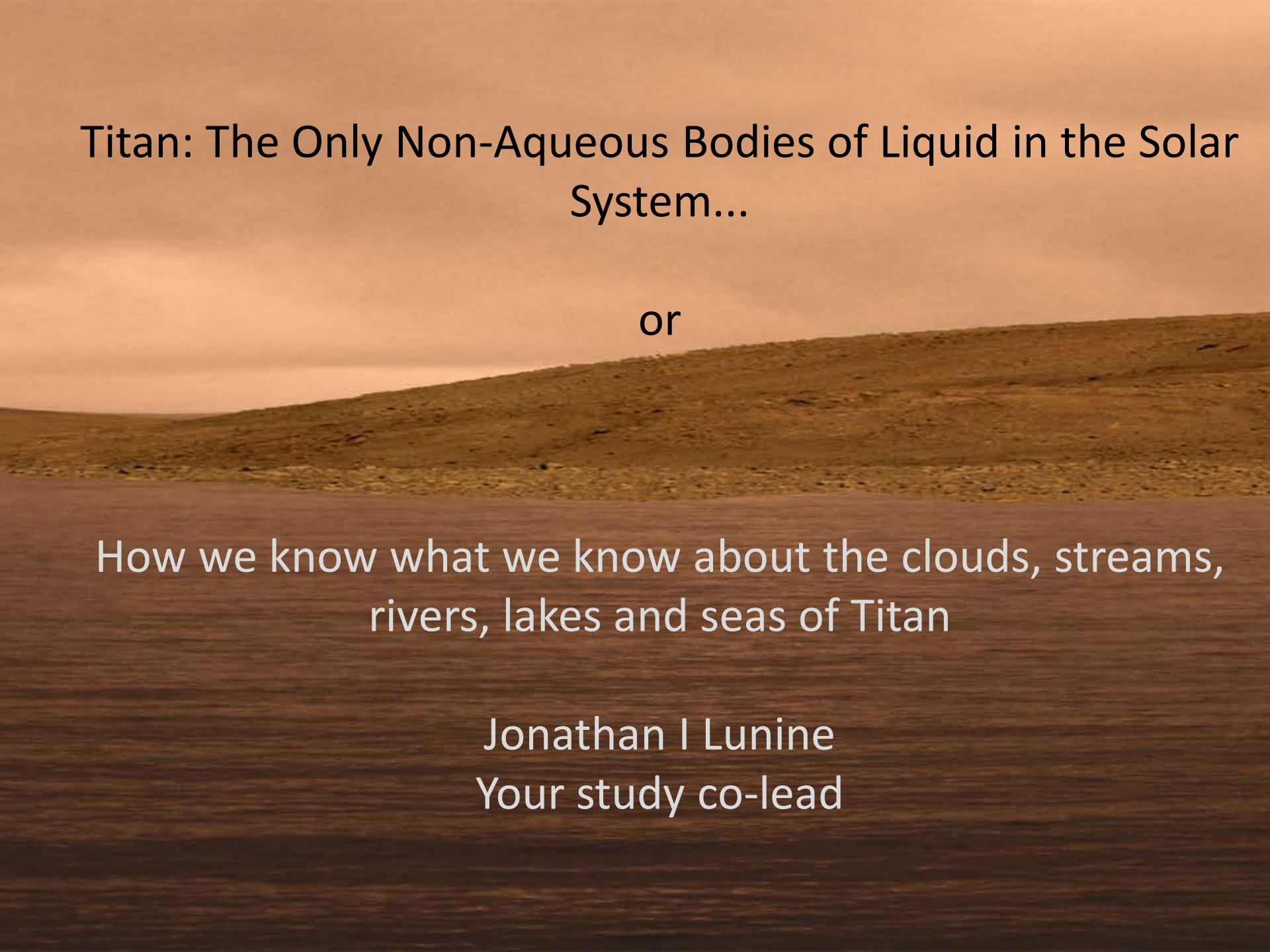


Titan: The Only Non-Aqueous Bodies of Liquid in the Solar System...

or

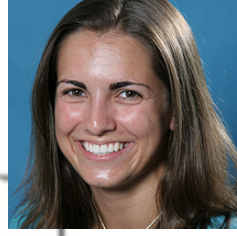
How we know what we know about the clouds, streams, rivers, lakes and seas of Titan

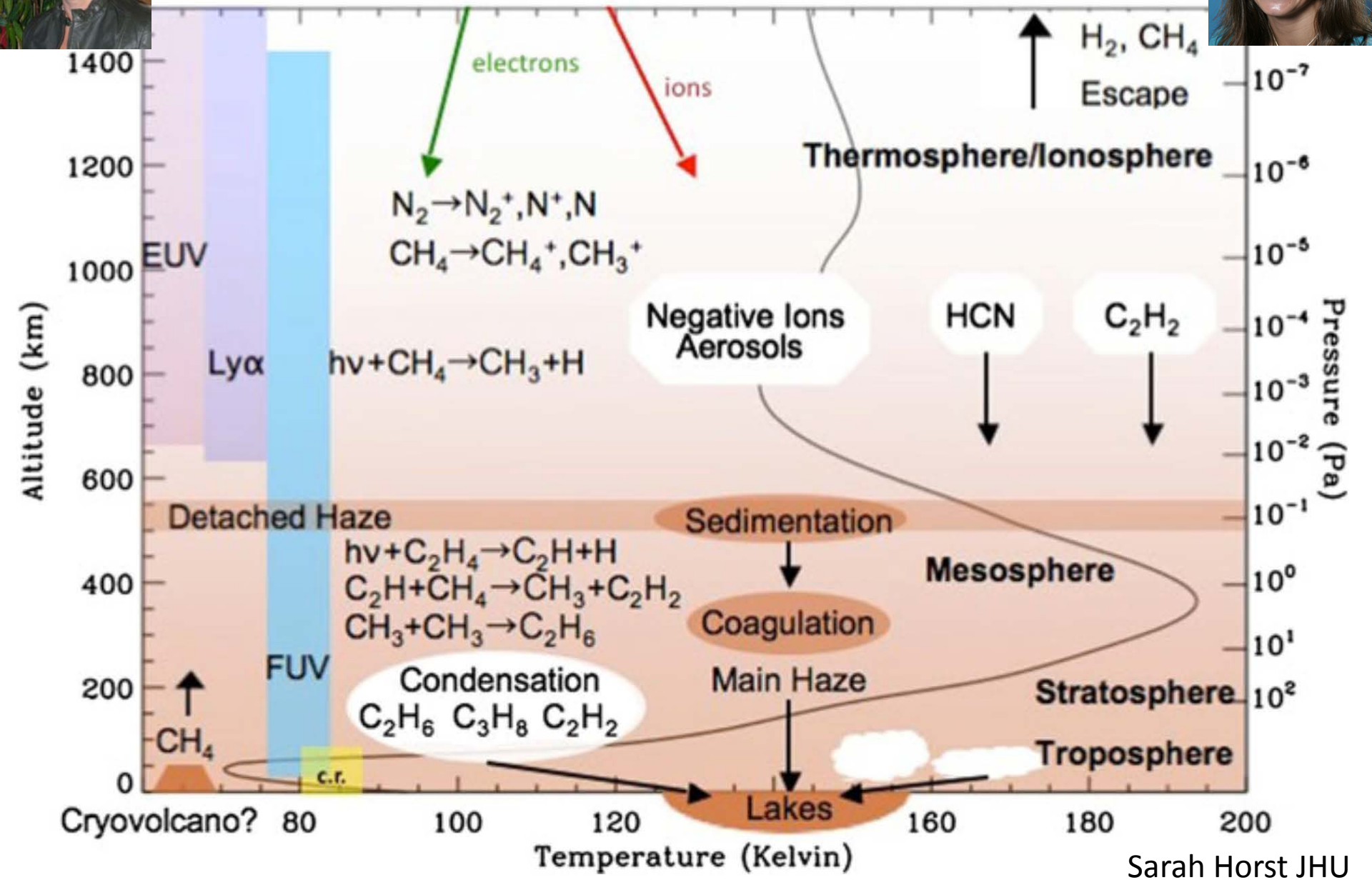
Jonathan I Lunine
Your study co-lead

Things you must remember about Titan

- Titan orbits Saturn: 1.5% Earth sunlight, 7 yr seasons
- Titan is bigger than Mercury and is ½ rock, ½ (water) ice
- Titan has a dense, hazy, opaque atmosphere
- The air is 95-98% molecular nitrogen; remainder is mostly methane.
- Temperature near surface is 94 K at equator, atmosphere-surface near methane triple pt.

There are diverse sources of energy in Titan's atmosphere





Sarah Horst JHU

Photochemistry at the heart of Titan's surface-atmosphere evolution

ethane

$\lambda < 1450$ Å

$\lambda \approx 2000$ Å

H

acetylene

nitrogen

HCN

Post-Voyager conclusion:

The observed atmospheric composition is not sustainable over geologic time.

(All methane in the atmosphere will be destroyed in ~ few % age of solar system)

External resupply ✗

Surface resupply ?

Interior resupply ?

