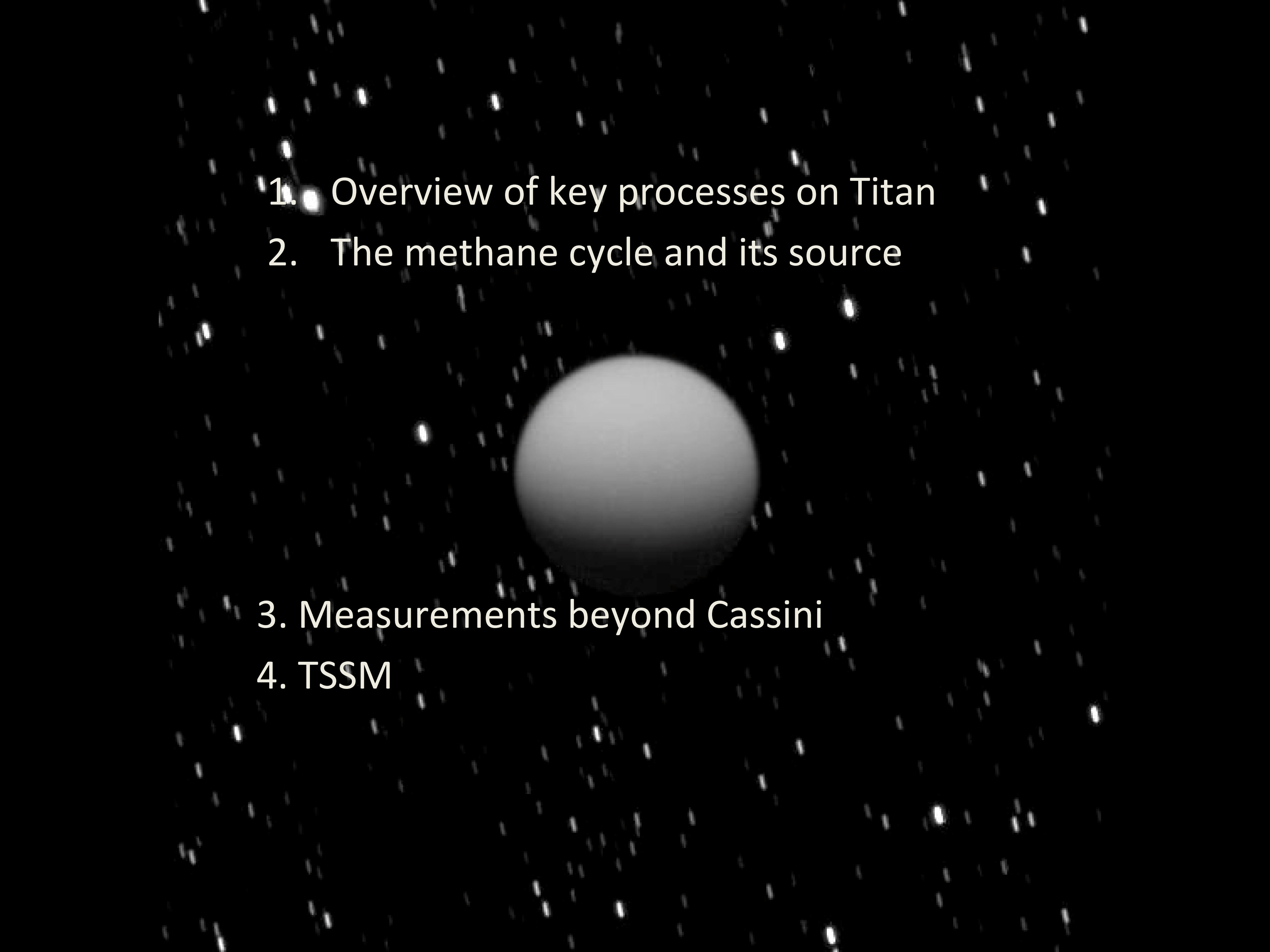
Titan Saturn System Mission

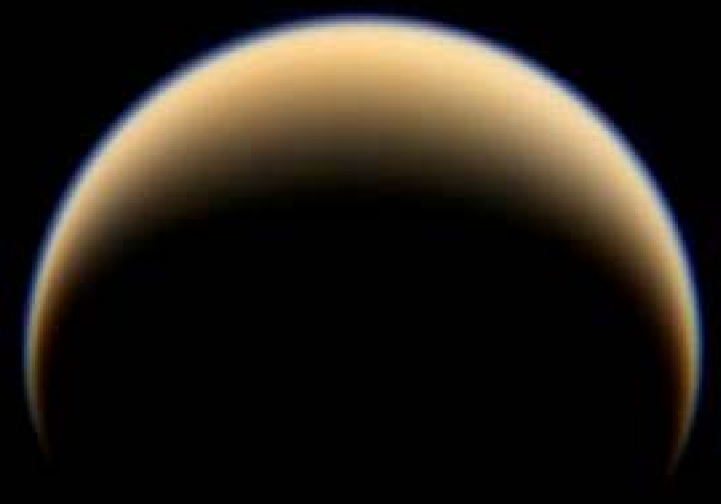
Jonathan Lunine

Co-Chair, TSSM JSDT



1. Overview of key processes on Titan
2. The methane cycle and its source

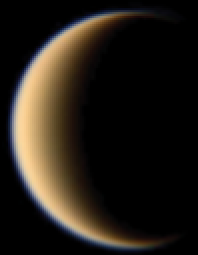
3. Measurements beyond Cassini
4. TSSM



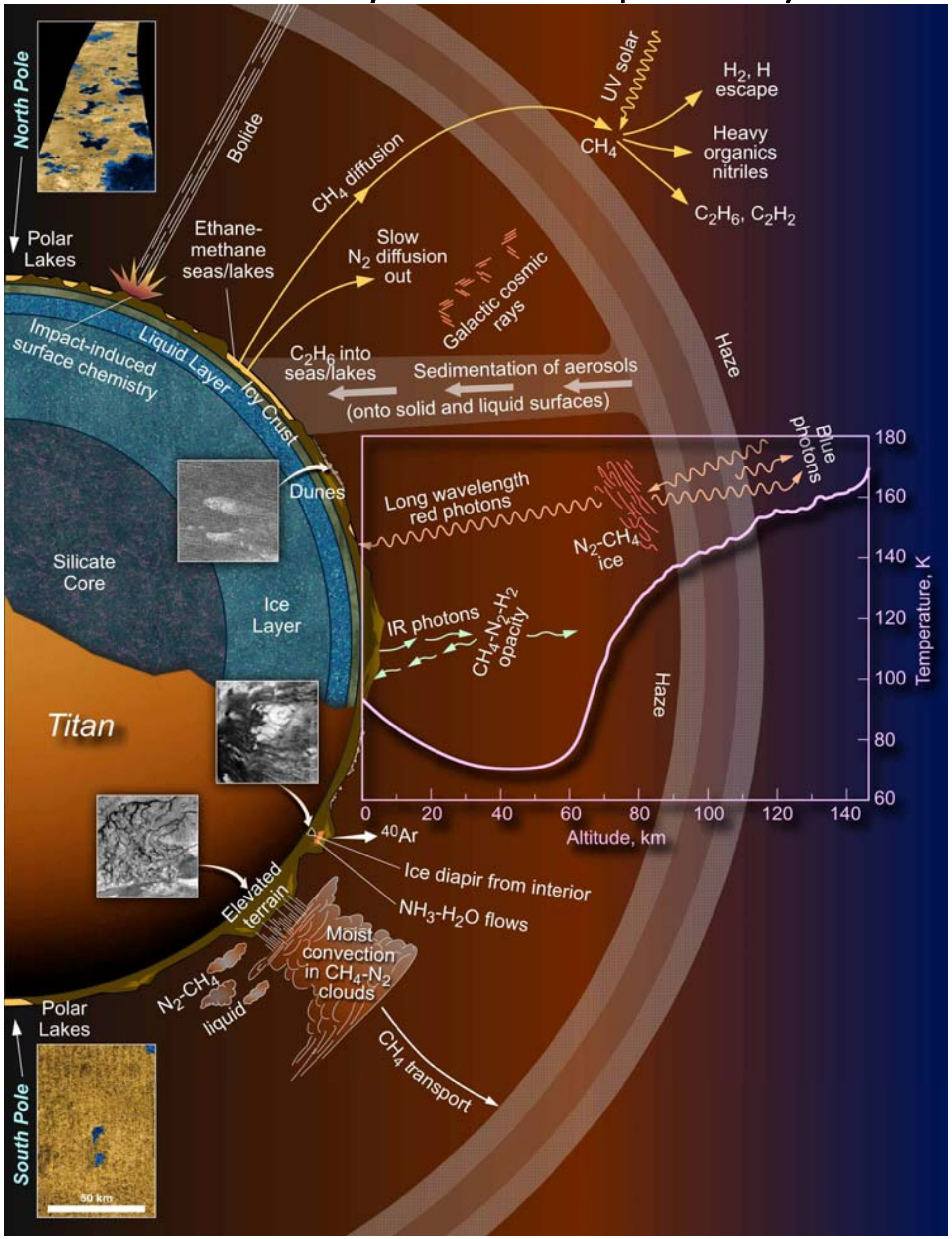
Overview of Key Processes on Titan

- Four worlds with atmospheres that support exploration by balloon and parachute

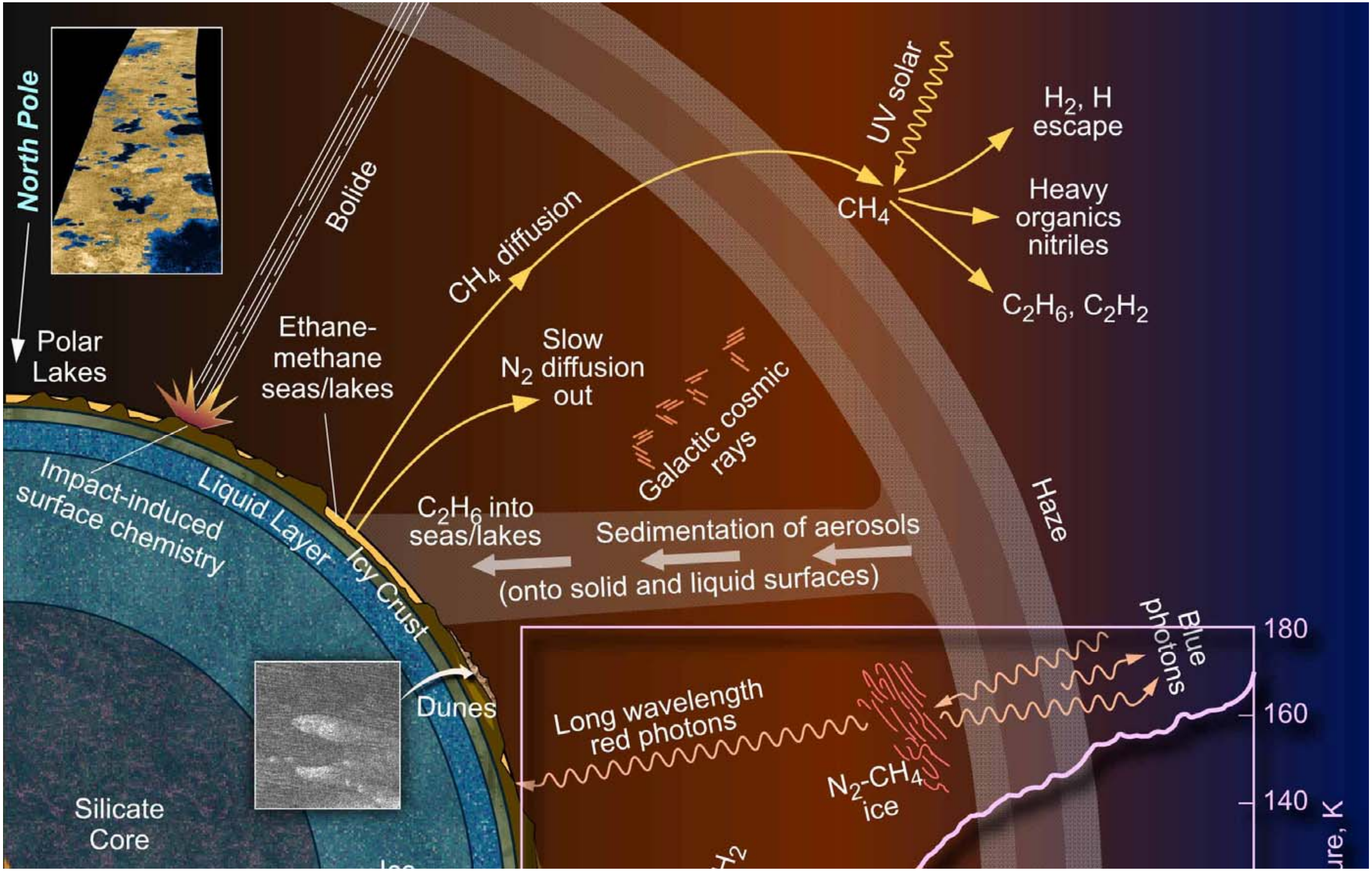
- “Complete” worlds whose interior, surface, atmosphere couple through volatile cyclling



