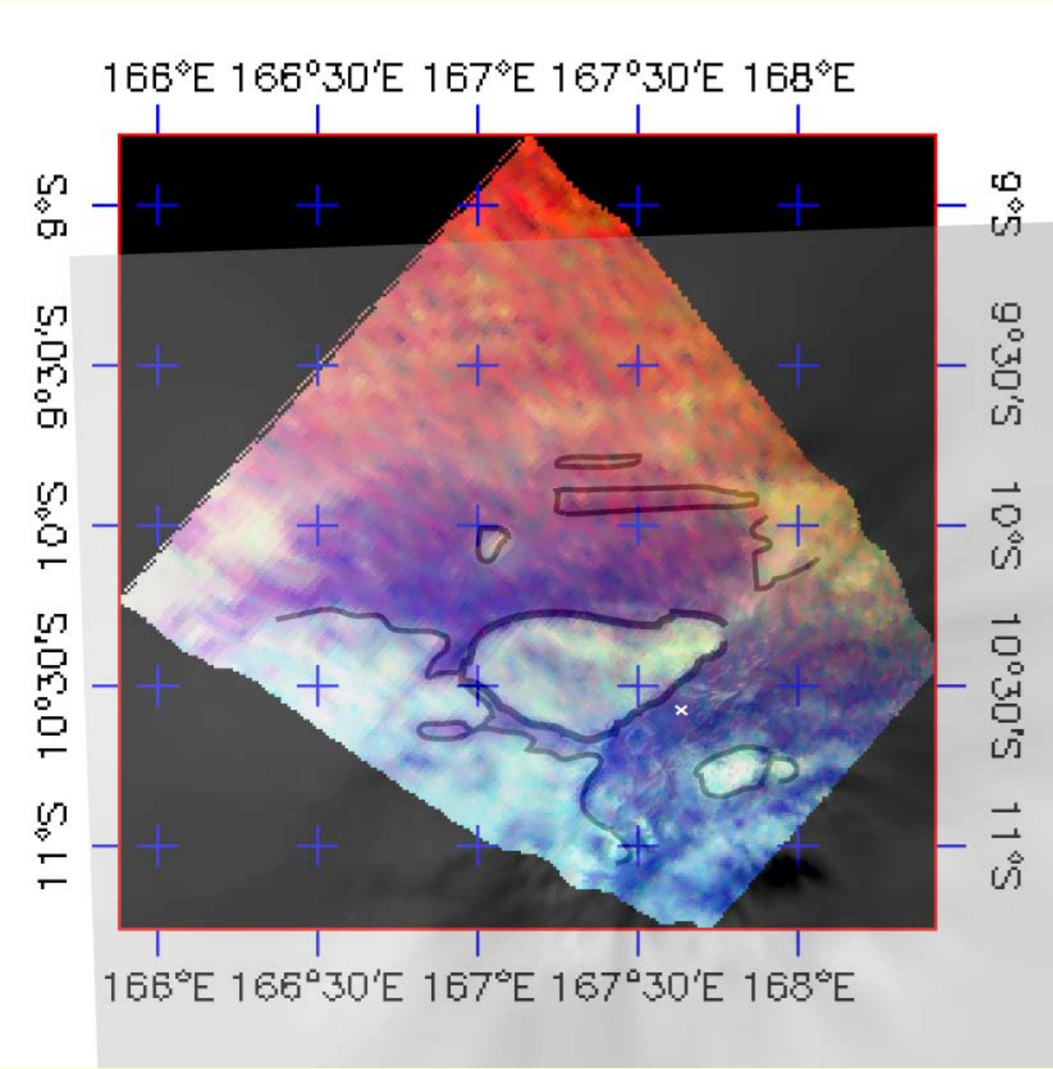


2 - The first implications is that the rotation is close to synchronous.

Comparison DISR - VIMS

With a 2 degree counterclockwise rotation, there is a perfect fit between the DISR image and the VIMS image. It allows us to determine the location of the Huygens Landing Site.

The kernels use the obliquity determined by the radar team (Stiles et al., 2008). Synchronous rotation is assumed.