Cassini-Huygens is a joint NASA-ESA-ASI mission

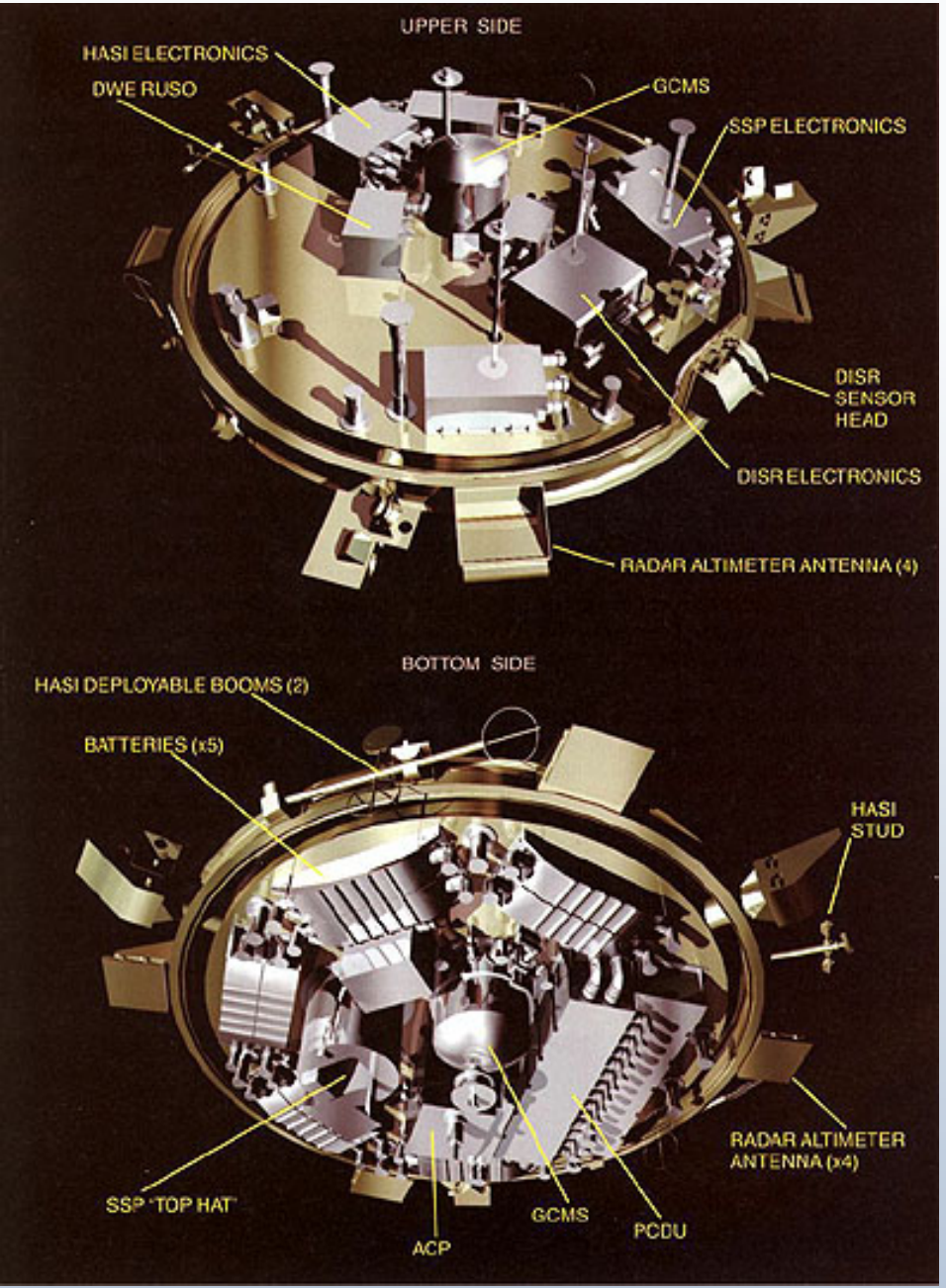
Launched in 1997

Arrived at Saturn 2004

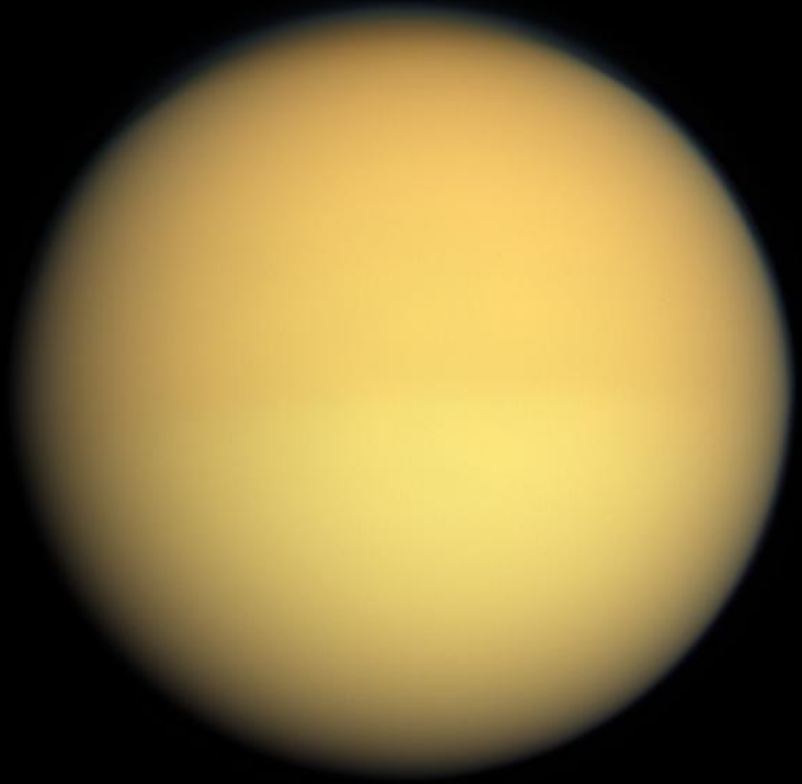
Huygens landed 2005 on Titan

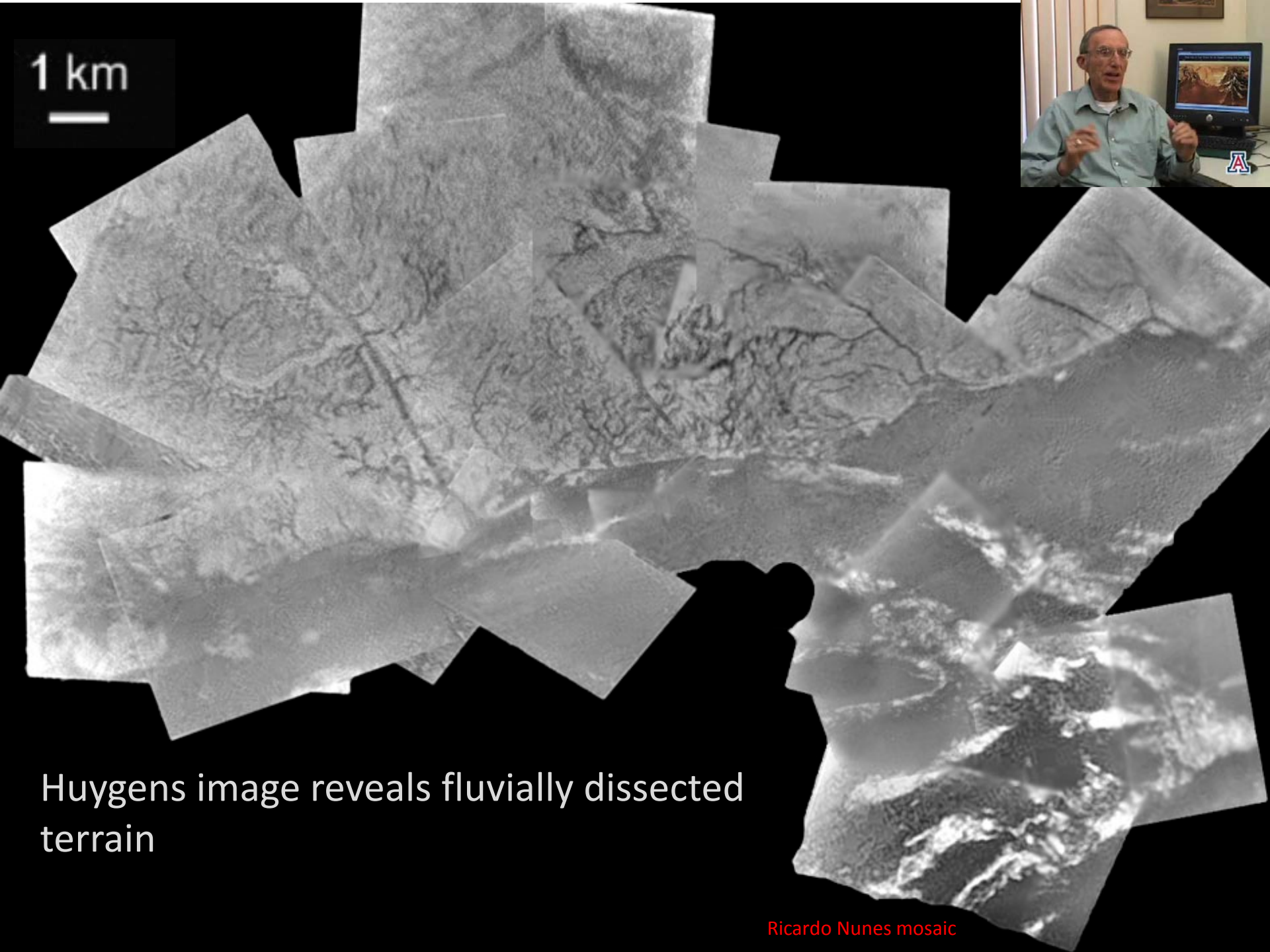
Orbiter now in extended mission to 2017.

Huygens Probe built by ESA



Clouds, rain and rivers

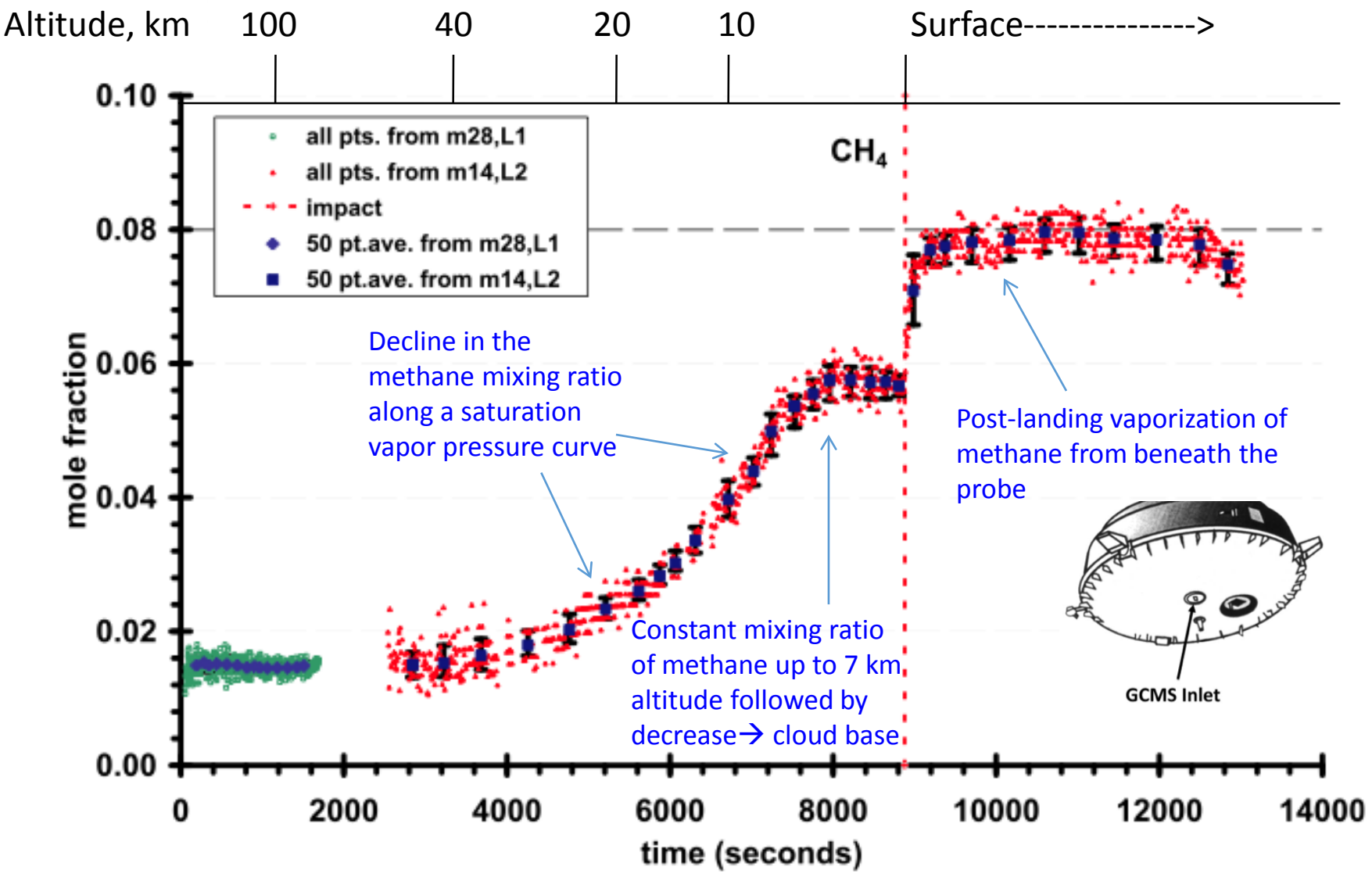


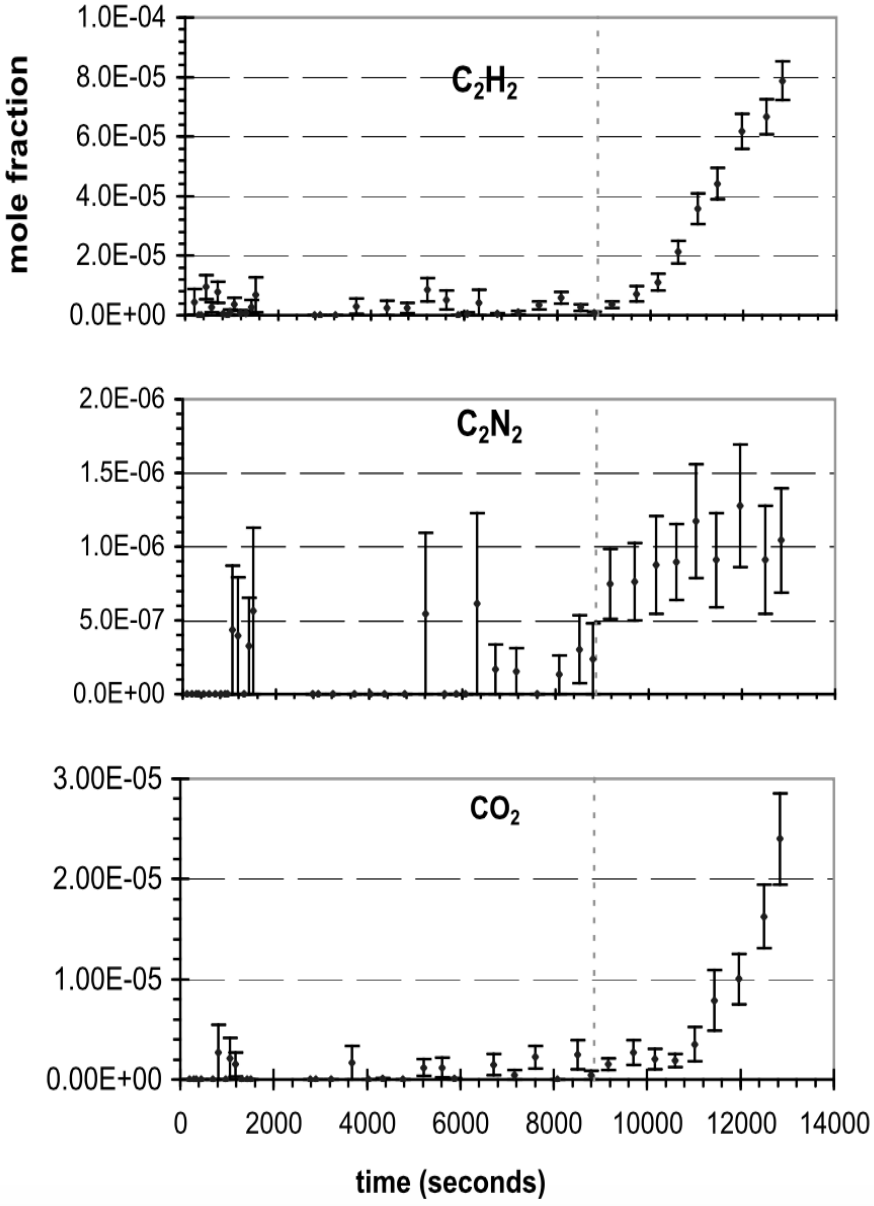


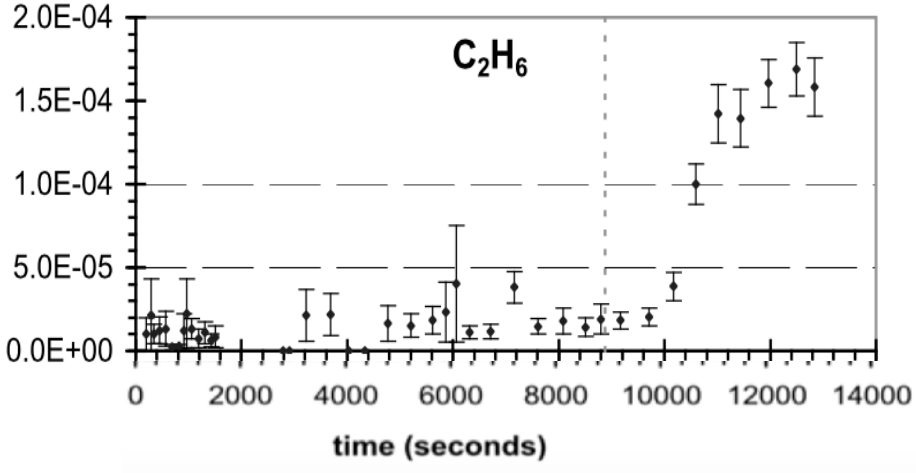
Huygens image reveals fluvially dissected terrain