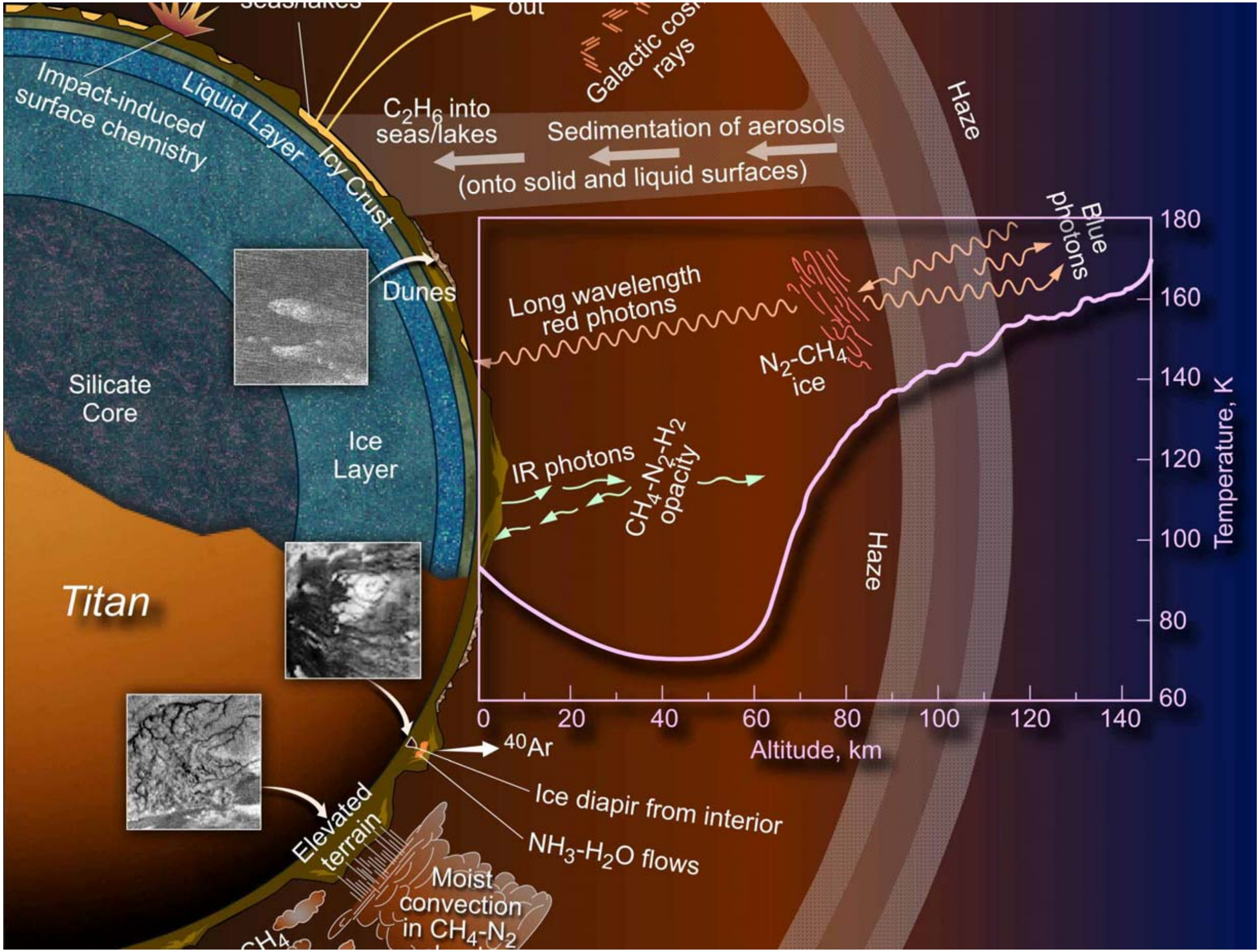
Titan as an object is of keen interest for virtually all areas of planetary science