From Sotin et al. (2010)

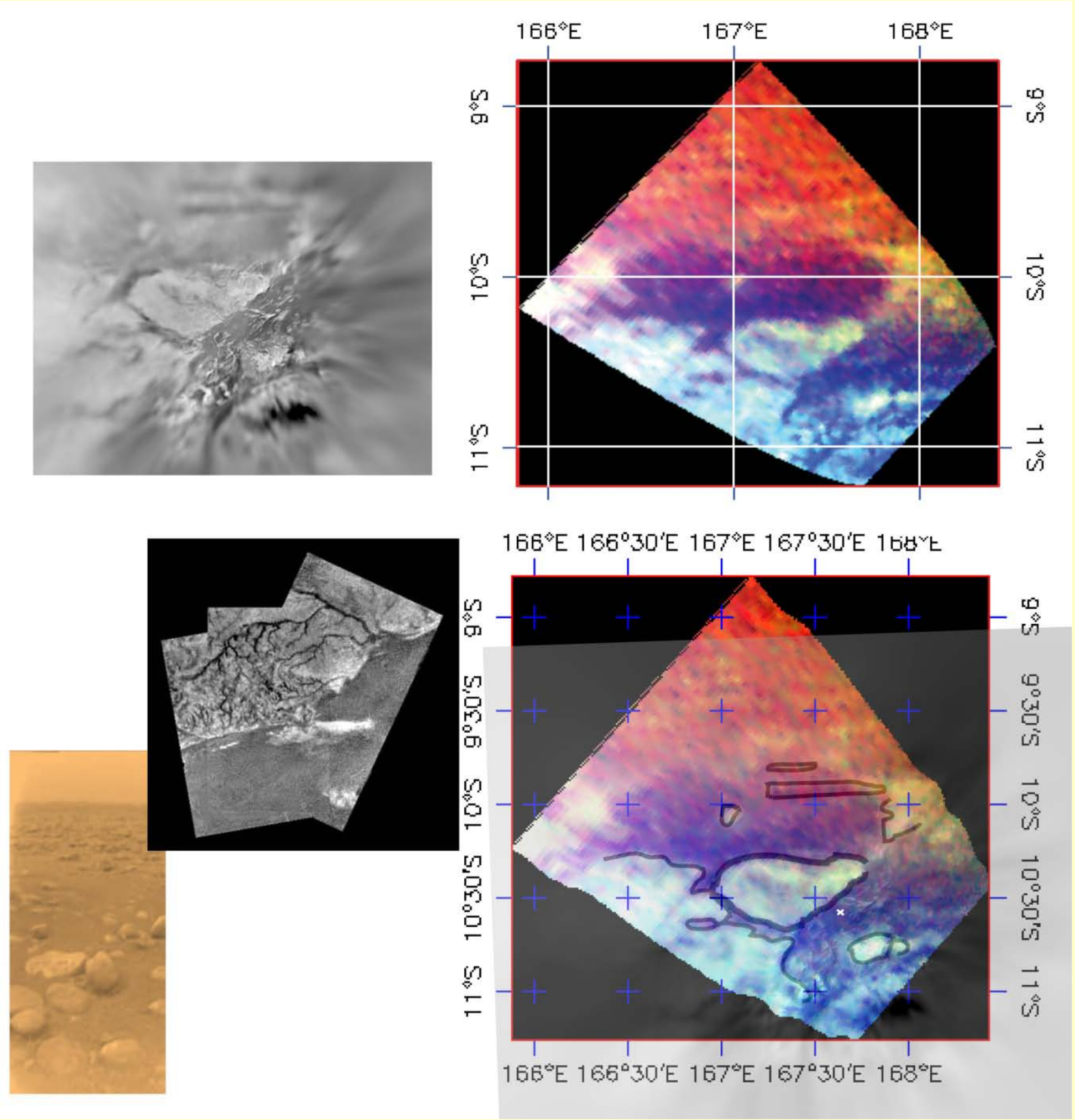
Comparison DISR - VIMS

Synthesis to show the difference between a 1.2 km resolution image (VIMS) and the few meter resolution images obtained by DISR.

OR

How the resolution turns a boring area into an active and exciting place where rivers and erosion processes have operated.