Ricardo Nunes mosaic

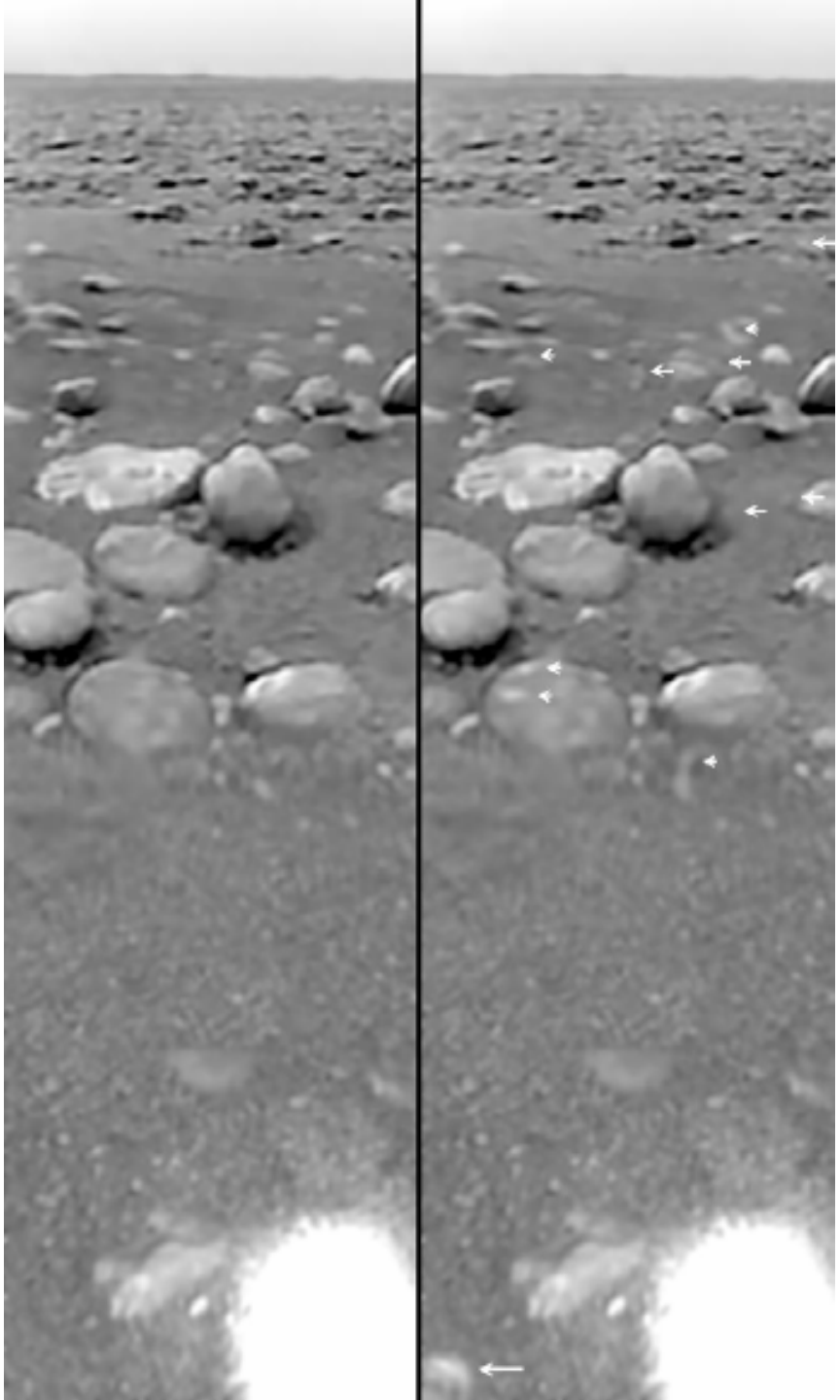
Huygens GCMS results (Niemann et al., 2010)







Niemann et al, 2010



Huygens resting place…rounded rocks and (lower left on second image) a methane dewdrop.

Erich Karkoschka, U Arizona

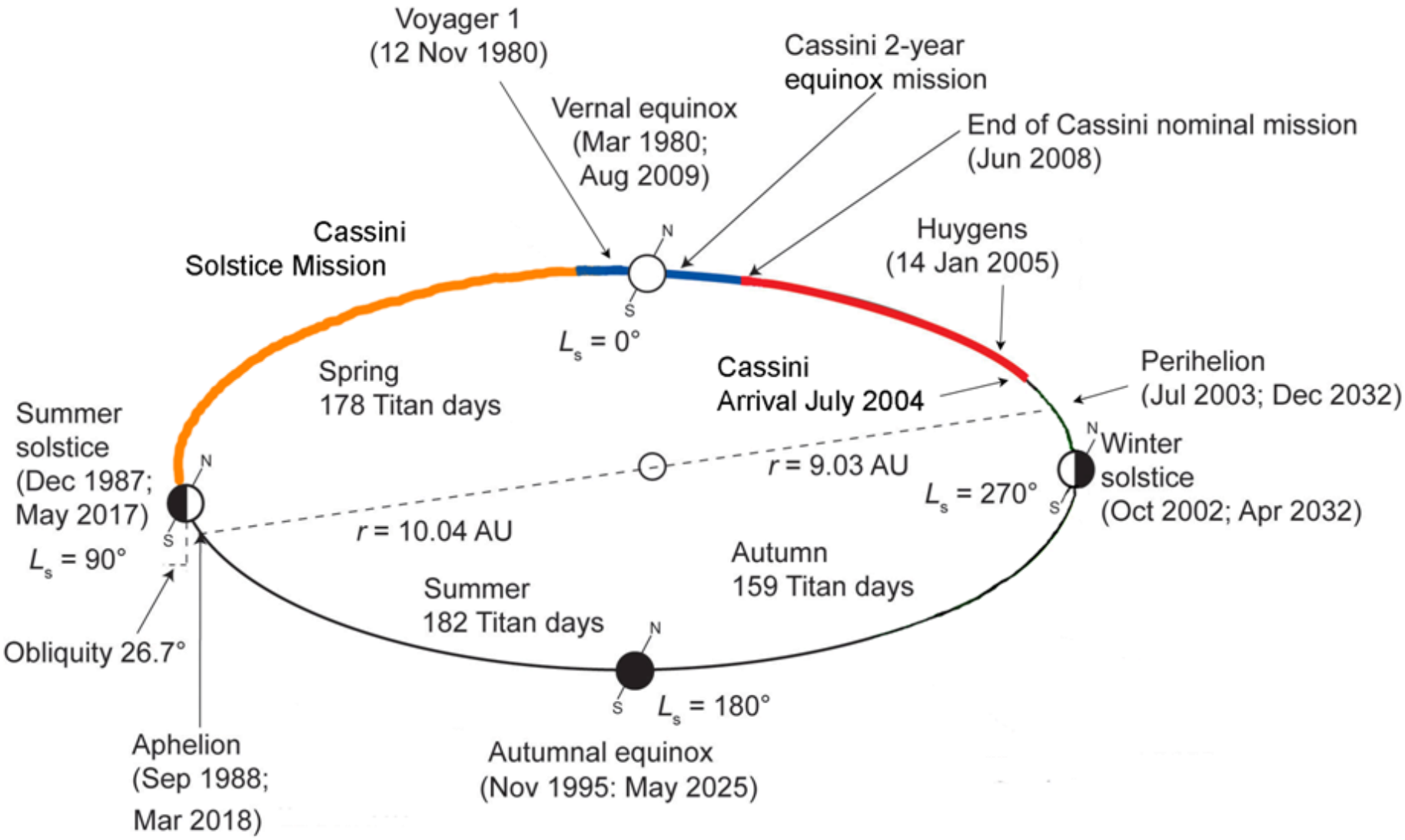
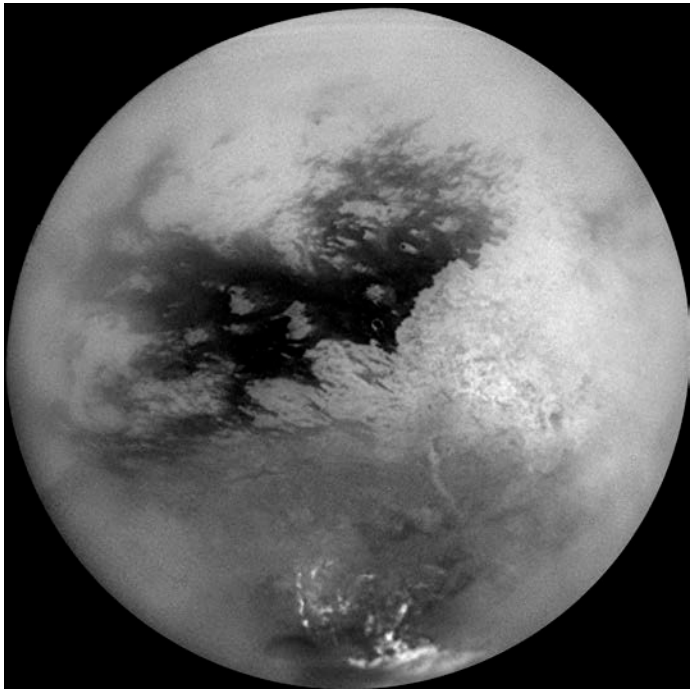
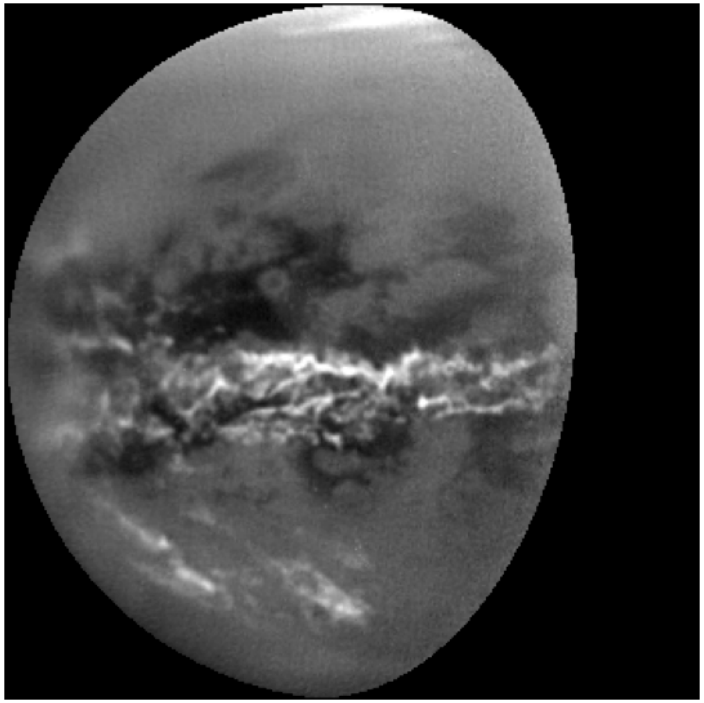


Figure by R. Lorenz

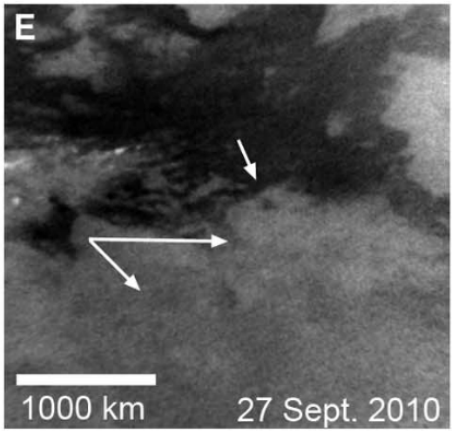


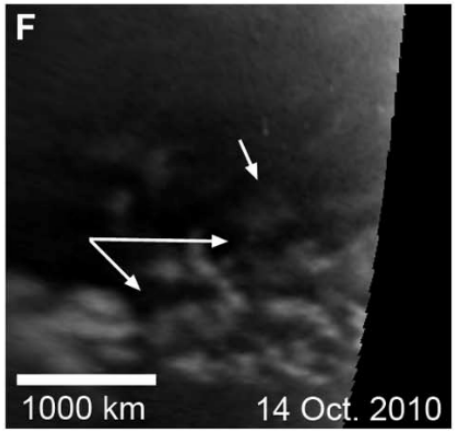
Just past winter solstice (2004)

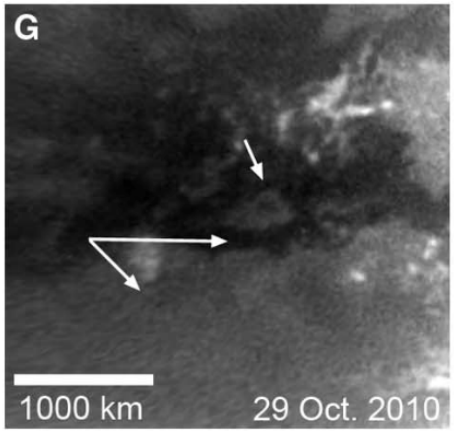


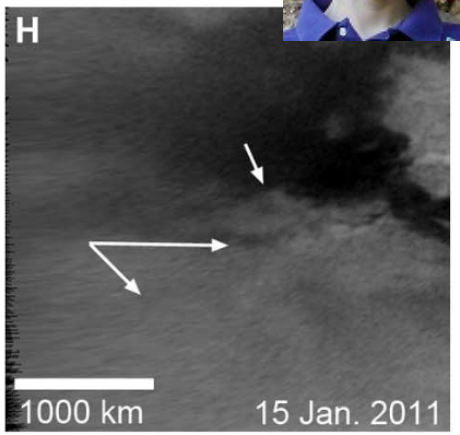
Vernal equinox (2010)