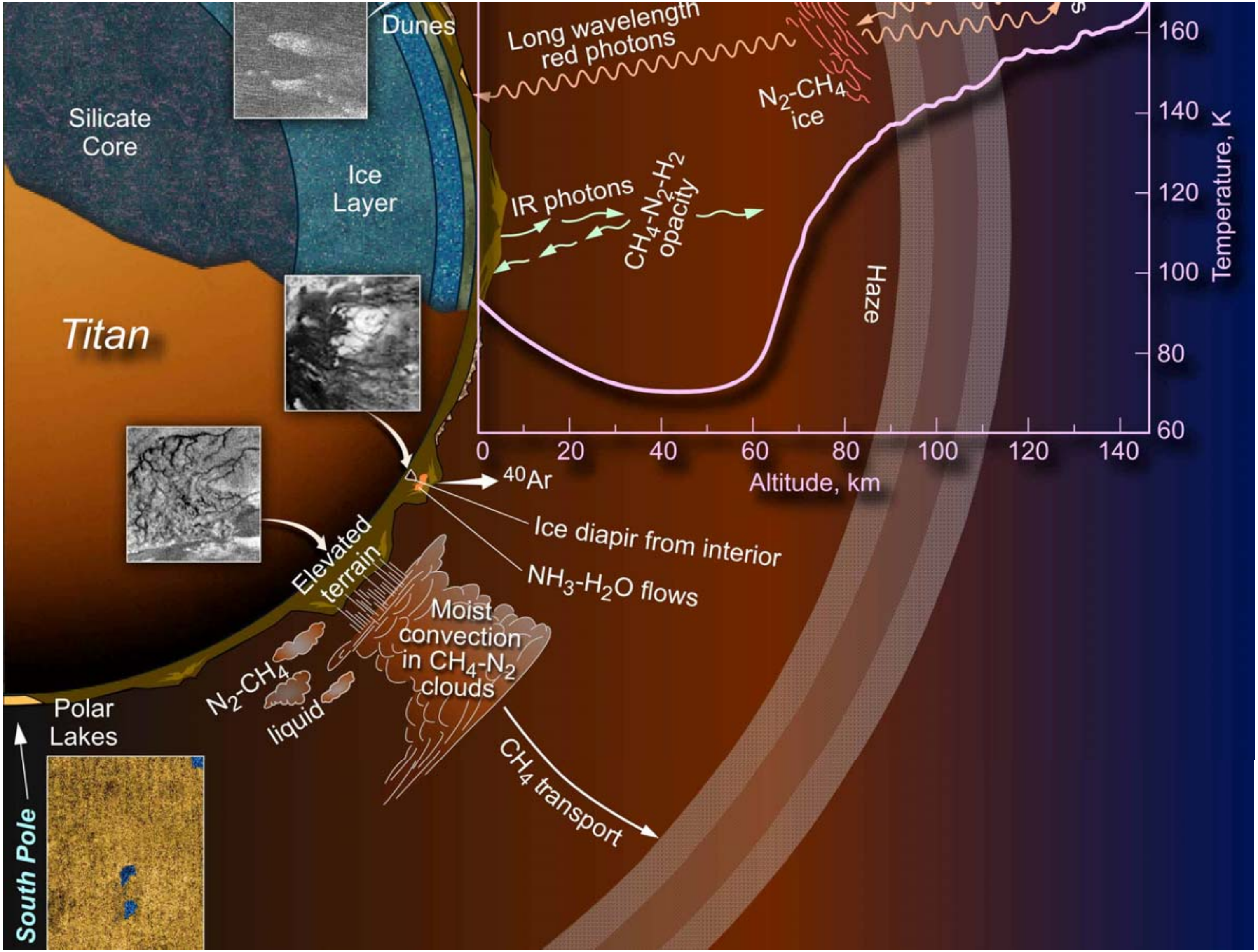
Titan's organic cycle

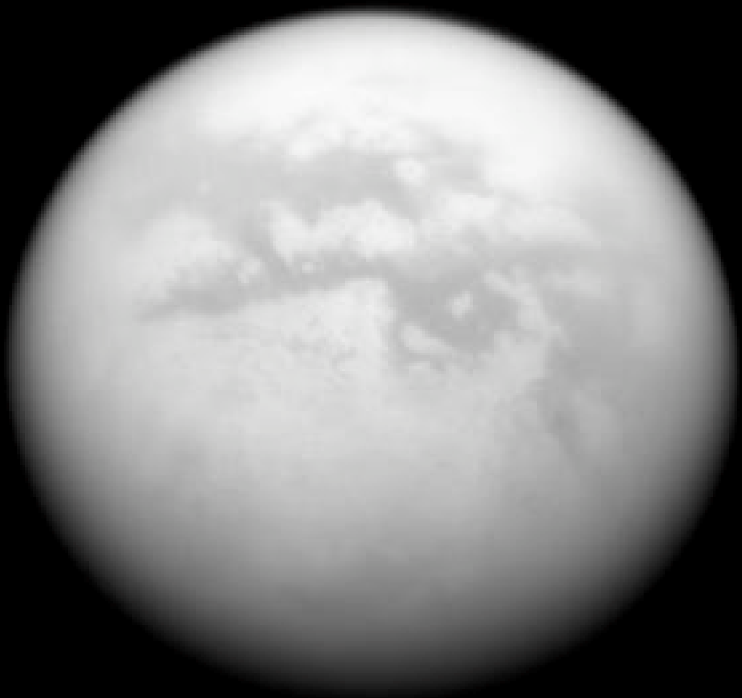


Titan's greenhouse climate

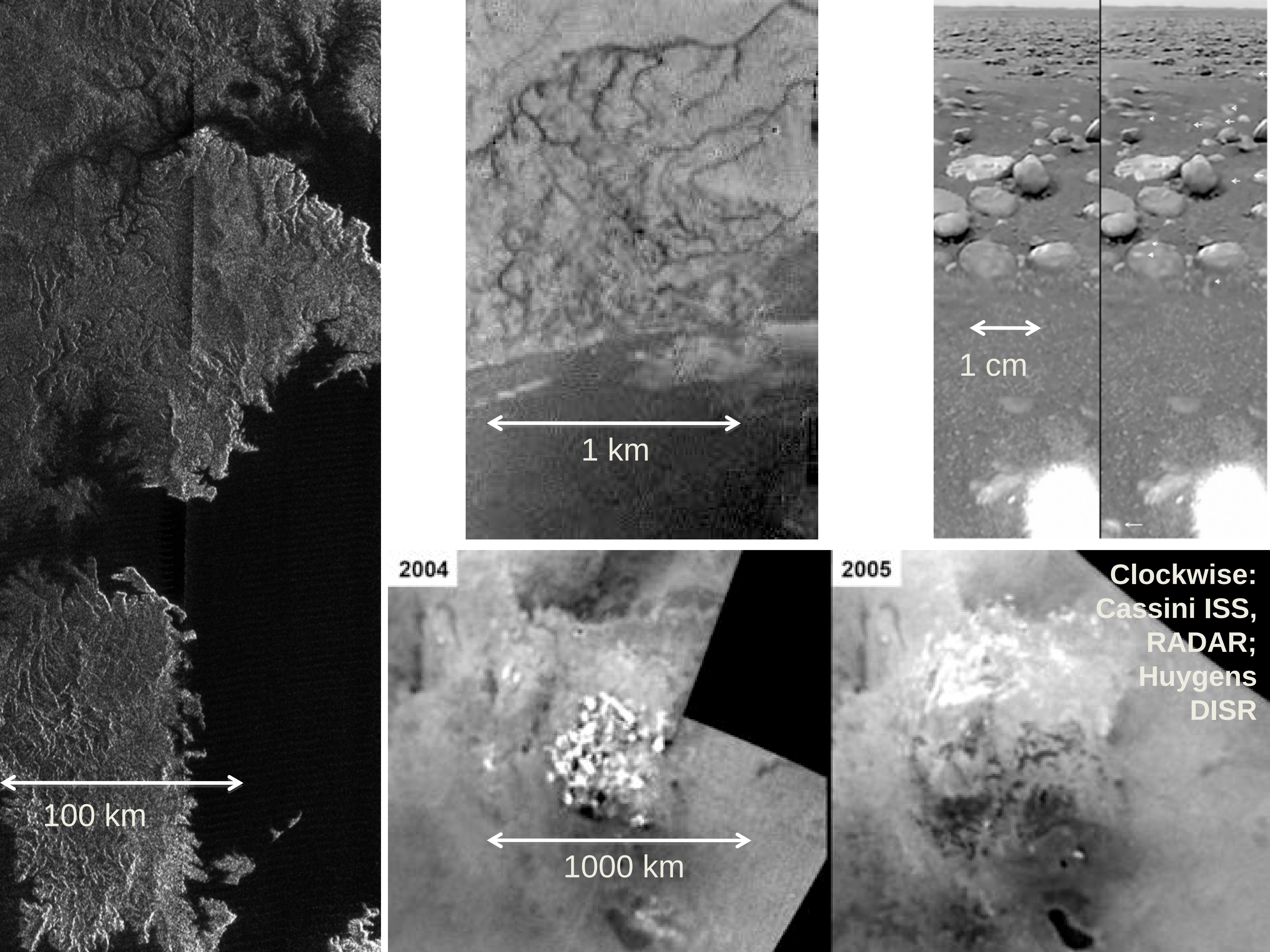


Titan’s intriguing unknowns

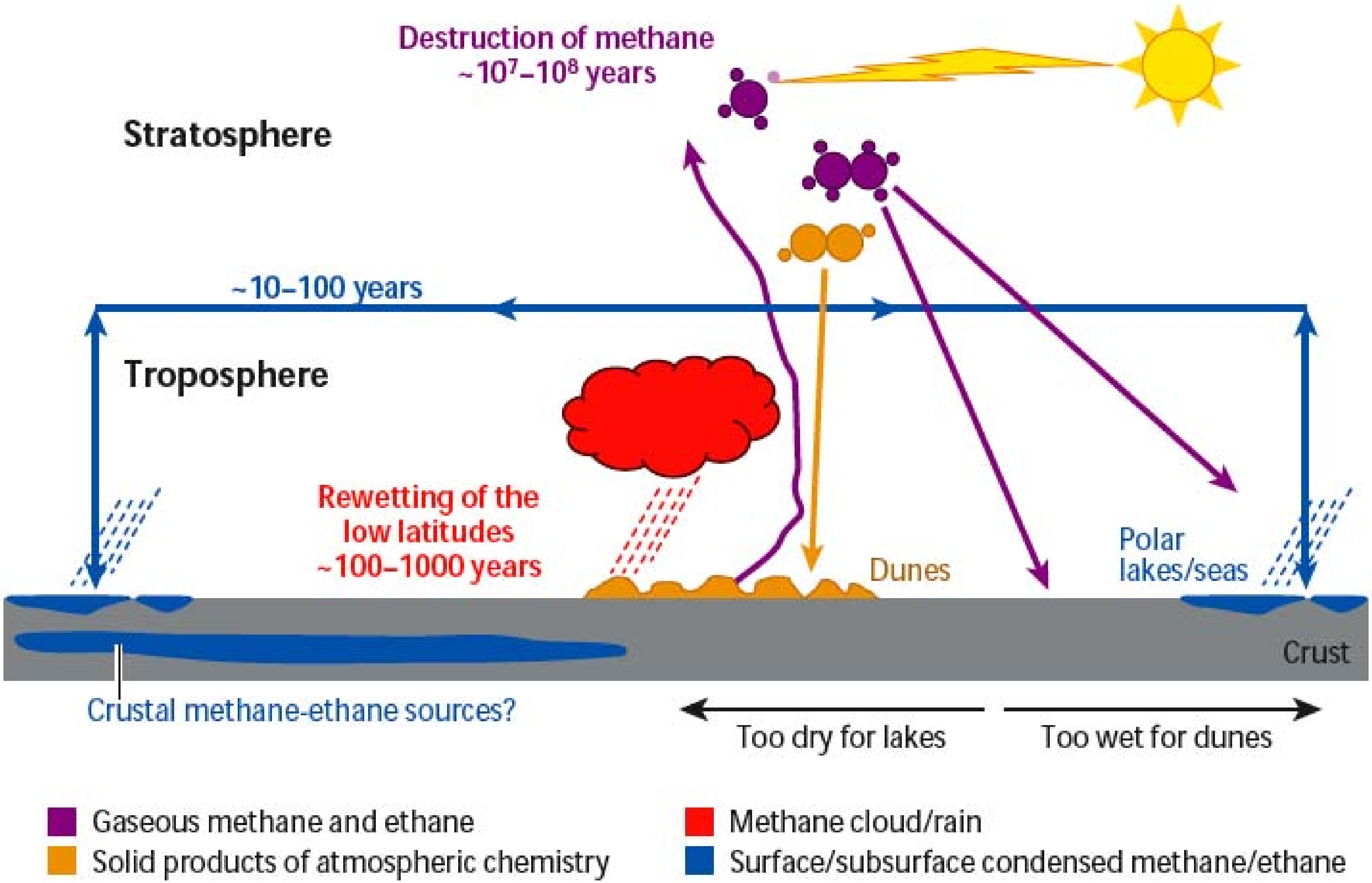




The methane cycle and its source



100 km
1 km
1 cm
2004
1000 km
2005
Clockwise:
Cassini ISS,
RADAR;
Huygens
DISR



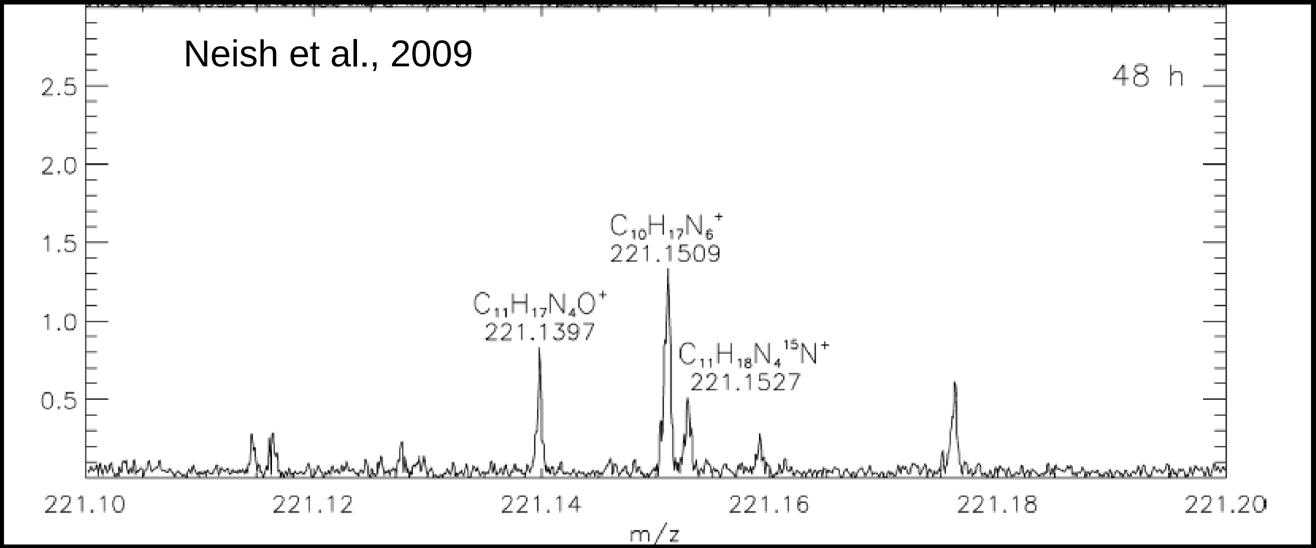
Titan's rapid methane loss models the inevitable long-term loss of Earth's water as the solar constant increases over time

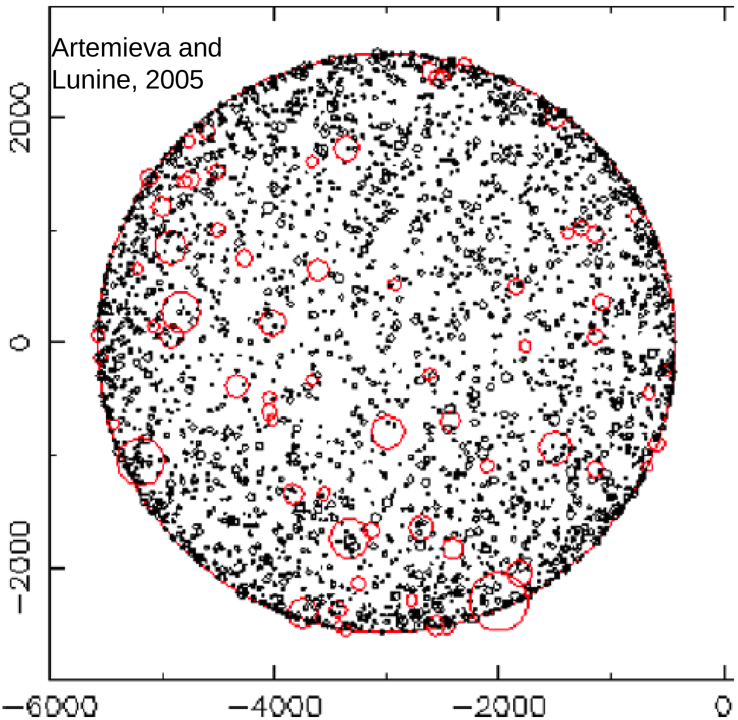
Lunine and Atreya, 2008

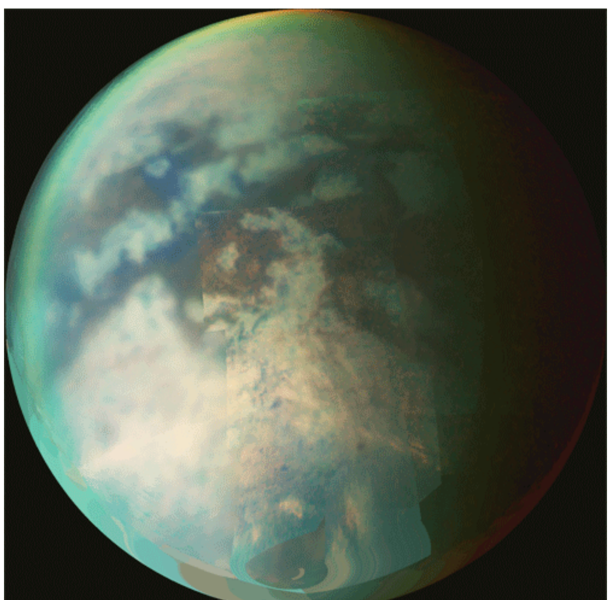
Interaction of the interior and the surface

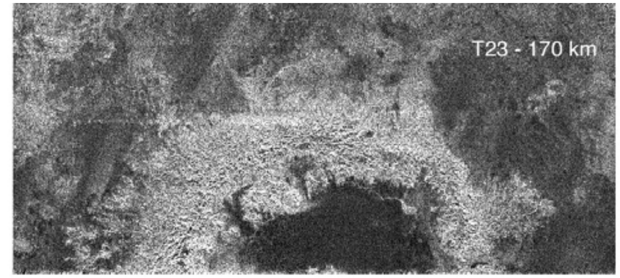
- Low $^{36}Ar/N_2$: Nitrogen came from ammonia.
- Enceladus: Ammonia is resident in Saturnian satellites (2008).
- ^{40}Ar: Titan outgasses over time.

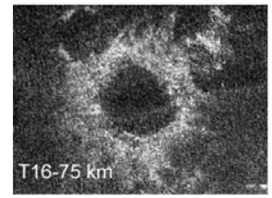
  - Ammonia is key for "cryo" volcanism
  - Impact or cryovolcanic melting of the crust exposes organics to liquid water→ interesting prebiotic chemistry
  - Some products of this chemistry will end up in Titan's lakes and seas