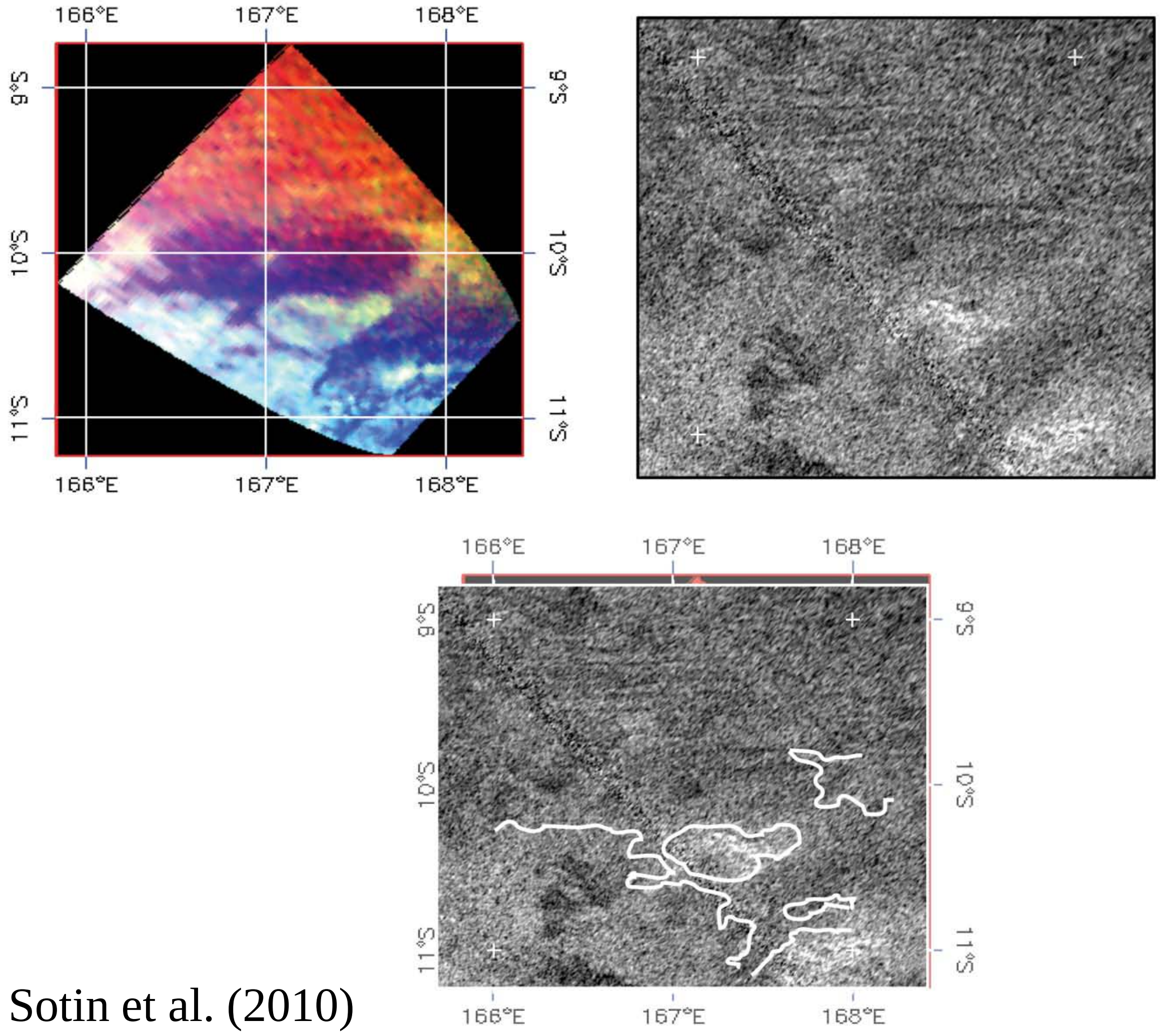
It emphasizes the importance of Huygens observations.



From Sotin et al. (2010)

Comparison Radar - VIMS

TA and T25 radar images from the PDS have been used to compare the view of the HLS with the two instruments.
Work in progress to assess the differences between the Radar 500 m resolution image and the VIMS 1.2 km resolution image.
The radar team has some very nice stereo of this area on top of which the VIMS highres images could be overlaid.



Sotin et al. (2010)

Conclusions about Geology

- No convincing evidence of active cryo-volcanoes has been found so far
- The number of impact craters is small. It suggests that Titan’s surface is young. What “young” means? 100 Myrs? 3 Byrs?
- There are mountains about 1 km in altitude. Some linear features may also be mountain ranges.
- Spatial resolution is important to understand the nature of the geological features