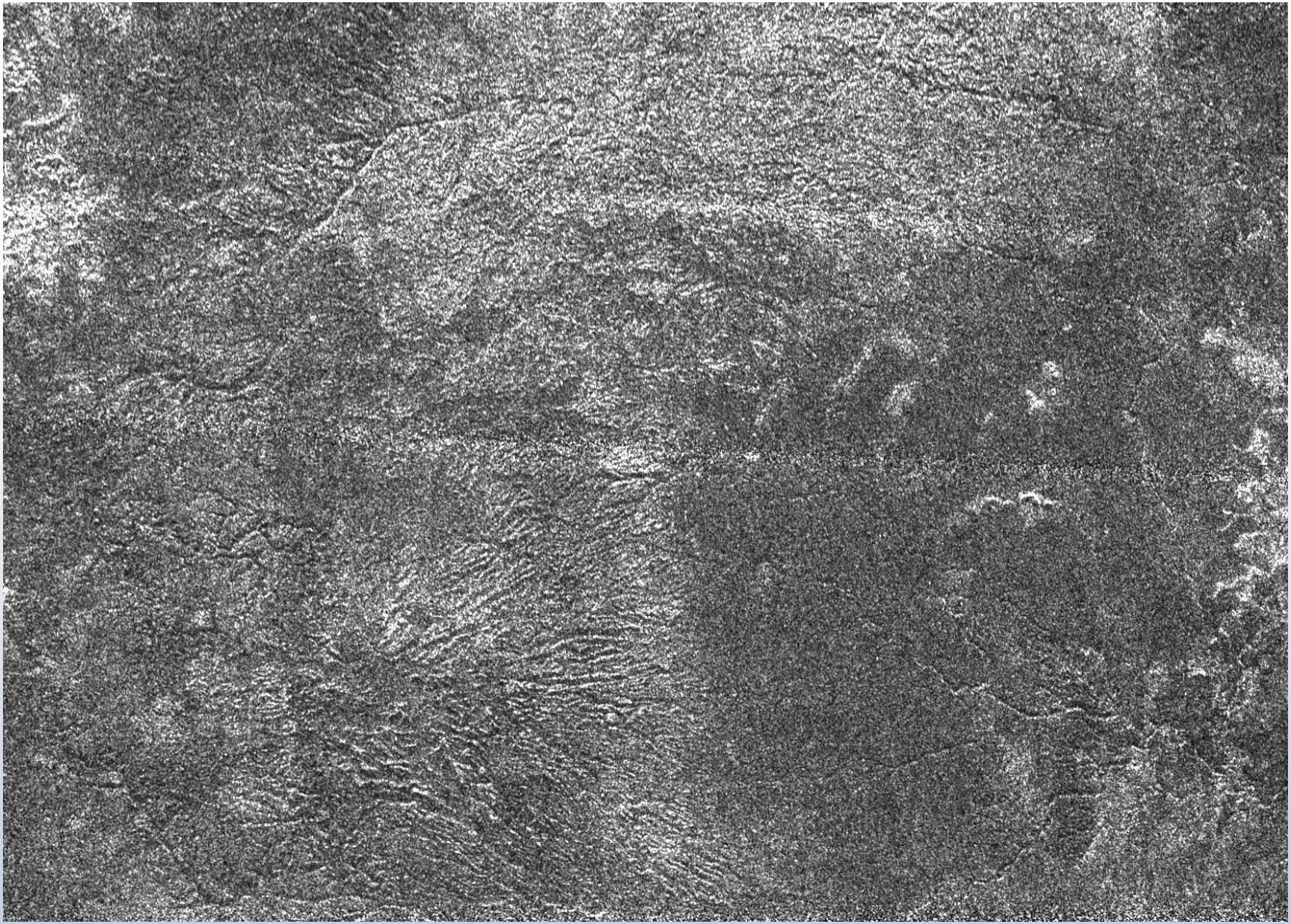
Cassini imaging data Zibi Turtle et al 2011.







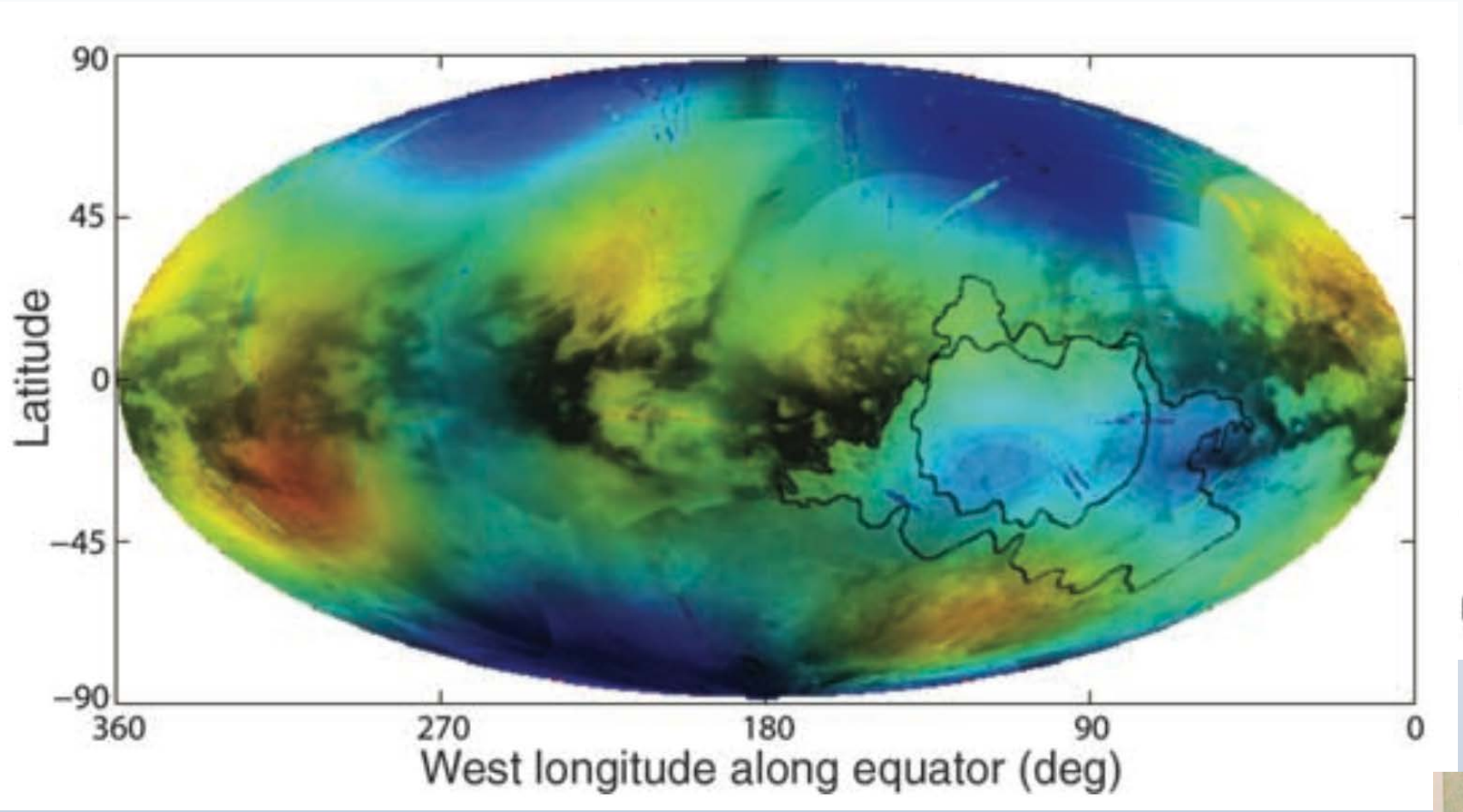




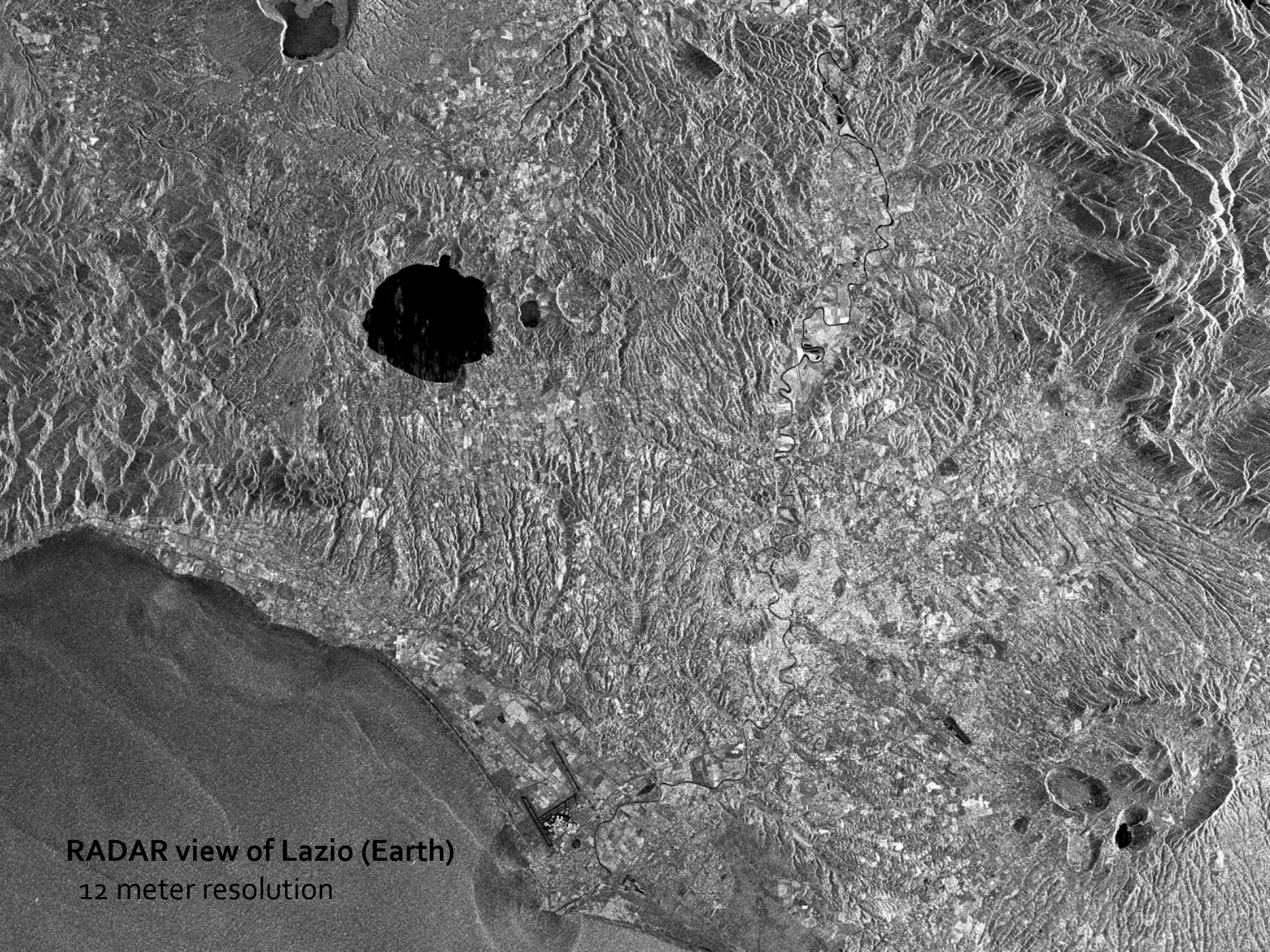
100 kilometers

Channels seen with Cassini radar

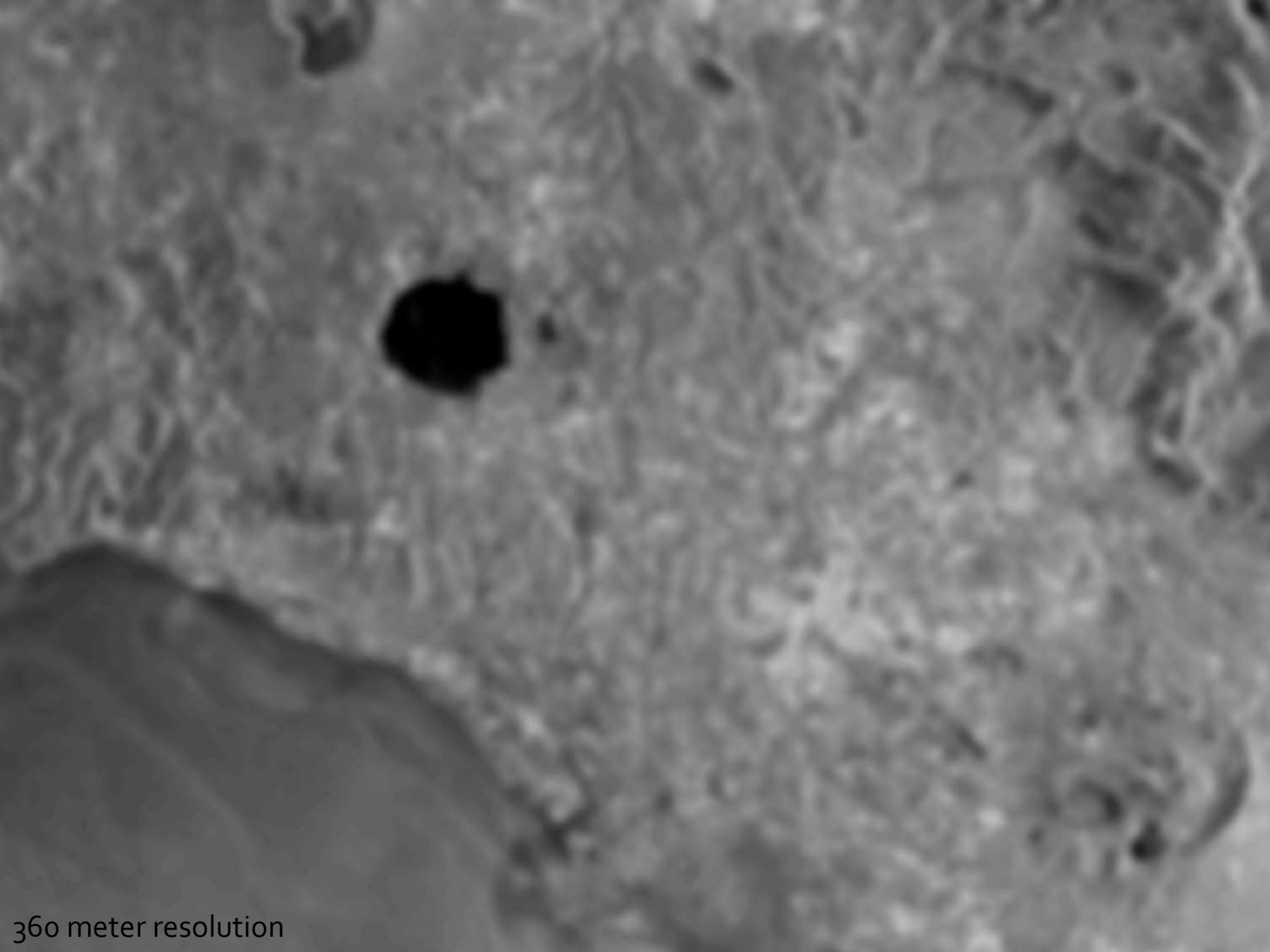
The global pattern of topography suggests general movement of liquid is toward the poles.