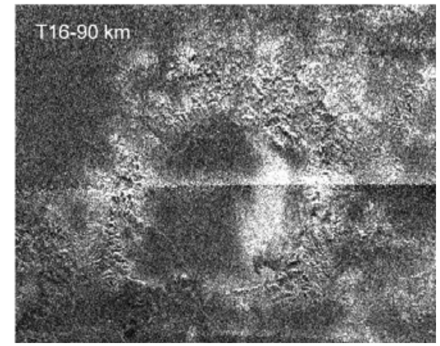


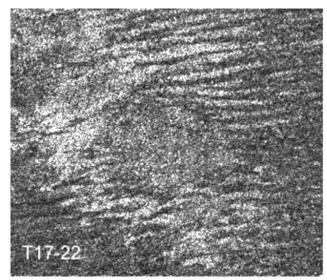


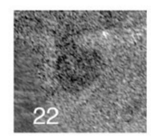


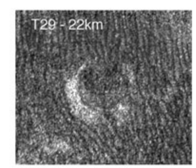


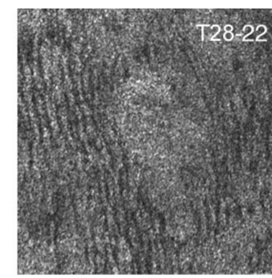


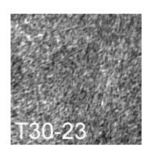


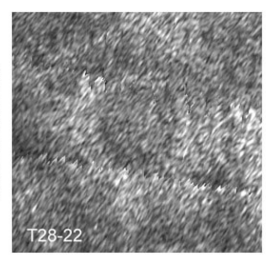


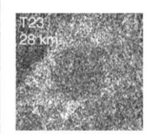


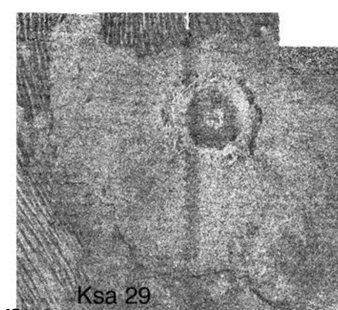








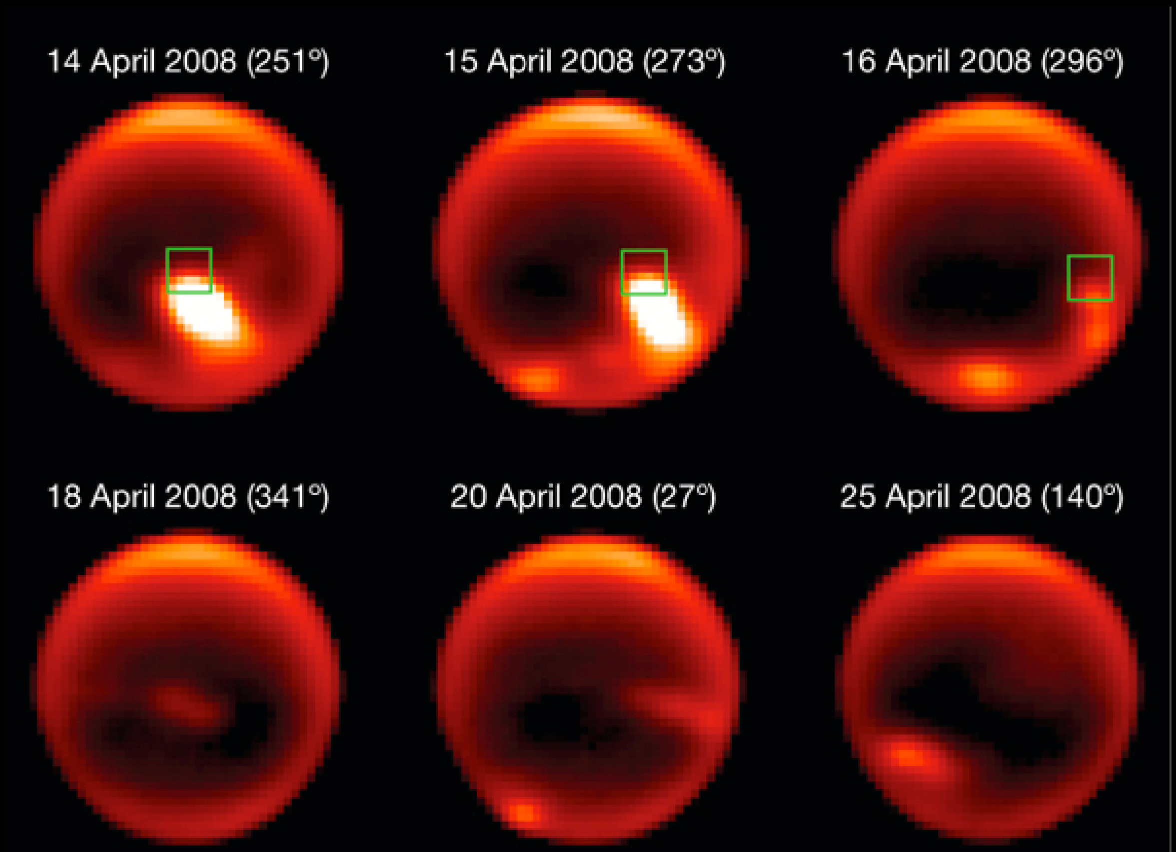




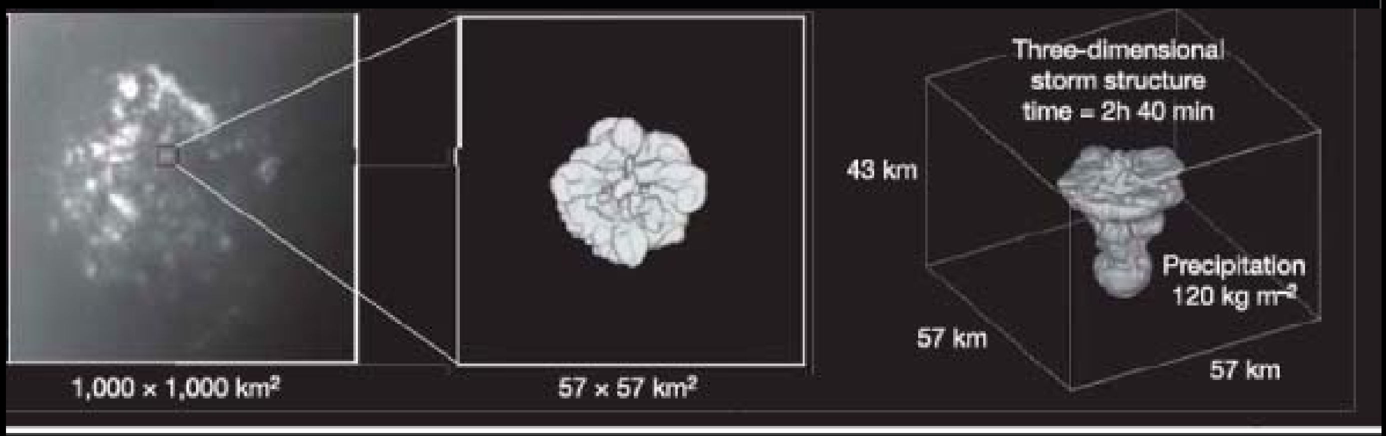
Impact craters exist, though many have been erased or buried. (Wood et al., in press).

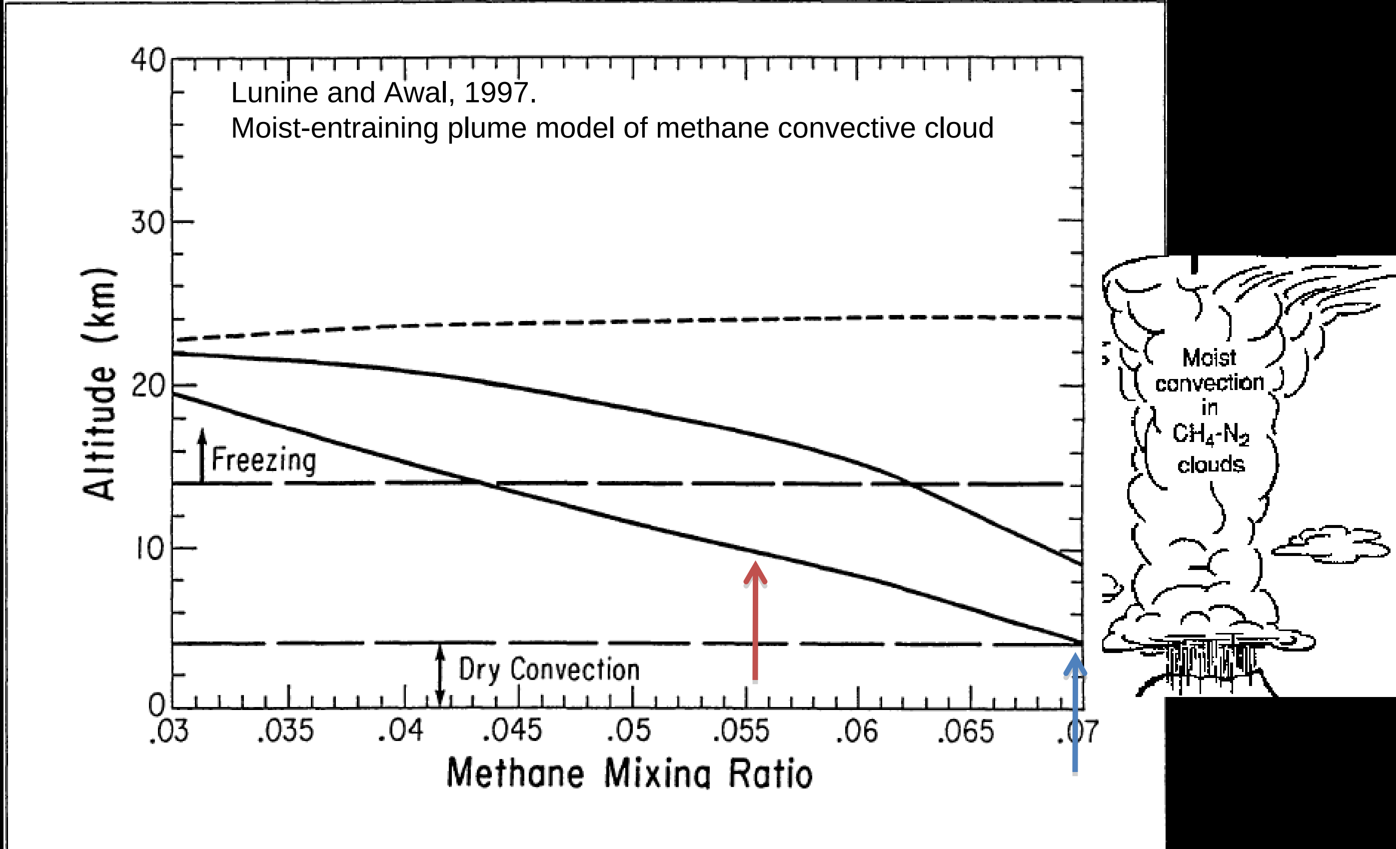
Is the methane resupplied from the subsurface?

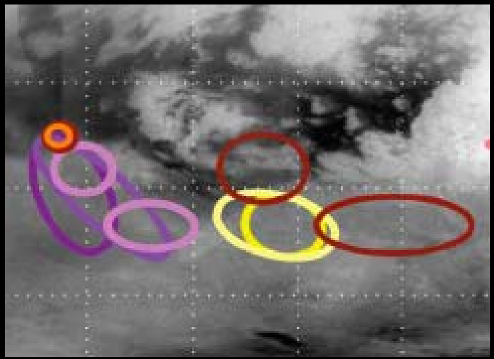
Schaller et al *2009:* Convective cloud outburst near the equator, powerful enough to trigger waves that initiated a southern secondary cloud formation.



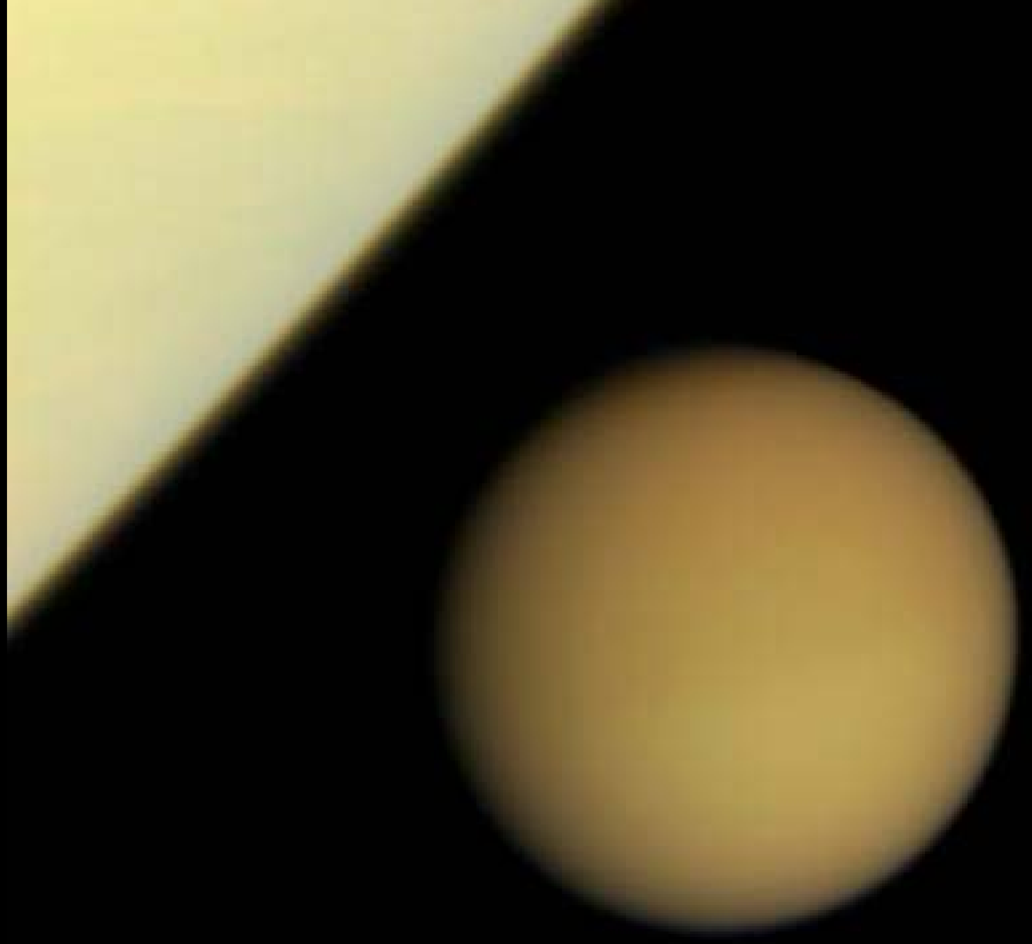
Hueso & Sànchez-Lavega 2006: Methane convective storm models