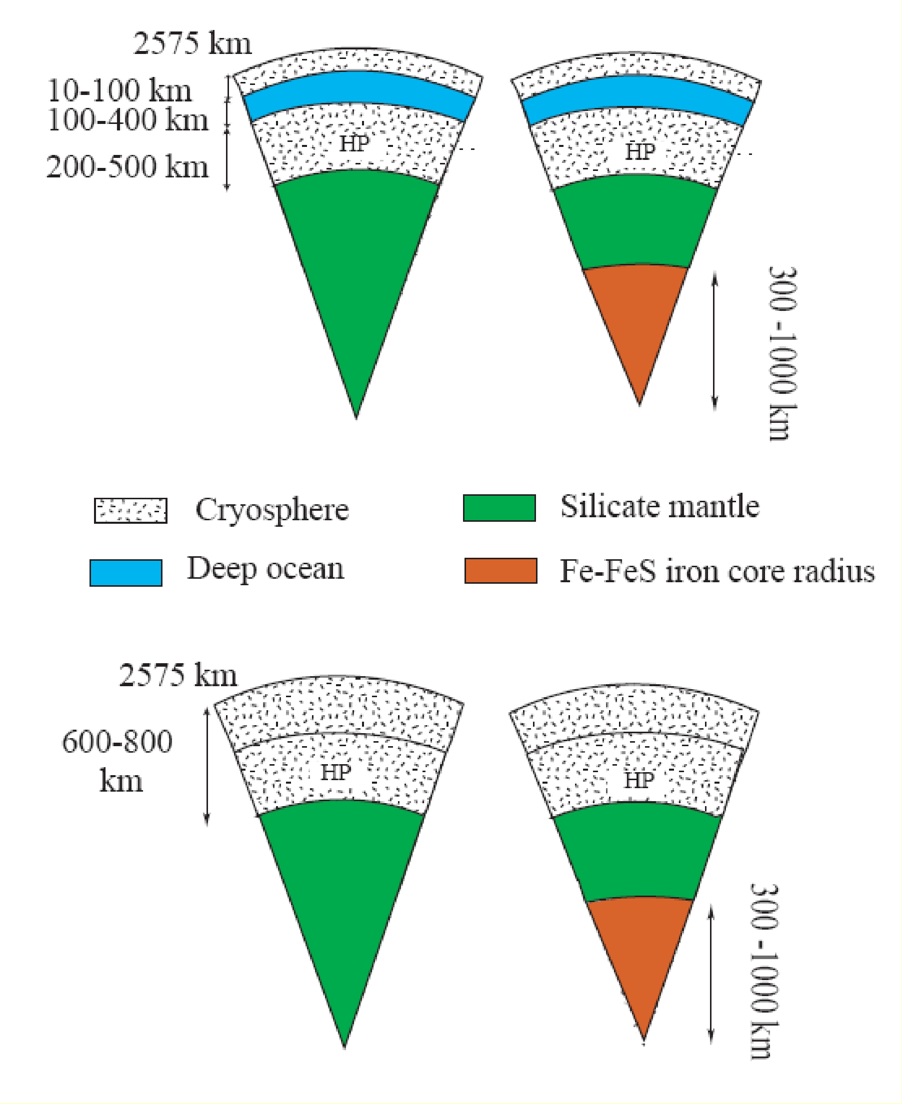
NEXT

- Interior structure
- Models simulating global evolution

Gravity field and internal structure: HP ices layer

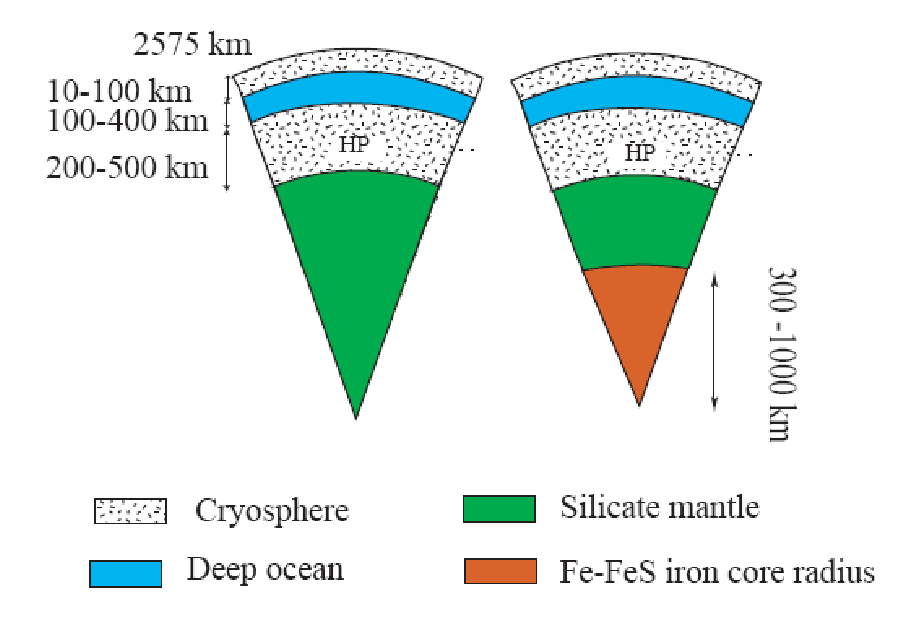
Different models have been proposed from a fully differentiated Titan to a non-differentiated Titan.