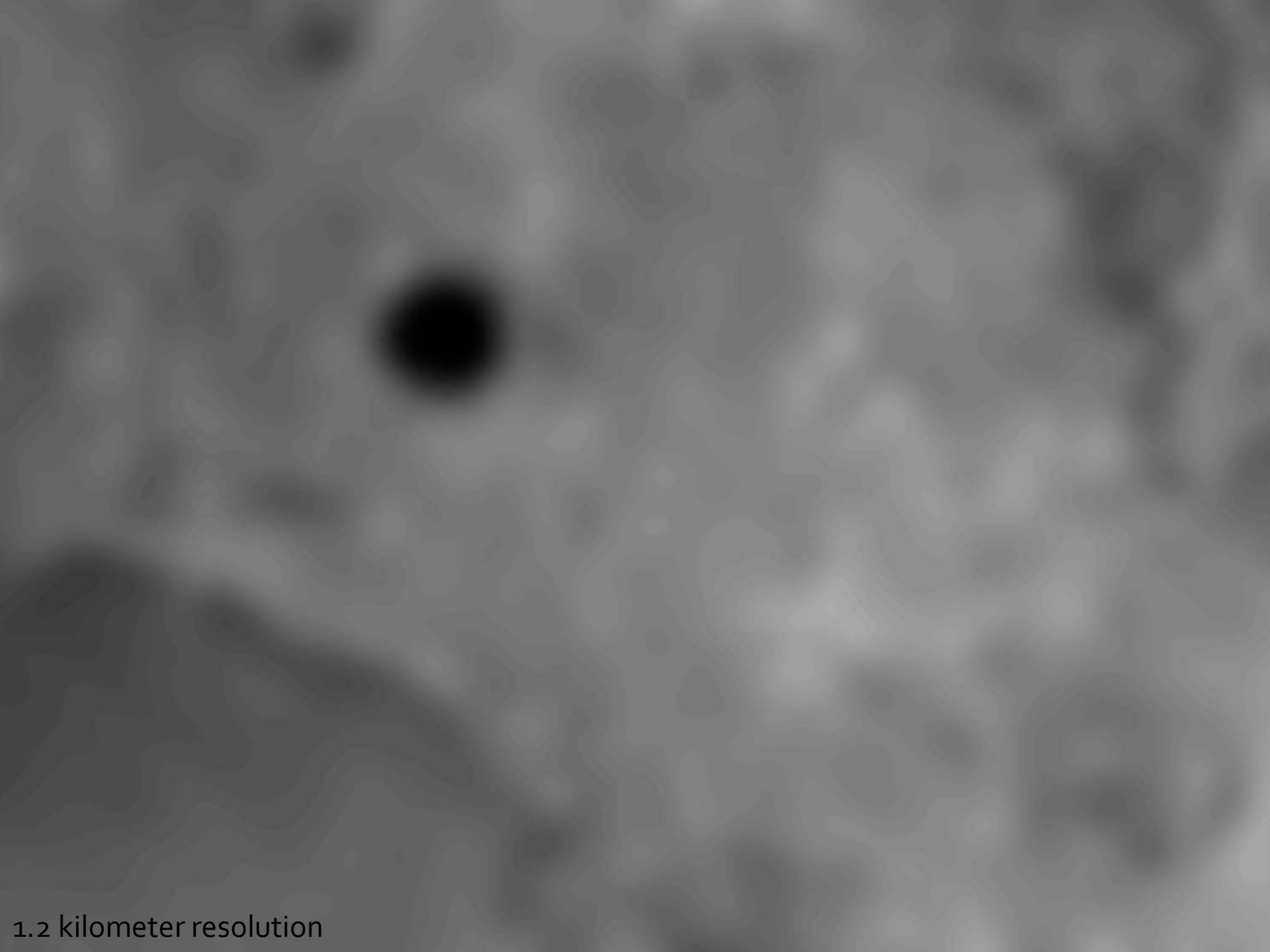
Zebker et al 2009



RADAR view of Lazio (Earth)
12 meter resolution

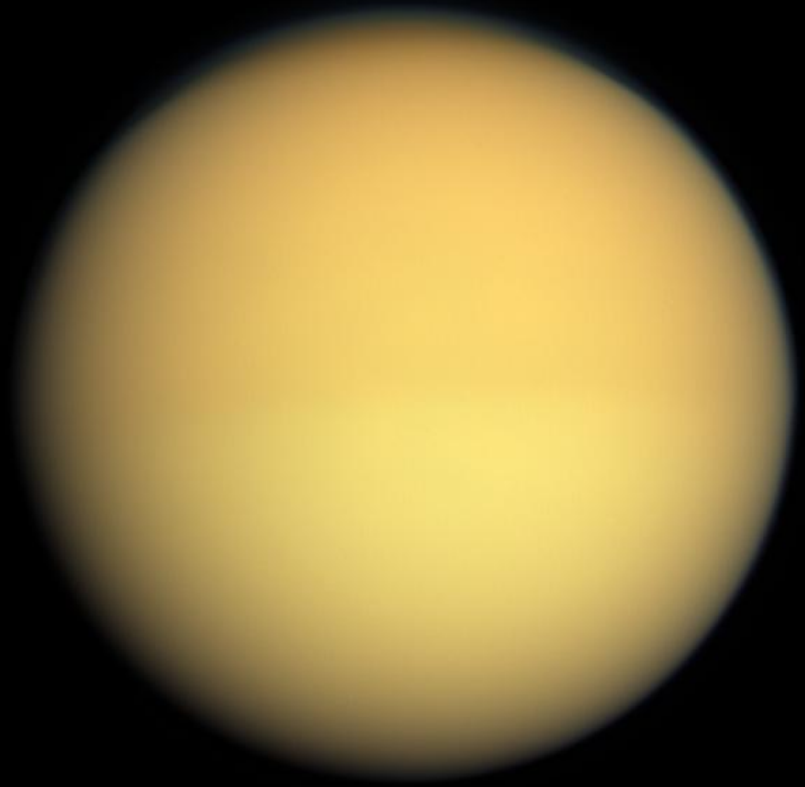


360 meter resolution

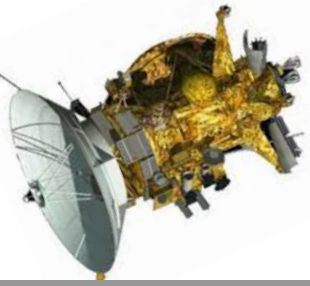


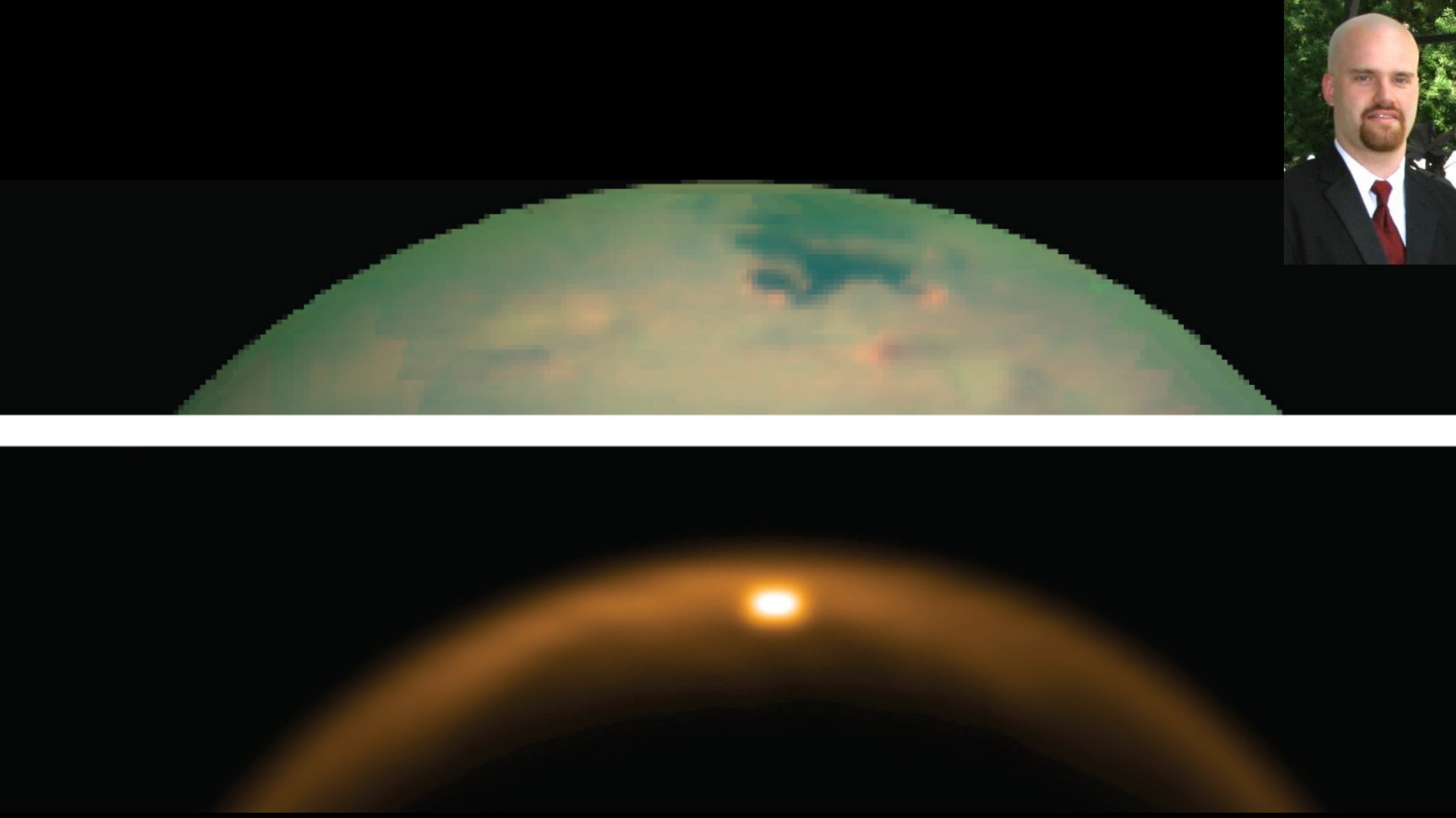
1.2 kilometer resolution

Lakes and seas



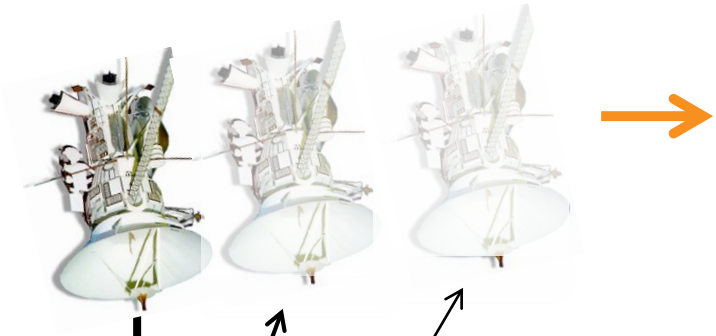
Orbiter radar discovered lakes and seas mostly in high northern latitudes





Specular reflection off of Titan's seas; VIMS (Barnes et al.)