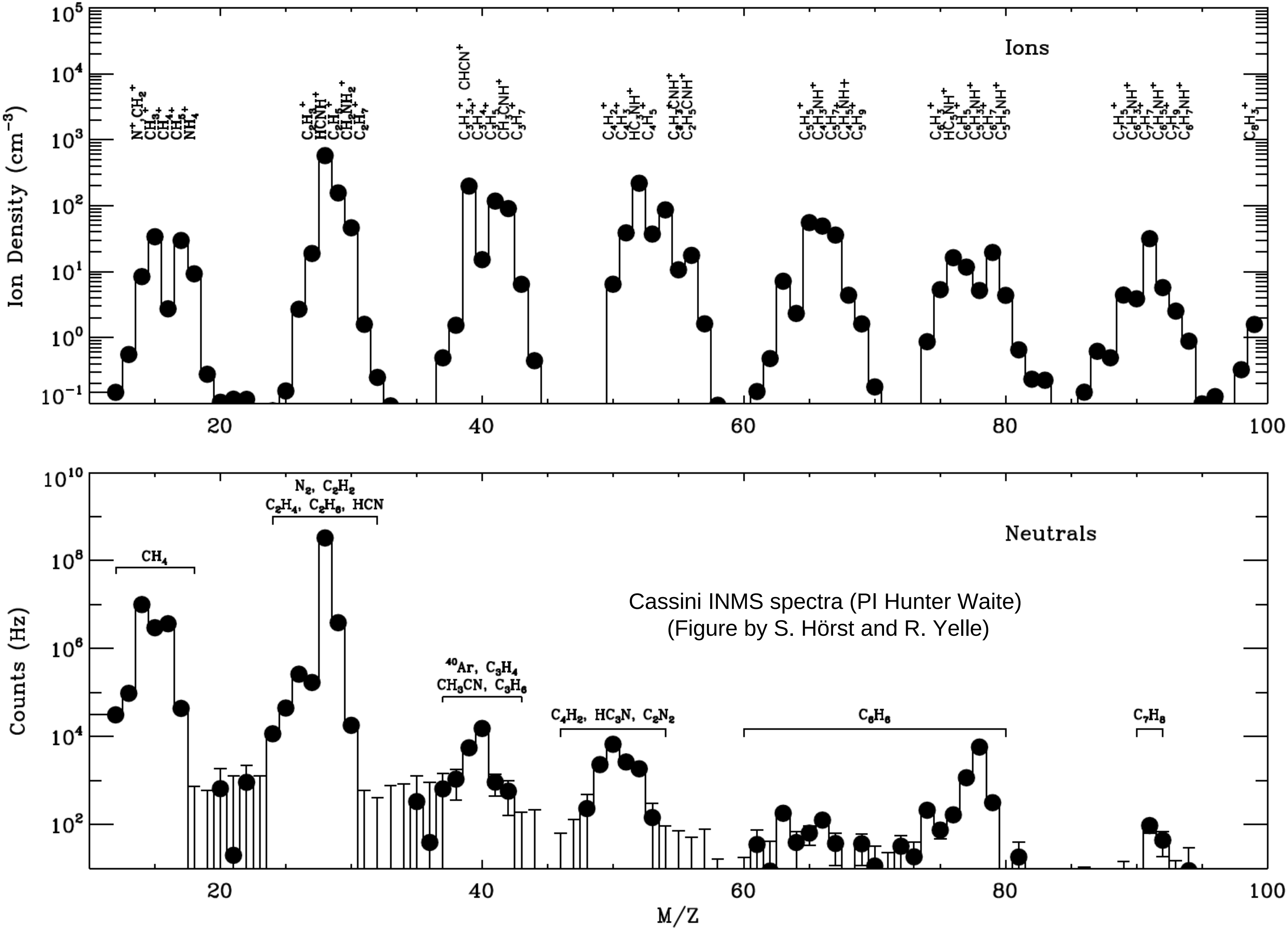


Therefore the cloud outburst is circumstantial evidence for emission of methane and/or heated air from the surface in the outburst source region. (Schaller et al., Nature, 2009).



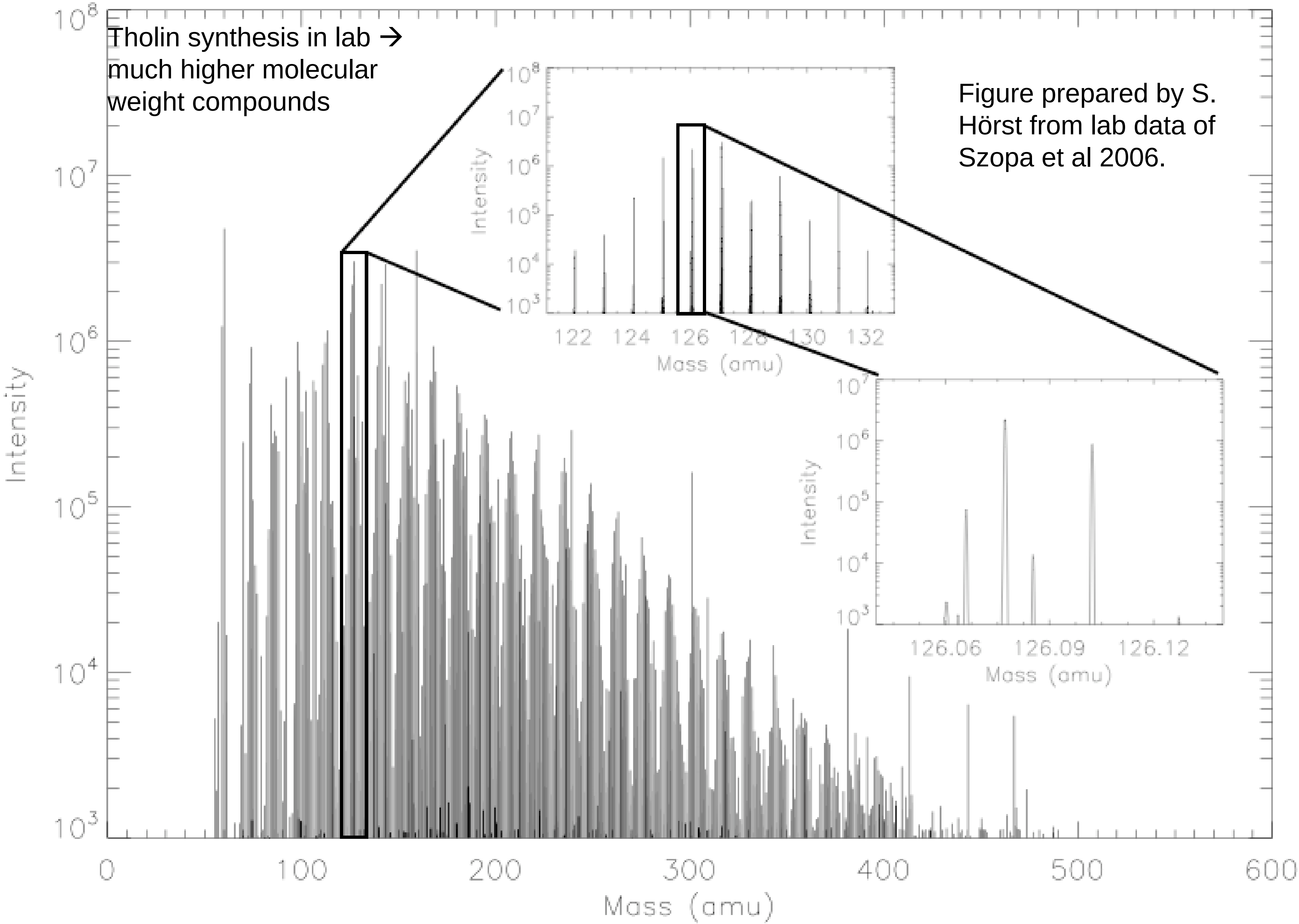
Measurements beyond Cassini

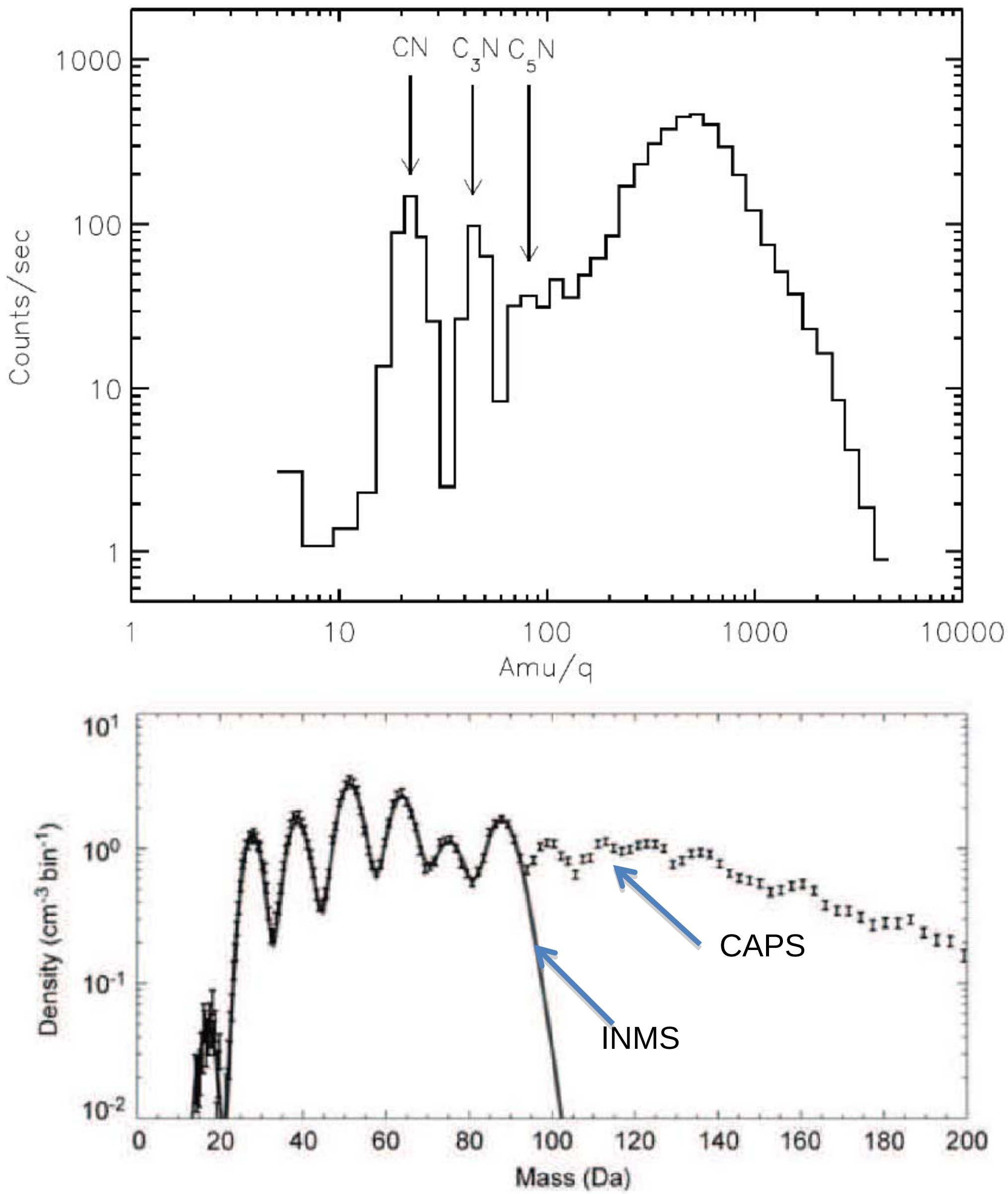
a. Mass resolution and range
b. Spatial resolution and range
c. Temporal resolution and range
d. Altitude resolution and range



Ions
Ion Density (cm^{-3})
Neutrals
Counts (Hz)
M/Z
CH$_4$
N$_2$, C$_2$H$_2$
C$_2$H$_4$, C$_2$H$_6$, HCN
^{40}Ar, C$_3$H$_4$
CH$_3$CN, C$_3$H$_6$
C$_4$H$_2$, HC$_3$N, C$_2$N$_2$
C$_6$H$_6$
C$_7$H$_8$
Cassini INMS spectra (PI Hunter Waite)
(Figure by S. Hörst and R. Yelle)

a. Mass resolution and range for the organics

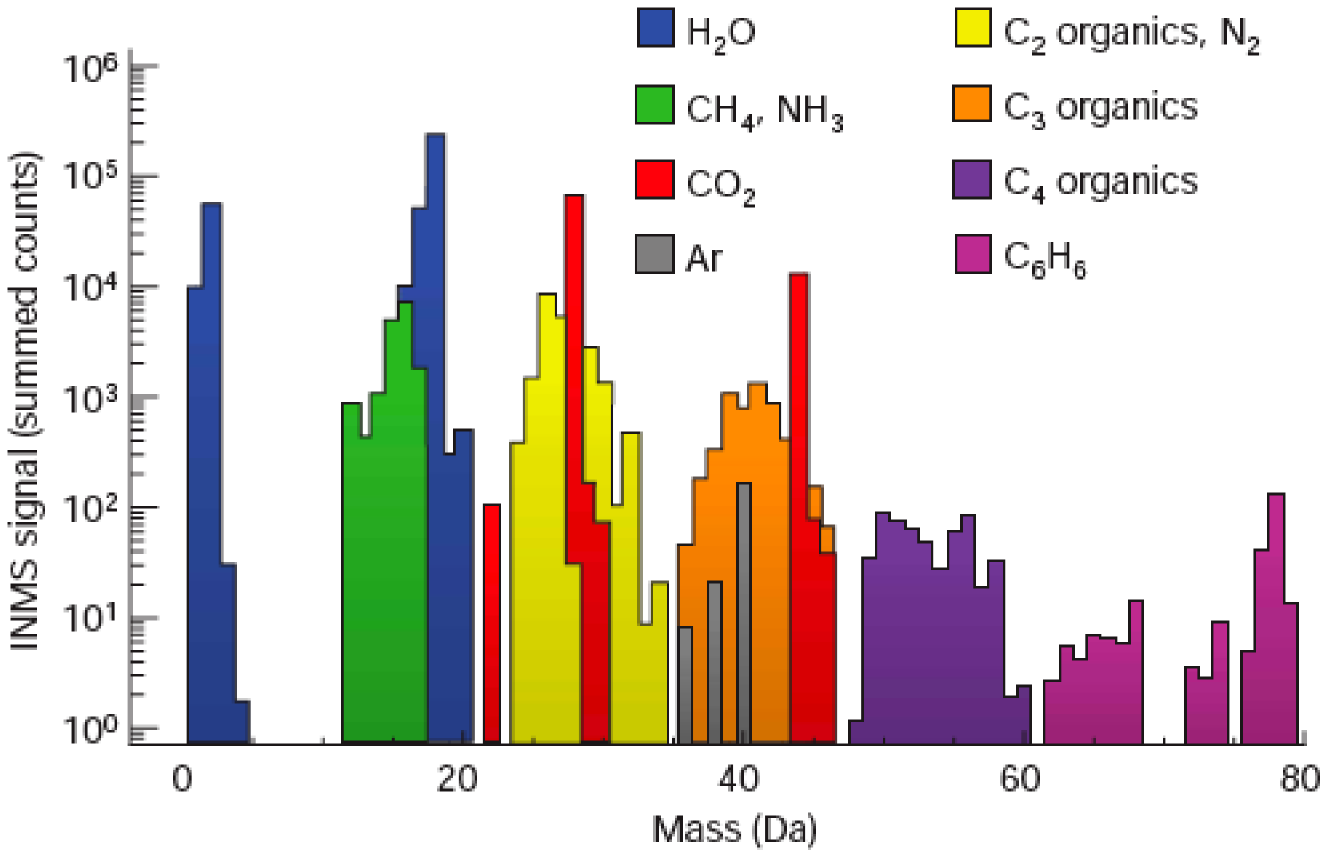




Negative (top) and positive ion (bottom panel) data for Titan's upper atmosphere from Cassini CAPS confirm existence of heavier species but does not have the resolution to identify them.