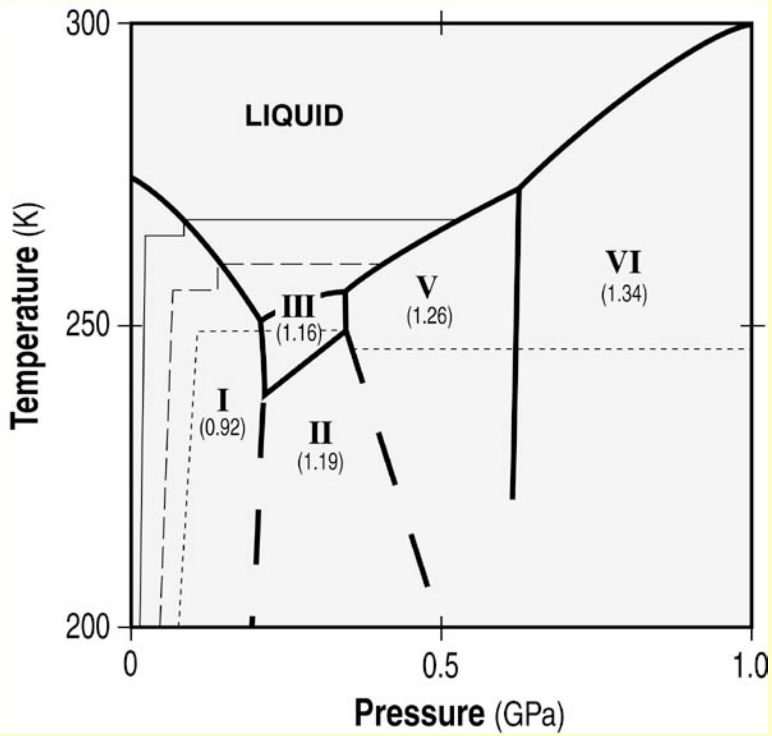
Is there an ocean between the two layers of ice?



The high-pressure ice layer

- Heat transfer in the high-pressure ice layer
- Properties of high-pressure ices