Bathymetry from Cassini RADAR



Time delay gives depth to sea bottom
Strength of sea bottom signal gives composition of sea

AGU Geophysical Research Letters 10.1002/2013GL058618

The bathymetry of a Titan sea

Marco Mastrogiuseppe[1], Valerio Poggiali[1], Alexander Hayes[2], Ralph Lorenz[3], Jonathan Lunine[2], Giovanni Picardi[1], Roberto Seu[1], Enrico Flamini[4], Giuseppe Mitri[5], Claudia Notarnicola[6], Philippe Paillou[7], and Howard Zebker[8]

Sea surface reflection

Seabed reflection

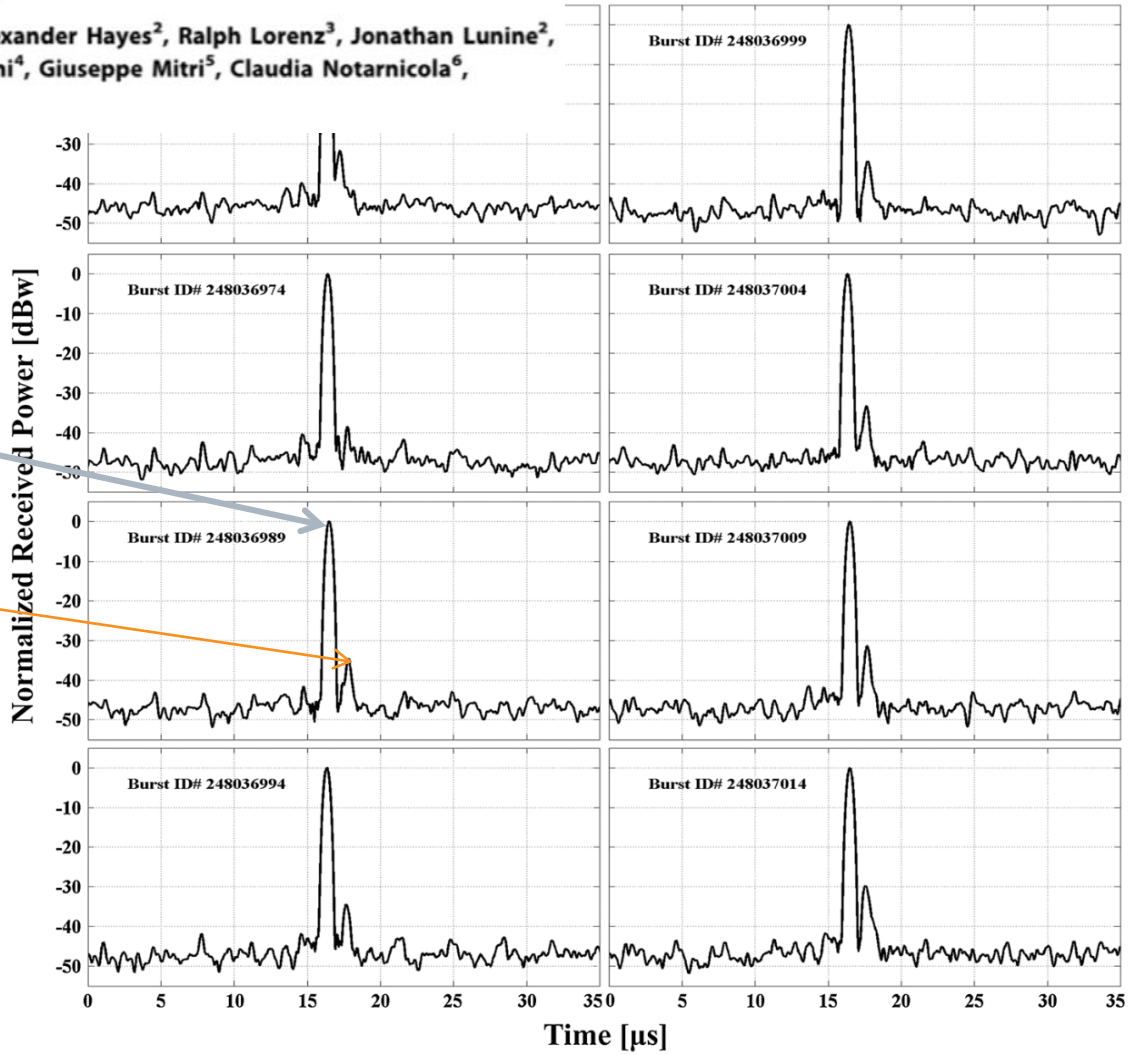
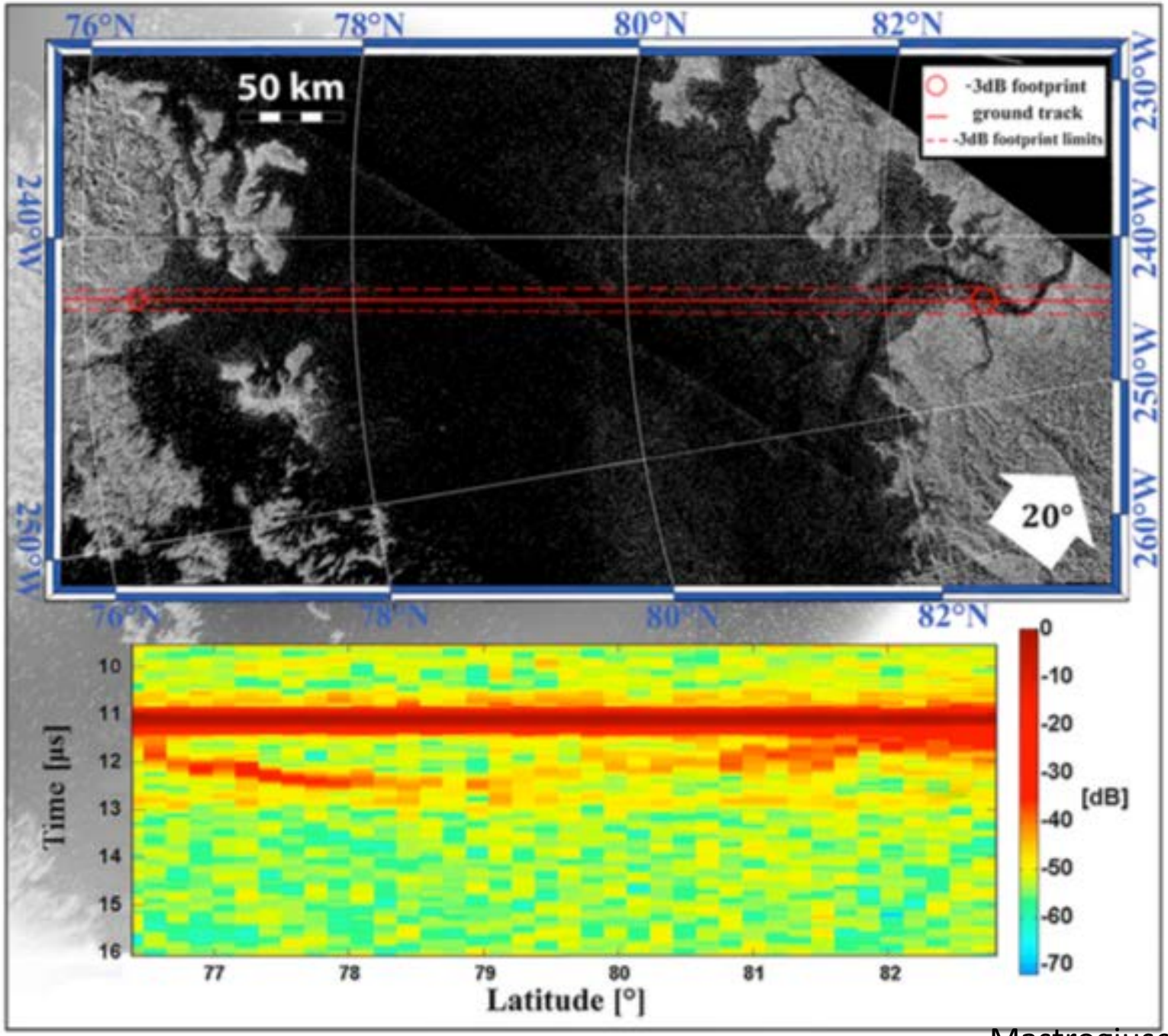


Figure 1. T91 Cassini altimeter pulses acquired over Ligeia Mare, Kaiser-Bessel taper function, and incoherent averaging were used to process echoes for data analysis. The first strong echo represents the reflection from the sea surface followed by a second weak reflection from the seabed.



Mastrogiuseppe et al

Methane absorption measured at JPL

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL059475

Laboratory measurements of cryogenic liquid alkane microwave absorptivity and implications for the composition of Ligeia Mare, Titan

Karl L. Mitchell[1], Martin B. Barmatz[1], Corey S. Jamieson[1,2], Ralph D. Lorenz[3], and Jonathan I. Lunine[4]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [2]SETI Institute, Mountain View, California, USA, [3]Johns Hopkins University Applied Physics Lab, Laurel, Maryland, USA, [4]Department of Astronomy, Cornell University, Ithaca, New York, USA

Key Points:
- Cryogenic liquid dielectric properties are measured using a novel approach
- The low loss of Titan's Ligeia Mare suggests that it is methane dominated
- These results challenge thermal equilibrium models of Ligeia Mare

Loss tangent is a measure of the energy lost by interaction with a physical medium--

Values x 10^5:

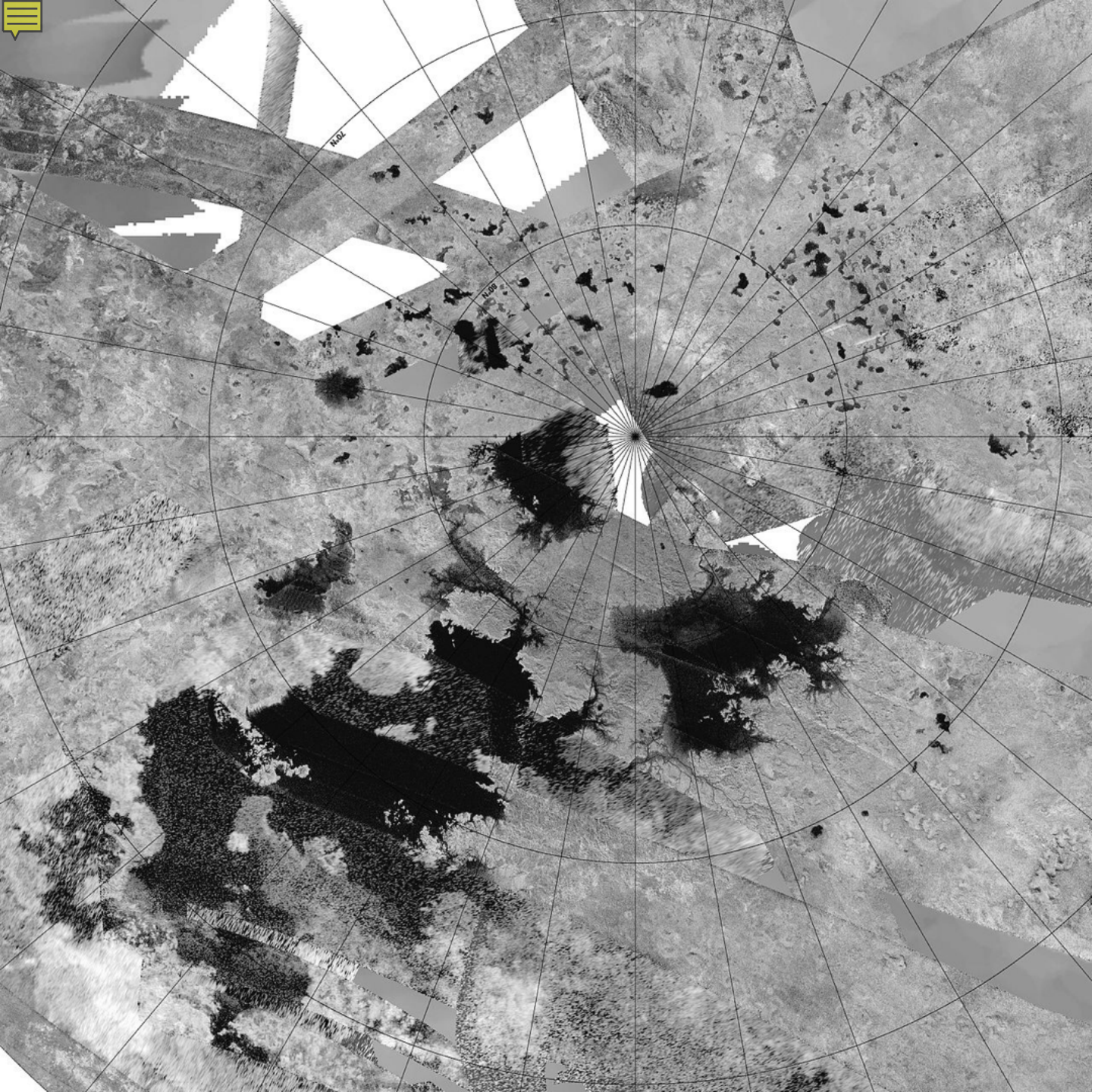
Ligeia Mare: 3± 1

Methane: 2.9 ± 0.5

Ethane: 12.2± 0.4

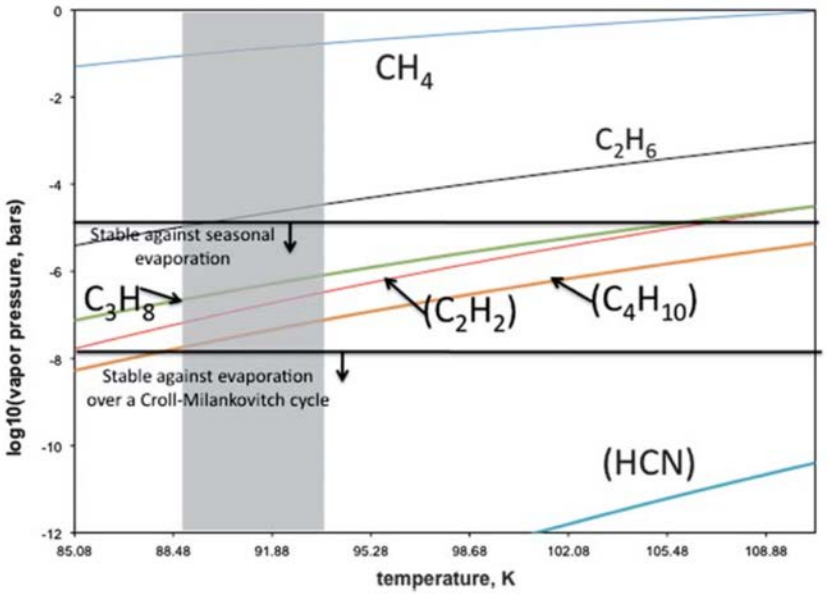
Water ice ~ 1000

=> 80% CH_4, 5%C_2H_6, 15%N_2 for Ligeia Mare (this is being adjusted to a less methane-rich value by Mastrogiuseppe et al. , in prep.)



Titan's great seas: hundreds of times more hydrocarbon than in the known oil and gas reservoirs on Earth.

Volatilities and solubilities



Acetylene separates from other solid products of Titan chemistry and moves to the poles.