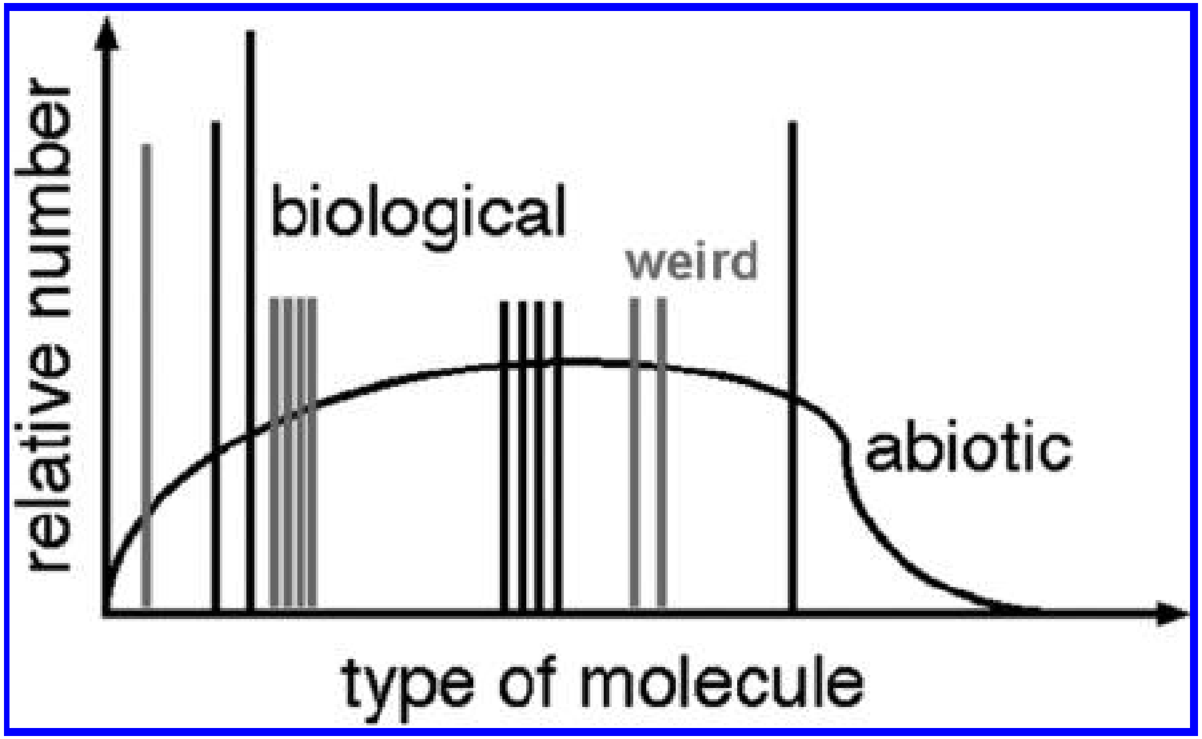
CAPS data plotted by S. Hörst.

The plumes of Enceladus have a rich organic inventory that almost certainly goes beyond the INMS mass range

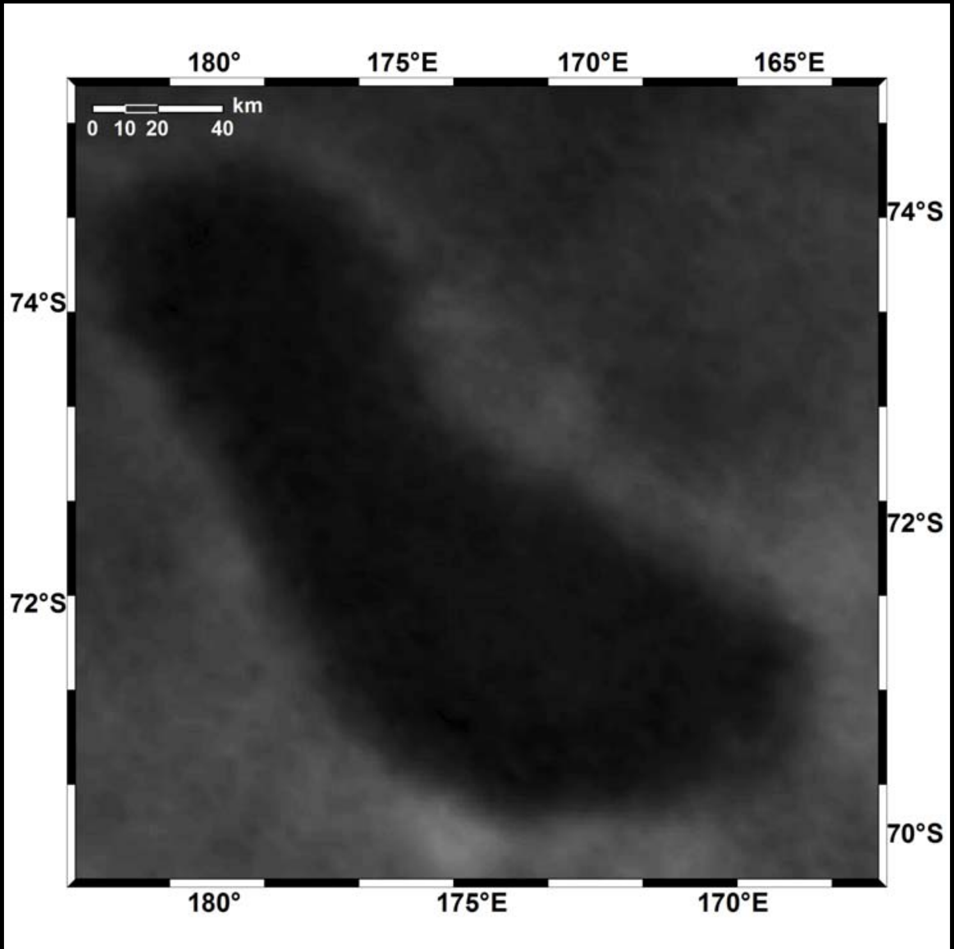


Measured plume composition displayed schematically.
Waite et al., 2009

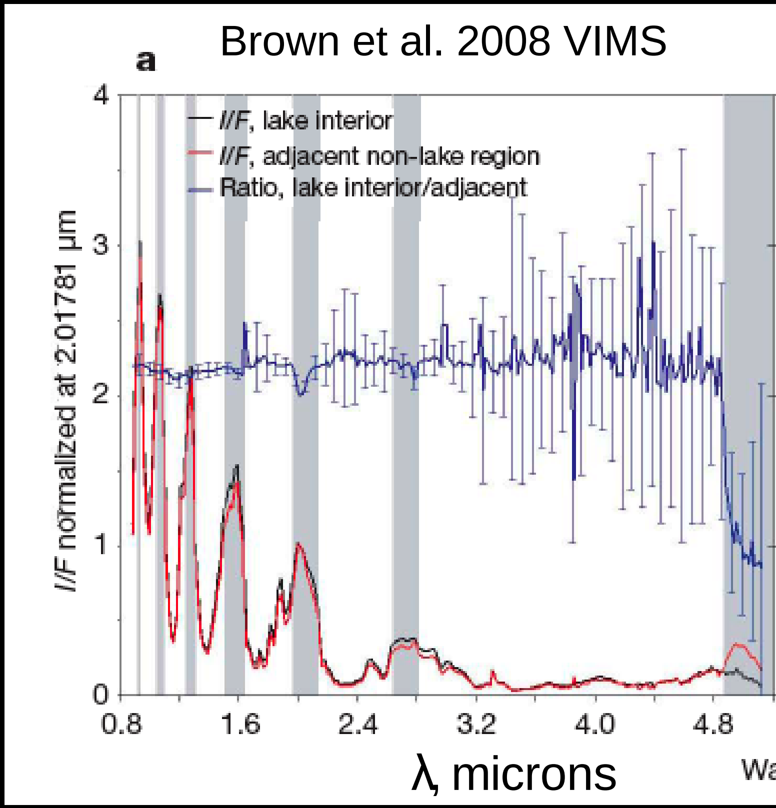
The search for self-organizing (autocatalytic) chemistry on Titan's surface or in the Enceladus plume also requires a much greater mass range than INMS/GCMS