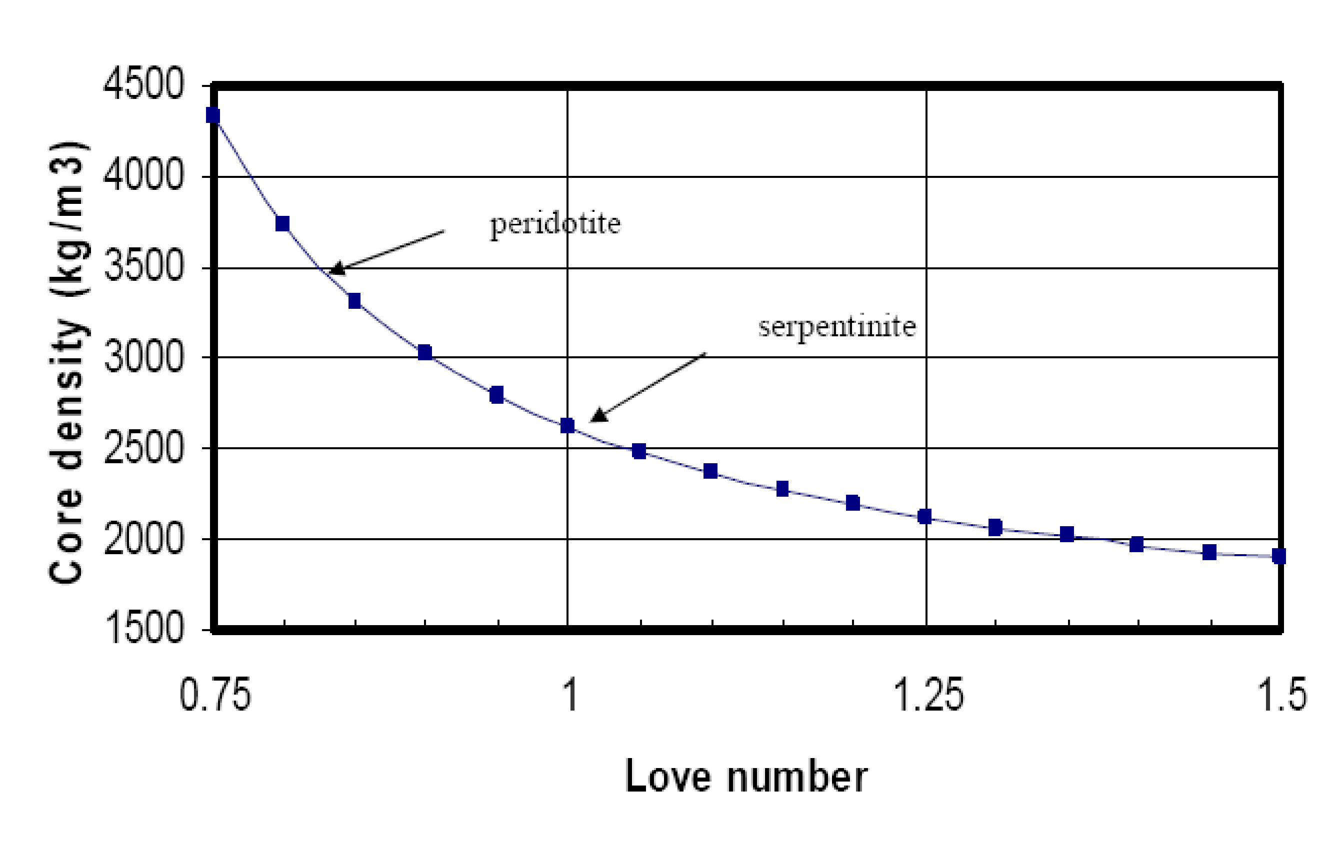


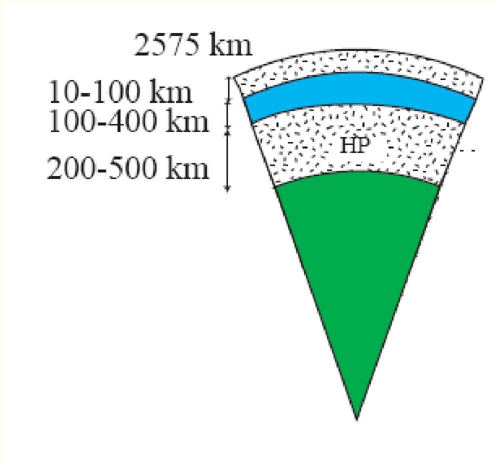


Gravity data (density, moment of inertia, mass anomalies)

- Relationships between interior structure and degree two coefficients
- Where are we after the first four gravity fly-bys (T11, T22, T33, T45)? The data are not consistent with only degree 2 variations of the gravity field. Inversion has been performed with degree 3 coefficients. A solution has been found and seems to agree with Titan being in hydrostatic equilibrium.
- Titan is partly differentiated (Iess et al., Science, 2010).

Case for Titan (Sotin et al., 2009)





$$C = \frac{8\pi}{15}\left(\rho_I\left(R^5 - R_C^5\right) + \rho_c R_c^5\right)$$

$$M = \frac{4\pi}{3}\left(\rho_I\left(R^3 - R_C^3\right) + \rho_c R_c^3\right)$$

Other information

No evidence for the presence of an induced magnetic field. But:

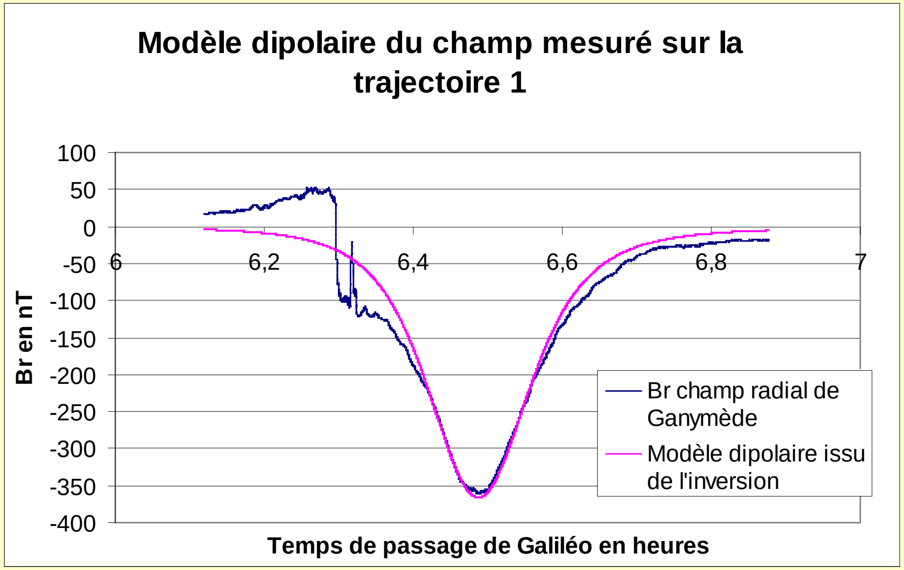
- Saturn's magnetic field is weaker than that of Jupiter
- Cassini flybys are at high altitude ($B \sim r^{-3}$)
- Titan's ionosphere provides a strong signal