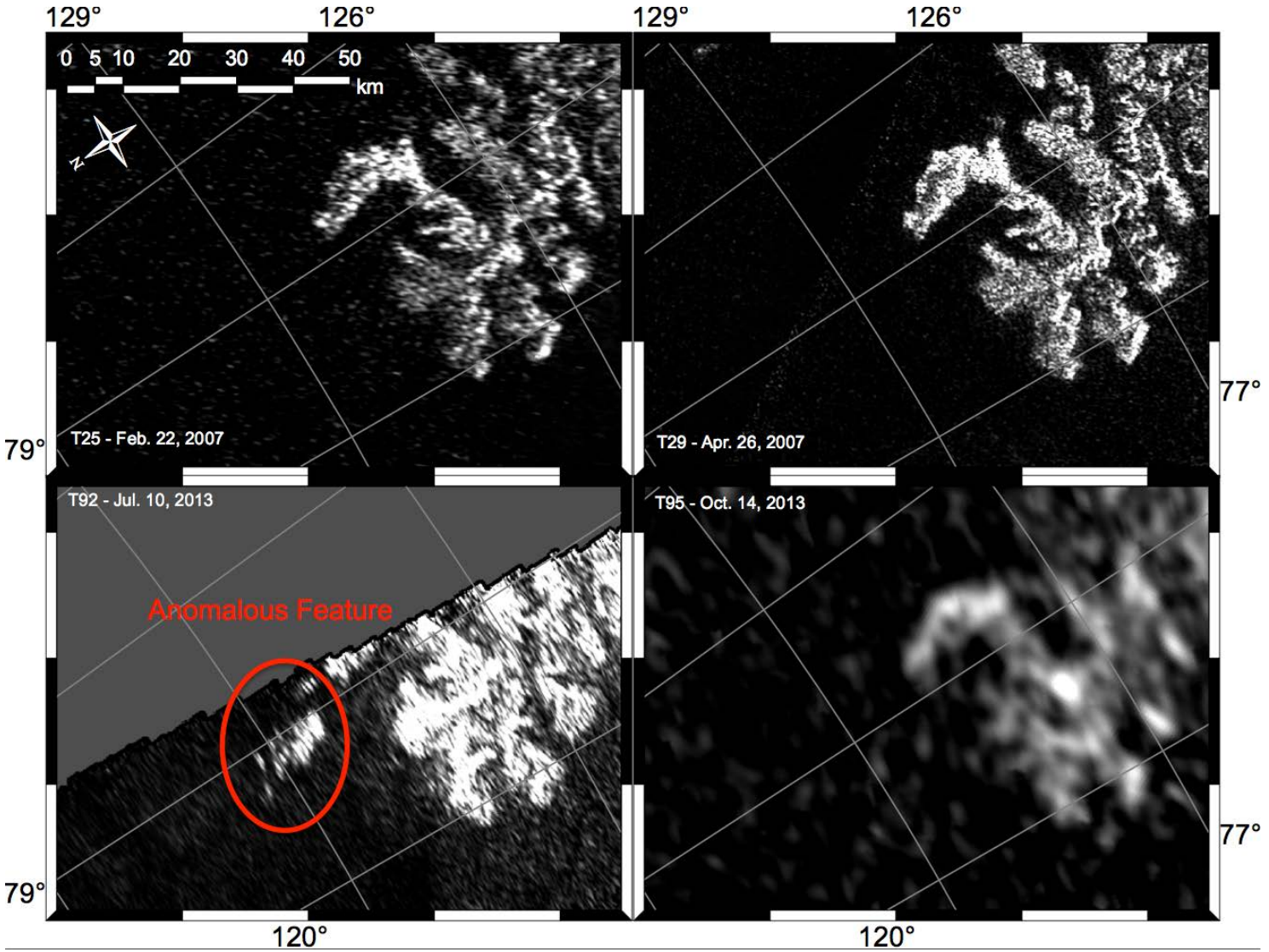
Table 4

Solubility (mole fraction) of nitriles and acetylene in pure methane at 94 K and 1.5 bar, with and without including the polar term in the PC-SAFT framework.

Component	Polar PC-SAFT	PC-SAFT
Acetylene	5.32×10^{-3}	5.32×10^{-3}
Acetonitrile	1.67×10^{-10}	3.04×10^{-8}
Propanenitrile	1.86×10^{-11}	1.33×10^{-5}
Acrylonitrile	1.55×10^{-11}	4.66×10^{-6}
Hydrogen cyanide	5.67×10^{-12}	1.12×10^{-11}

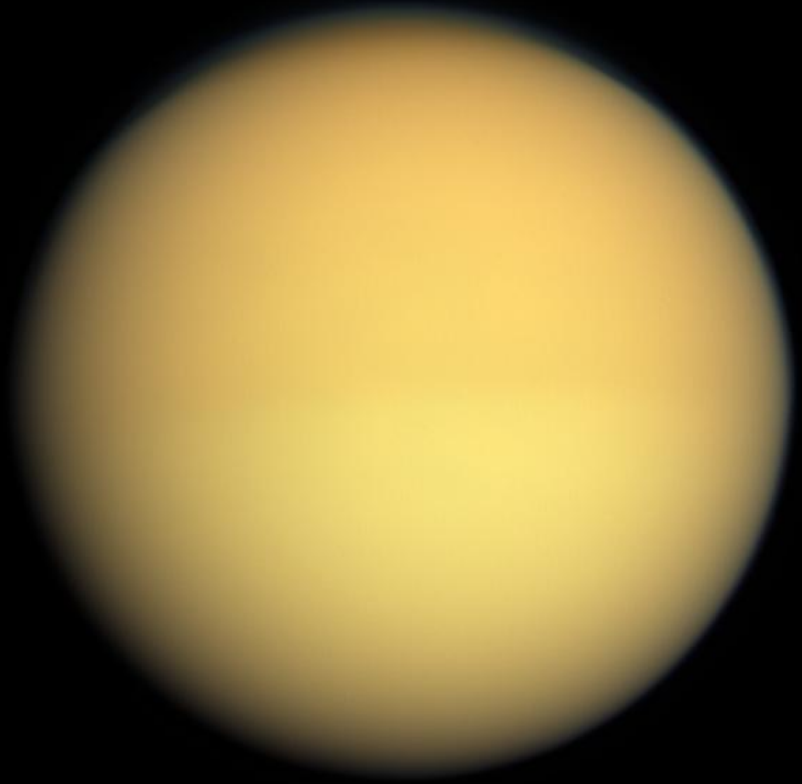
Acetylene is quite soluble
(J. Stevenson et al, 2015)

Northern spring: the seas are changing



Hofgartner et al 2014

The interior and the resupply of methane



Clathrate hydrate is the most plausible storage medium for large amounts of methane

ICARUS 15, 174–185 (1971)

Satellites of the Outer Planets: Their Physical and Chemical Nature[1]

JOHN S. LEWIS

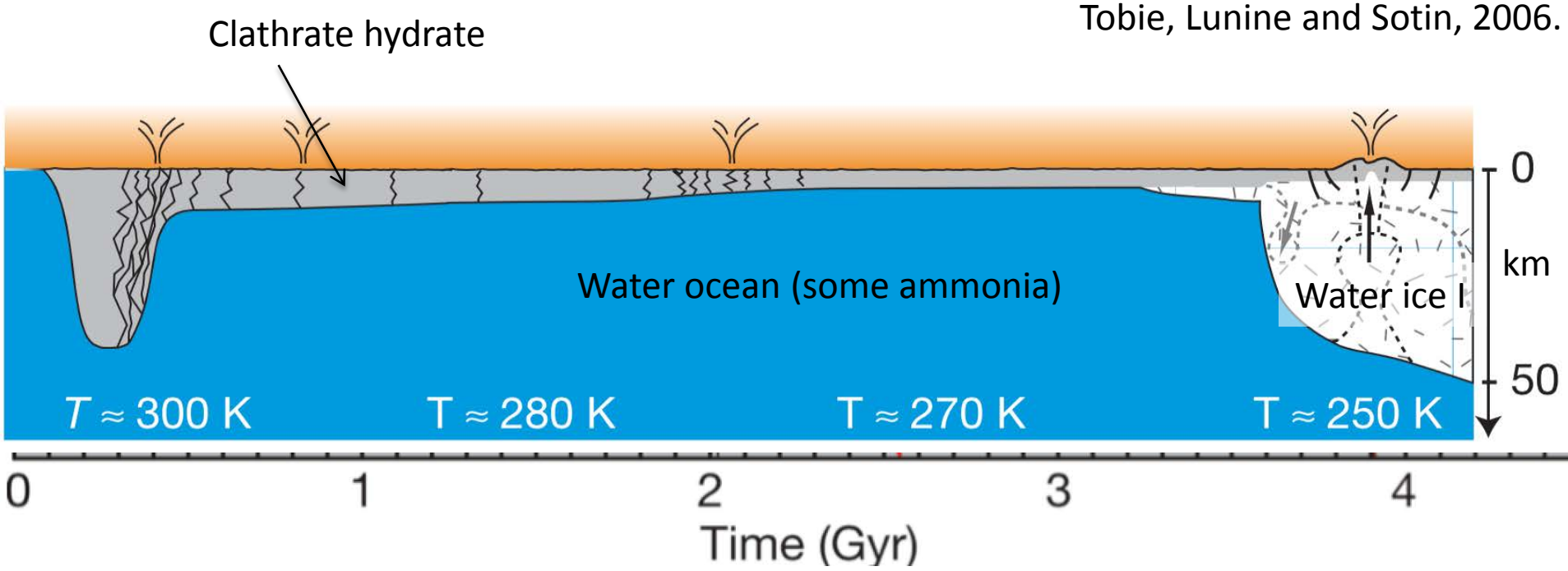
The observed CH_4 abundance on Titan is roughly 200 m·amagat (Kuiper, 1949), corresponding to a surface partial pressure of $\sim 2 \times 10^{-3}$ bar. This is in good accord with the idea that the surface of Titan may contain a mixture of ice and CH_4 hydrate.

Methane clathrate hydrate crust insulates interior....and provides a resupply of methane

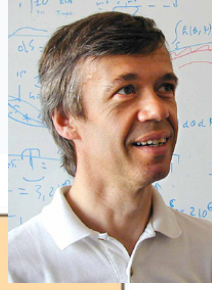
- 20 km thick crust of $CH_4 \cdot 6H_2O$ provides enough methane for 10 gyr.
- 50 km present day crustal thickness of ice supported by Huygens E-field data.

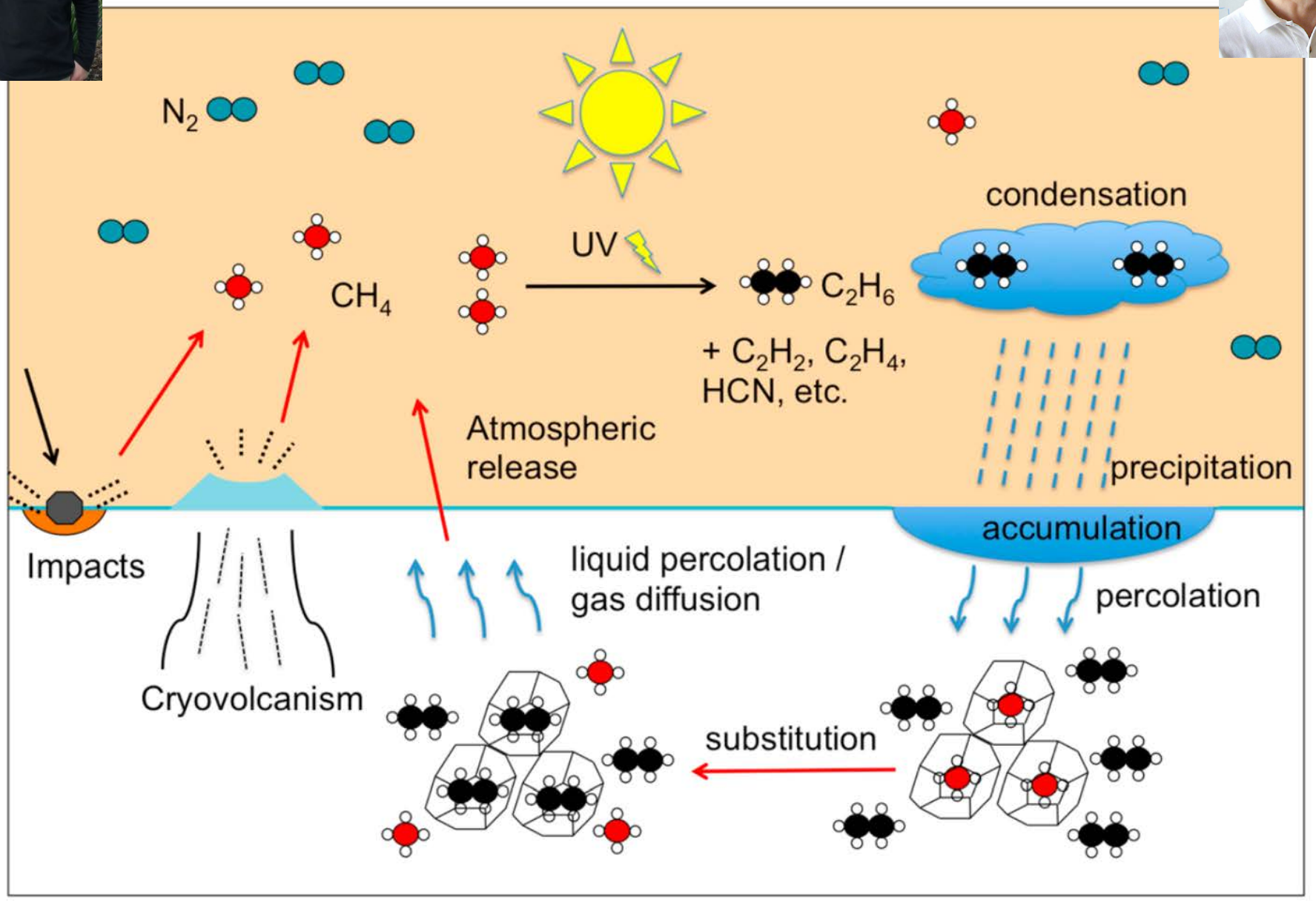
- Methane clathrate hydrate has a lower thermal conductivity and higher rigidity than normal Ice I.