Davies et al., 2009



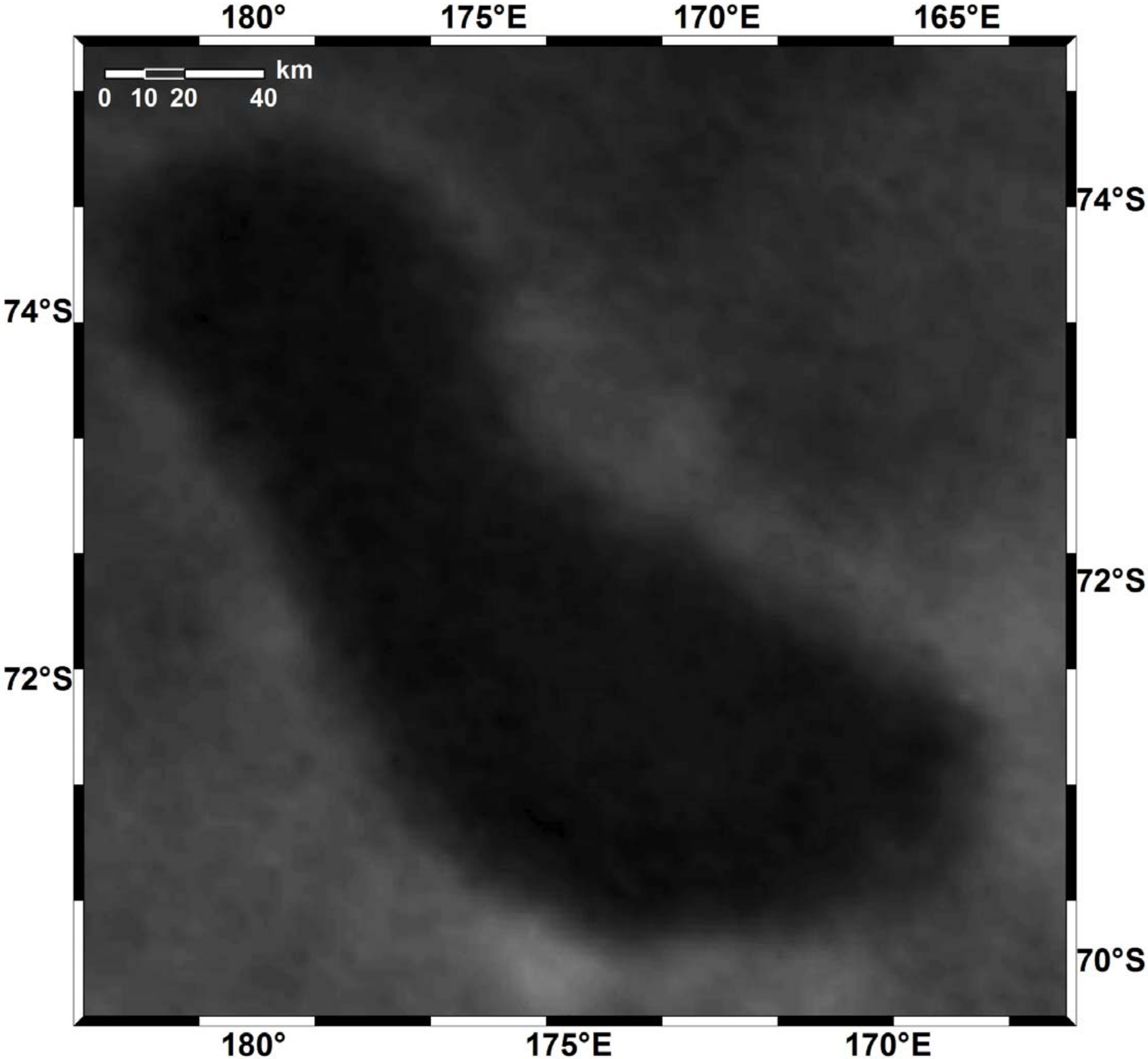
ISS Team, Ontario Lacus



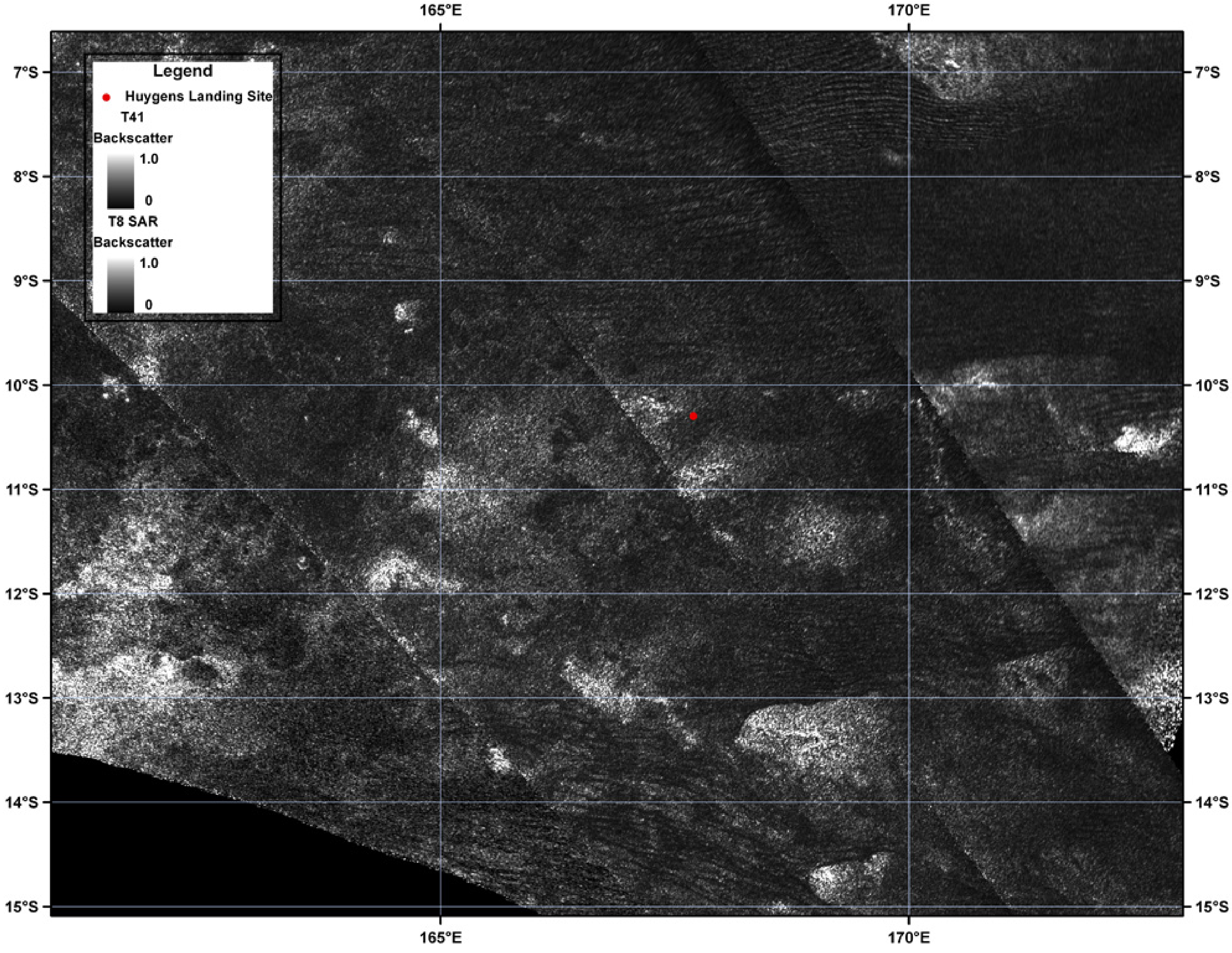
Lake/sea compositions/conditions require direct sampling