The non-synchronous rotation is no more an evidence for the presence of an ocean. (Revised value close to synchronous)

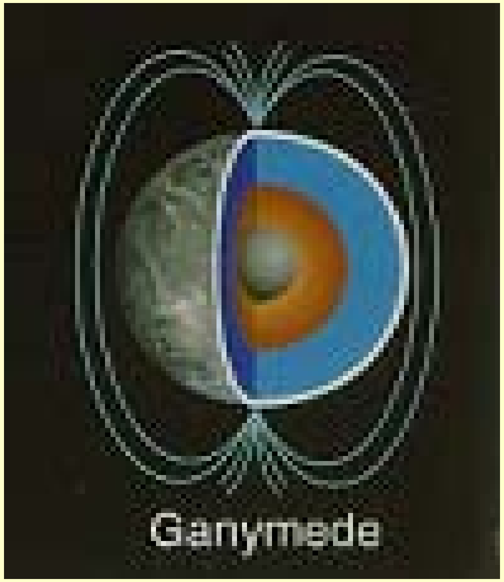
Electric signal detected by the Huygens probe suggests a conductive layer at 45 km depth: it could be the liquid layer

The strong value of the eccentricity suggests that the crust is cold (no tidal dissipation). It favors an ammonia-rich ocean at depth.

Magnetic data : case of Ganymede



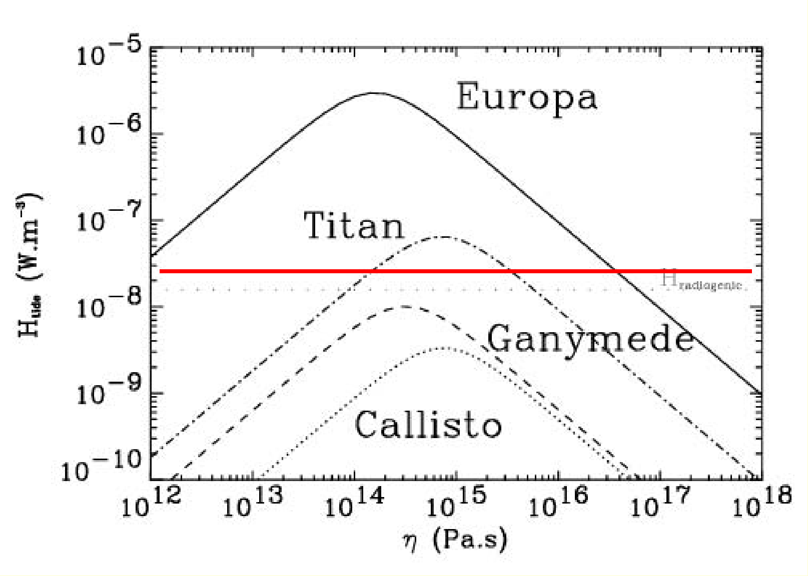
Major surprise of the Galileo mission was the discovery of an intrinsic magnetic field within Ganymede (Kivelson, 1996)