Tobie, Lunine and Sotin, 2006.



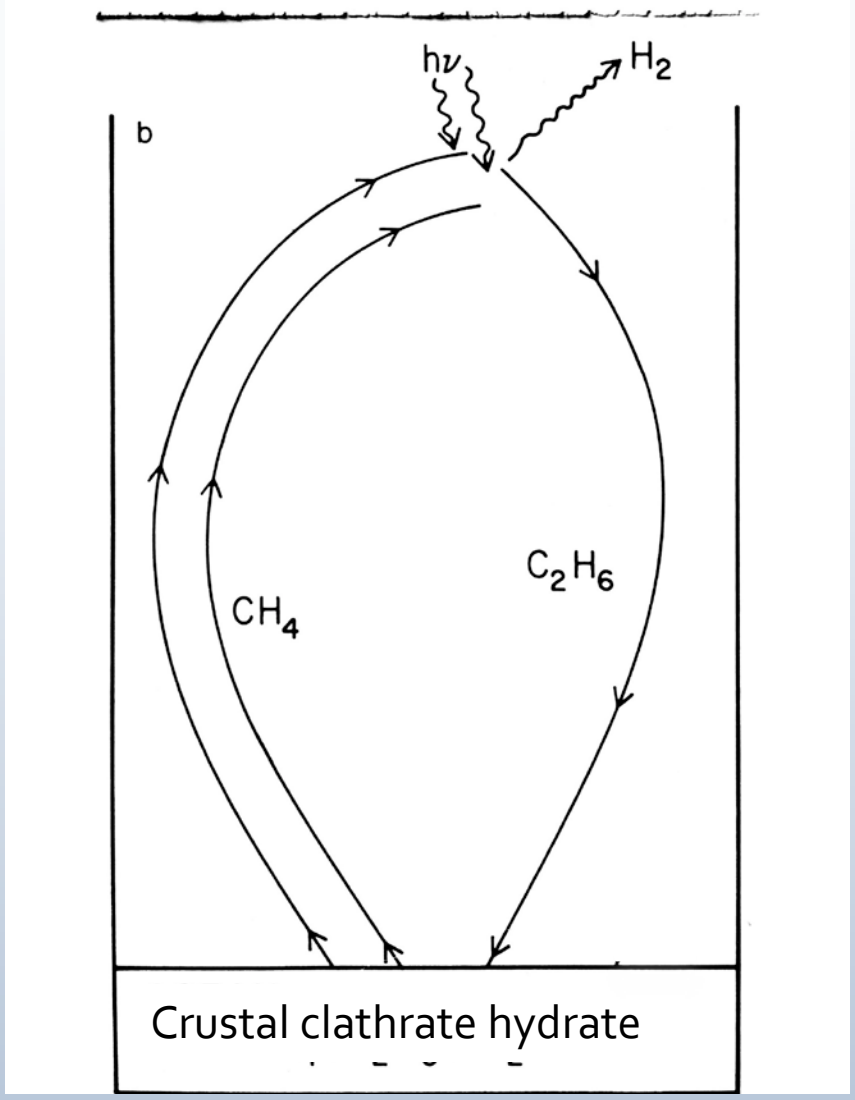
Choukroun and Sotin, 2012



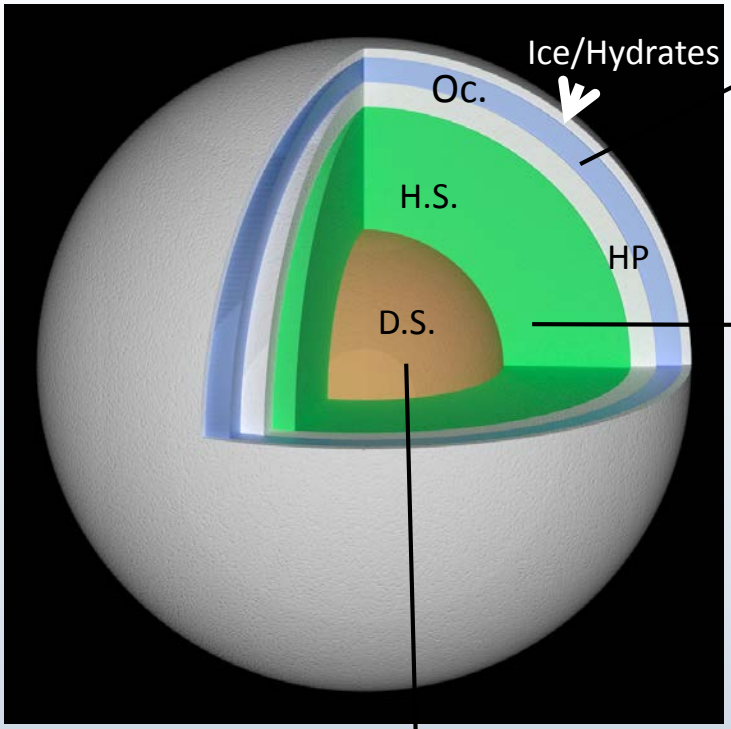


2-for-1 problem

- For a while, the substitution of ethane for methane in the clathrate will force methane out to the surface but eventually the 2-for-1 exchange will allow ethane to incorporate while leaving methane in place because free water ice is available



Sensitive doppler measurements from the Orbiter showed that Titan is (a) bloated and (b) squishy.

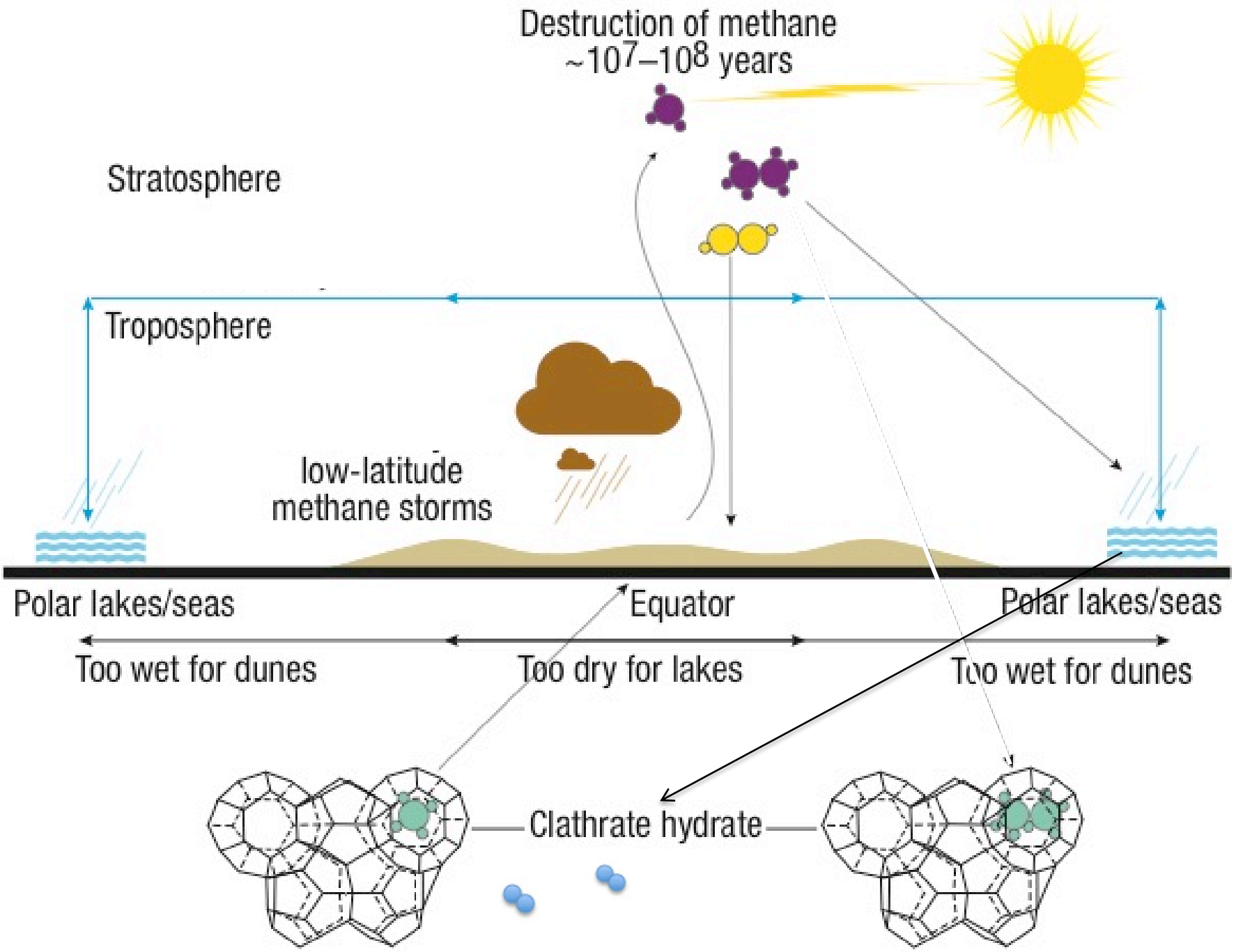


Ocean density may be up to 1.5 g/cm^3 (high-pressure)

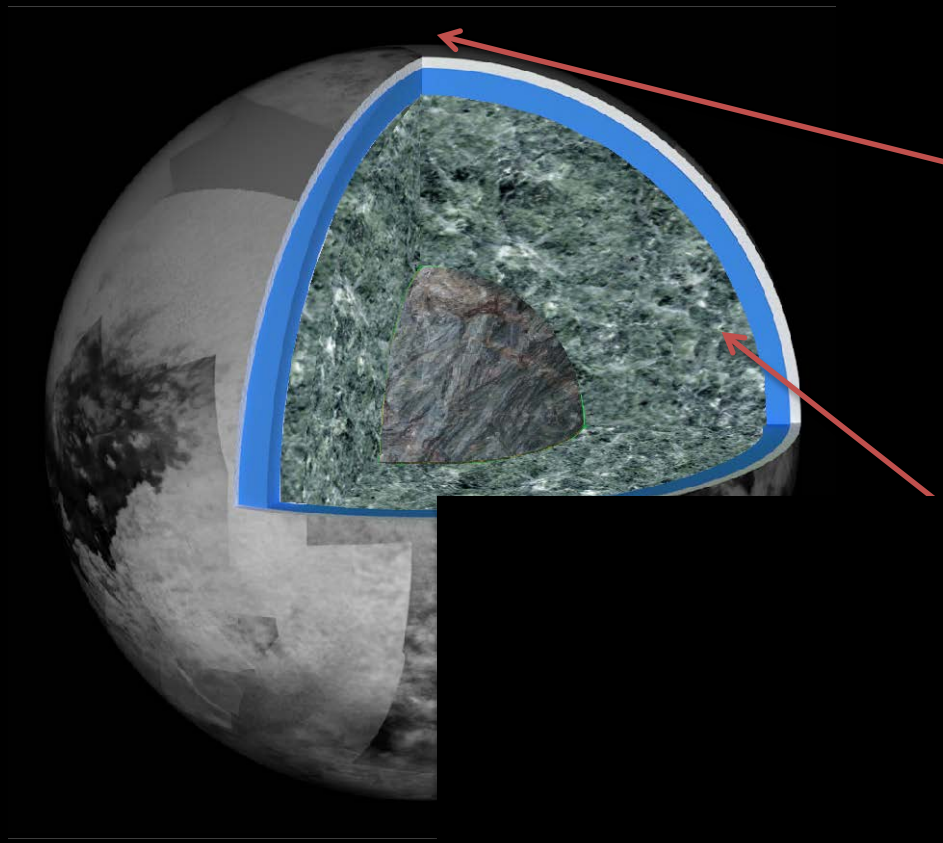
Hydrated silicate density can be 2.4-2.8 g/cm^3

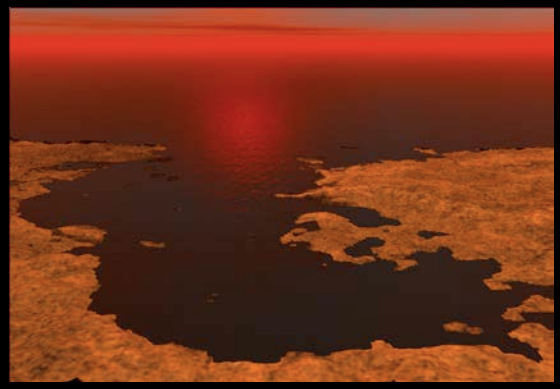
Anhydrous silicates, up to 1000 km in radius

Castillo-Rogez & Lunine


Destruction of methane
~10^7–10^8 years
Stratosphere
Troposphere
low-latitude
methane storms
Polar lakes/seas
Equator
Polar lakes/seas
Too wet for dunes
Too dry for lakes
Too wet for dunes
Clathrate hydrate

Where to look for life on Titan?





Can a form of life exist in ethane-methane instead of water?:

--totally alien biology

--strict test of life's cosmic commonality

The next step for the exploration of Titan: land in the sea

Titan Mare Explorer (TiME)

Conclusion: guide to alternative biology on Titan

- The great seas are mostly methane, but with admixtures of nitrogen and ethane.
- Some of the lakes may have higher concentrations of ethane (Ontario Lacus)
- Solubility of solids in seas varies widely—acetylene is high; HCN low.
- Nitriles and hydrocarbons separate from each other by volatility in global transport.
- There is evidence (VIMS) for chemistry between acetylene and HCN.
- Many terrestrial type processes occur in seas—rain, tides, winds, evaporation (in lakes) ….
- Remember, T is 94 K at Titan's surface!