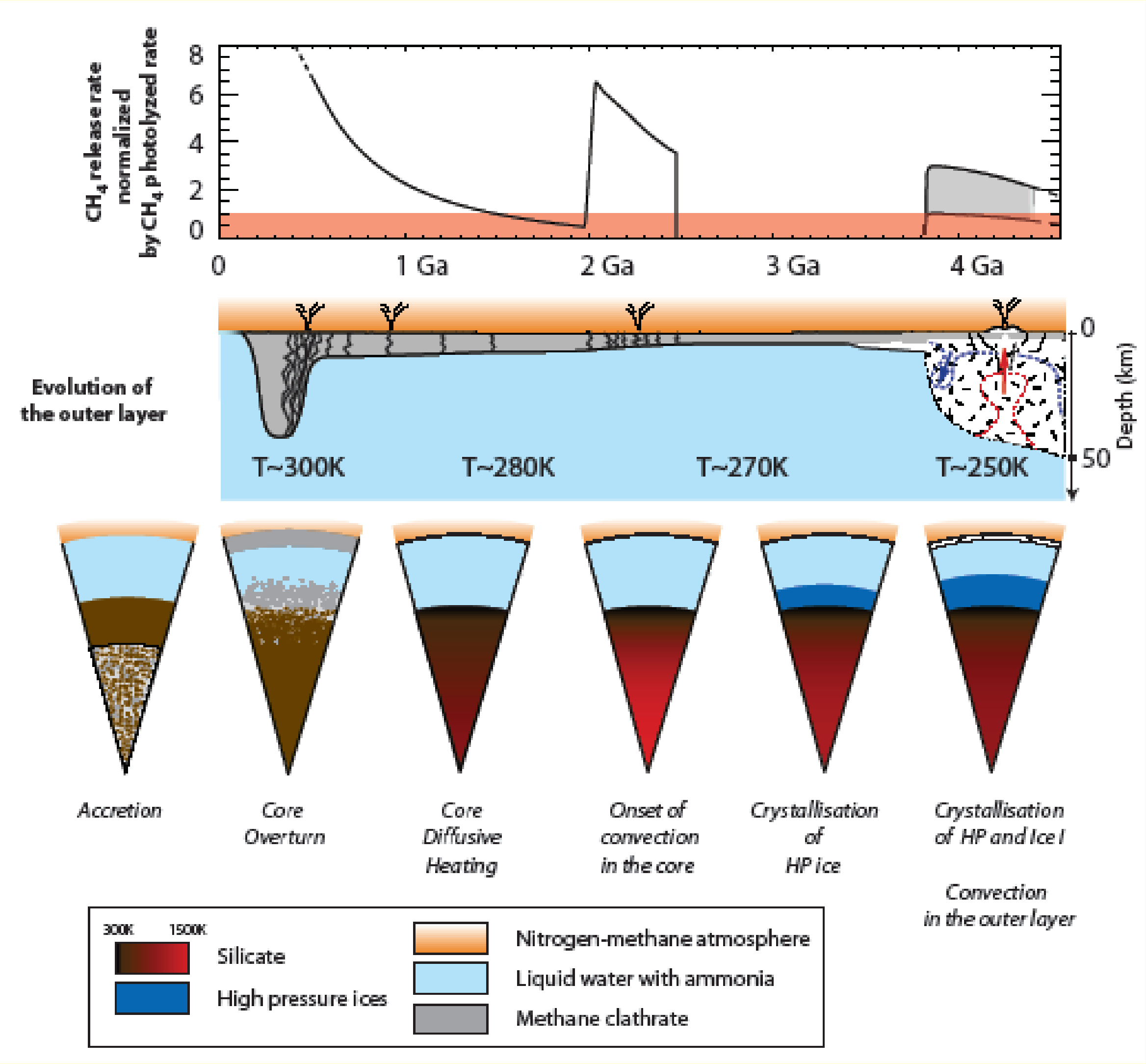
Trajectoire	Date	Altitude (km)	Latitude /Ganymede	Longitude /Ganymede
G1	27/06/1996	838	30	247
G2	06/09/1996	264	79	236
G7	05/04/1997	3105	56	270
G8	07/05/1997	1606	28	85
G28	20/05/2000	900	-13	269

Heat sources at present time

- Radiogenic heating – 800 GW
- Tidal heating
- Latent heat



Internal dynamics and evolution



(Tobie et al. 2006)

- atmospheric composition
- models of subsolidus convection
- different considerations (high eccentricity = tidal dissipation is minimum)

3 periods during which volatiles (methane) can be present

- During accretion
- Onset of onvection in the silicate core
- Onset of convection in the outer ice layer

Conclusions

- Rich diversity of processes
  - Formation of rivers, lakes and dunes
  - Mountains have been formed.
  - Outgassing processes to explain the atmospheric composition
  - Carbon cycle implies replenishment in methane
  - Still lacking convincing evidence for cryovolcanic features
- Future observations by the Cassini Solstice Mission
  - Complementing the coverage by radar and optical observations
  - Monitoring seasonal variations
  - Refining orbital characteristics
  - Acquiring more gravity and magnetic data
- Implications for future missions
  - Topography is needed for geological analysis
  - Seismology to measure activity and to determine interior structure.