b. Spatial resolution and range

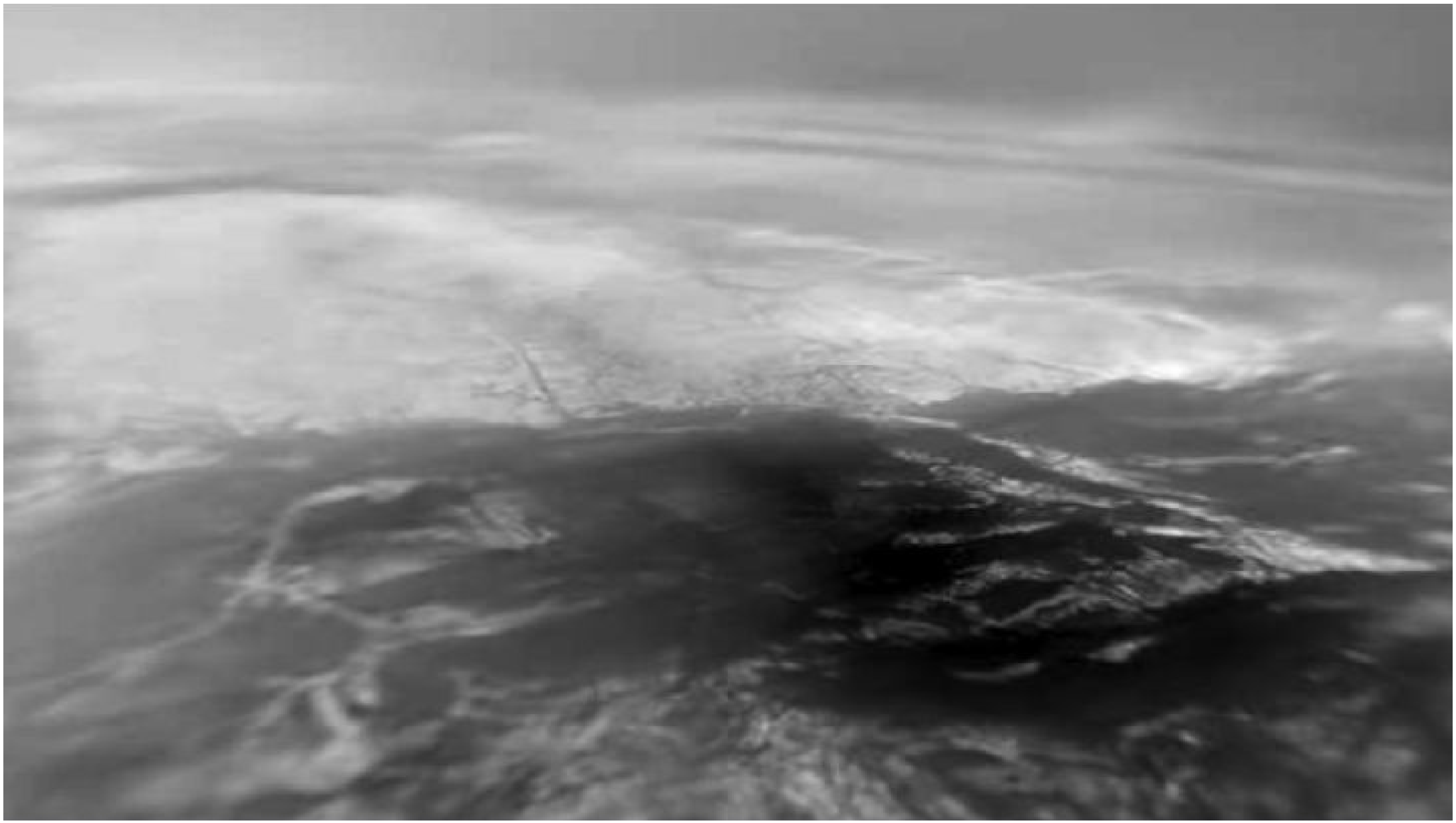
Cassini ISS resolution 3 km



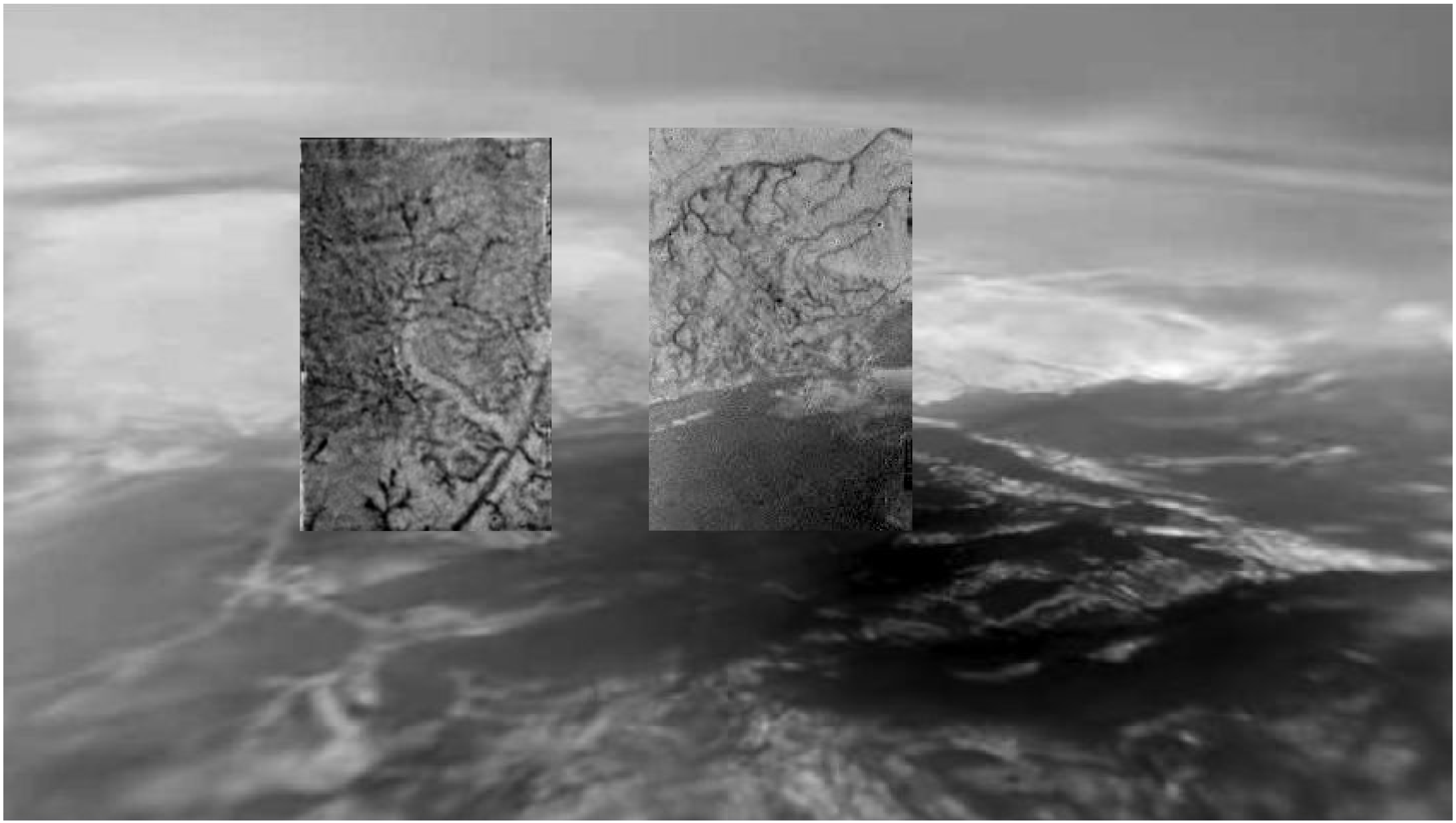
Cassini RADAR resolution 0.5 km



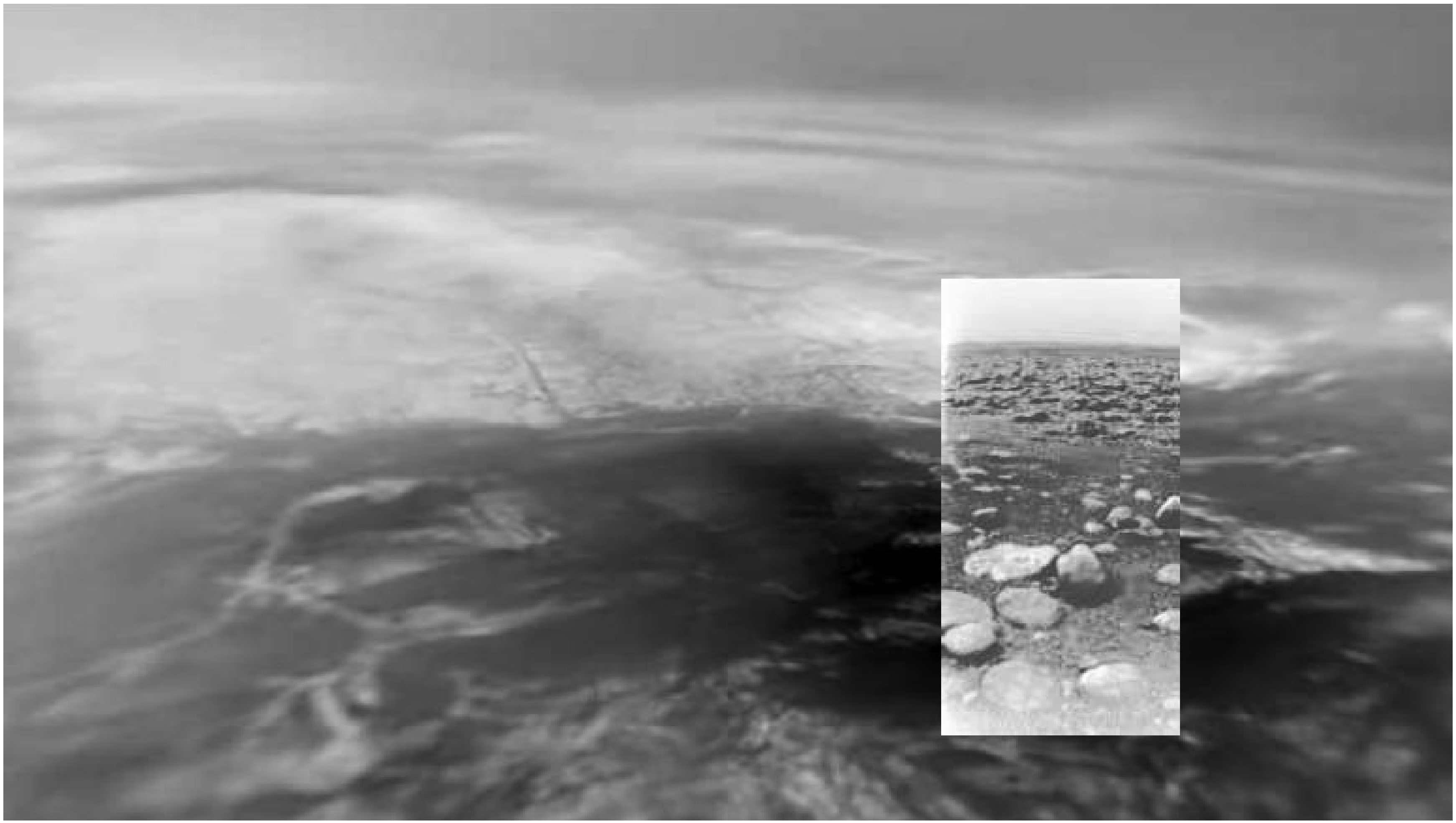
Huygens flyover area at 50 meters resolution

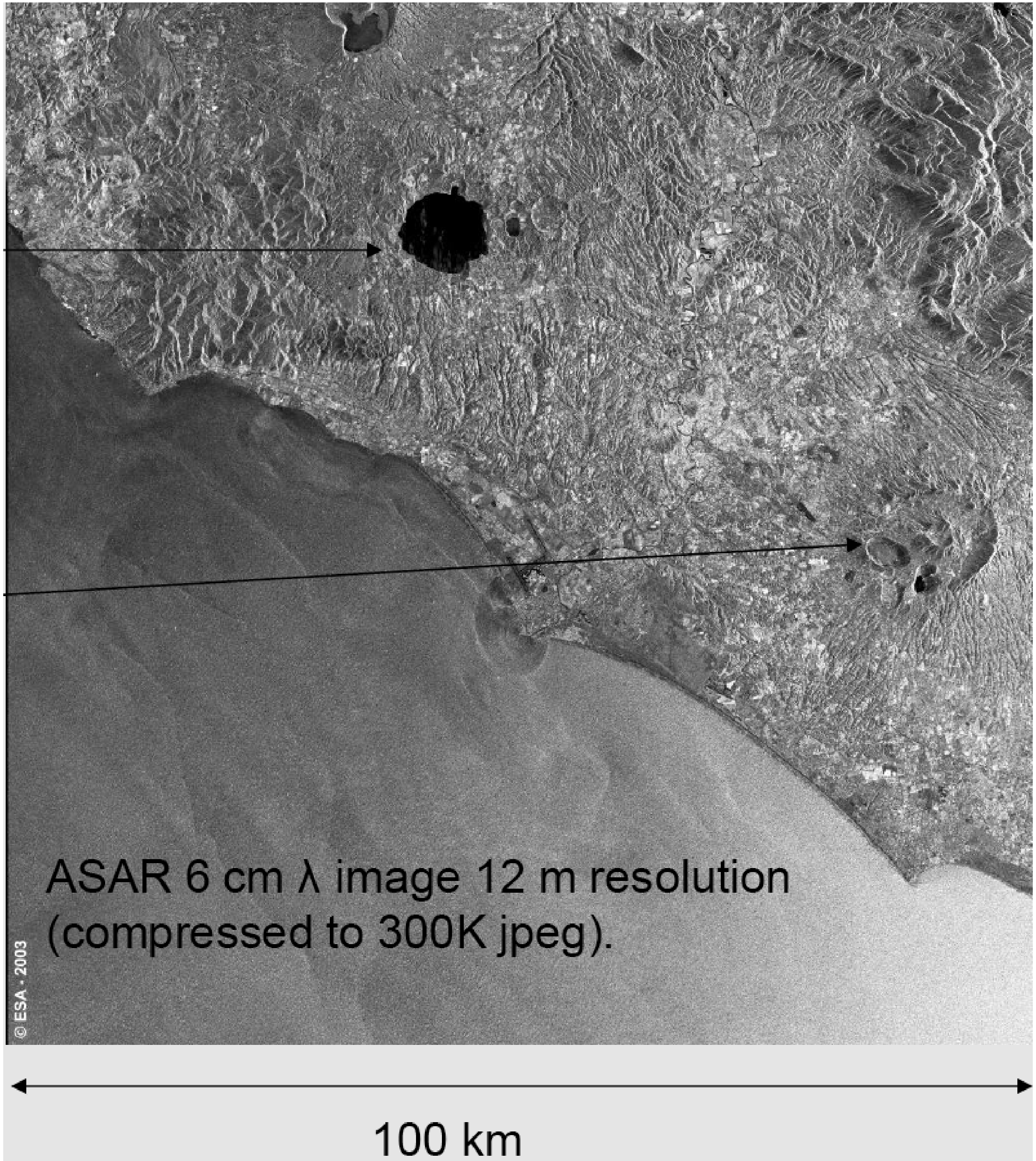


Fluvial features N of landing site at 10 meters resolution

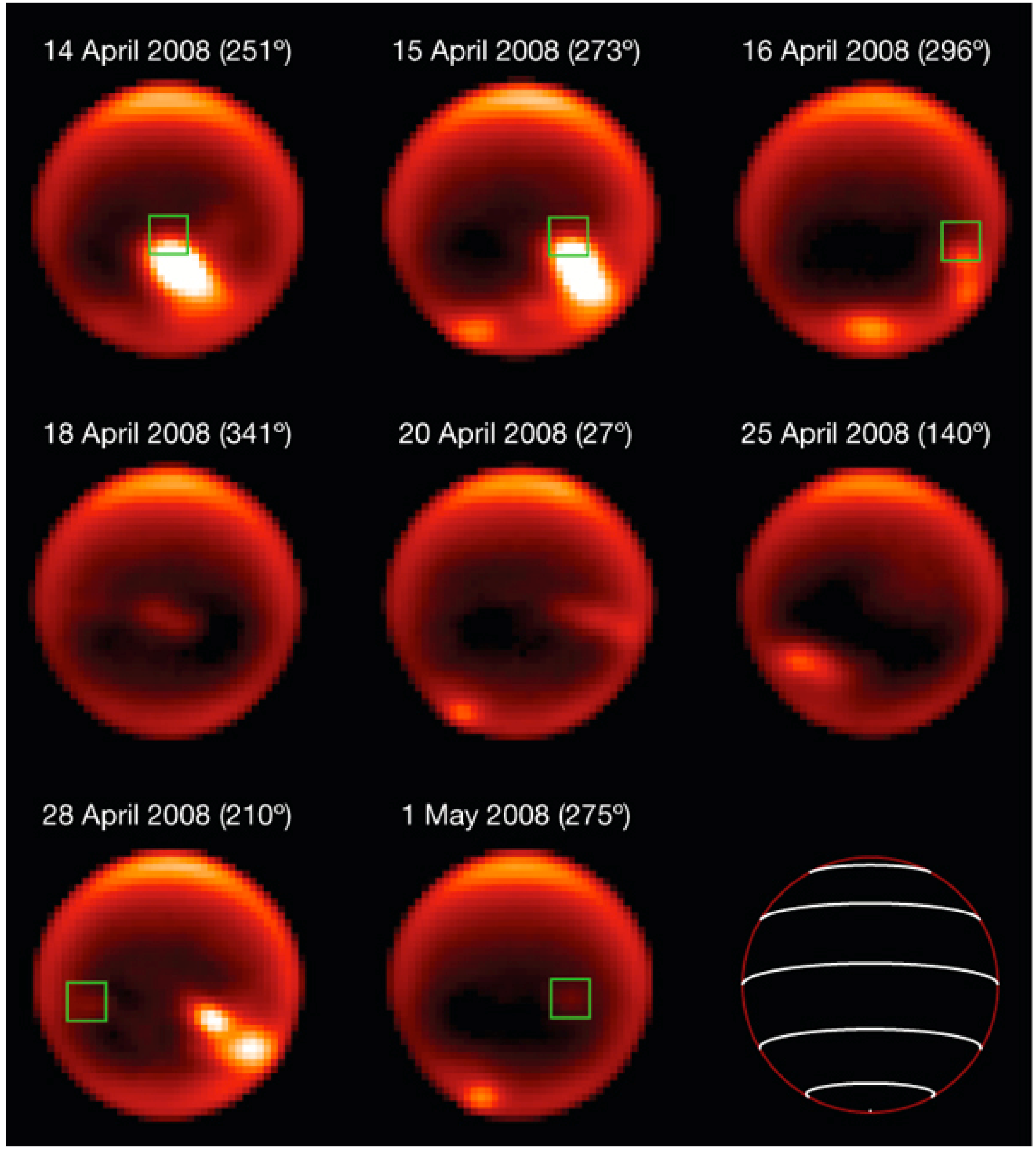


Huygens landing site at centimeter resolution



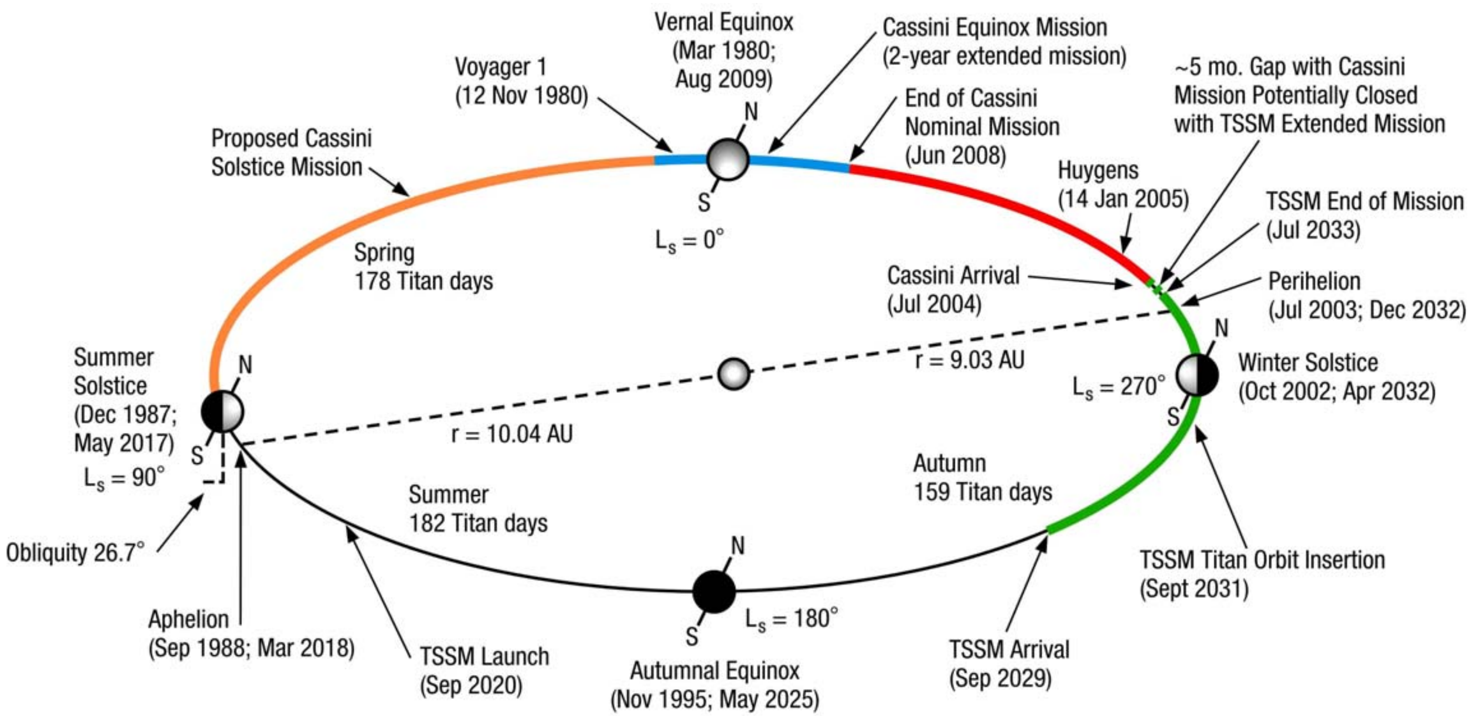

ASAR 6 cm λ image 12 m resolution
(compressed to 300K jpeg).
© ESA - 2003
100 km

c. Temporal resolution and range: i. Cassini was elsewhere in the Saturn system during almost the entire outburst episode.



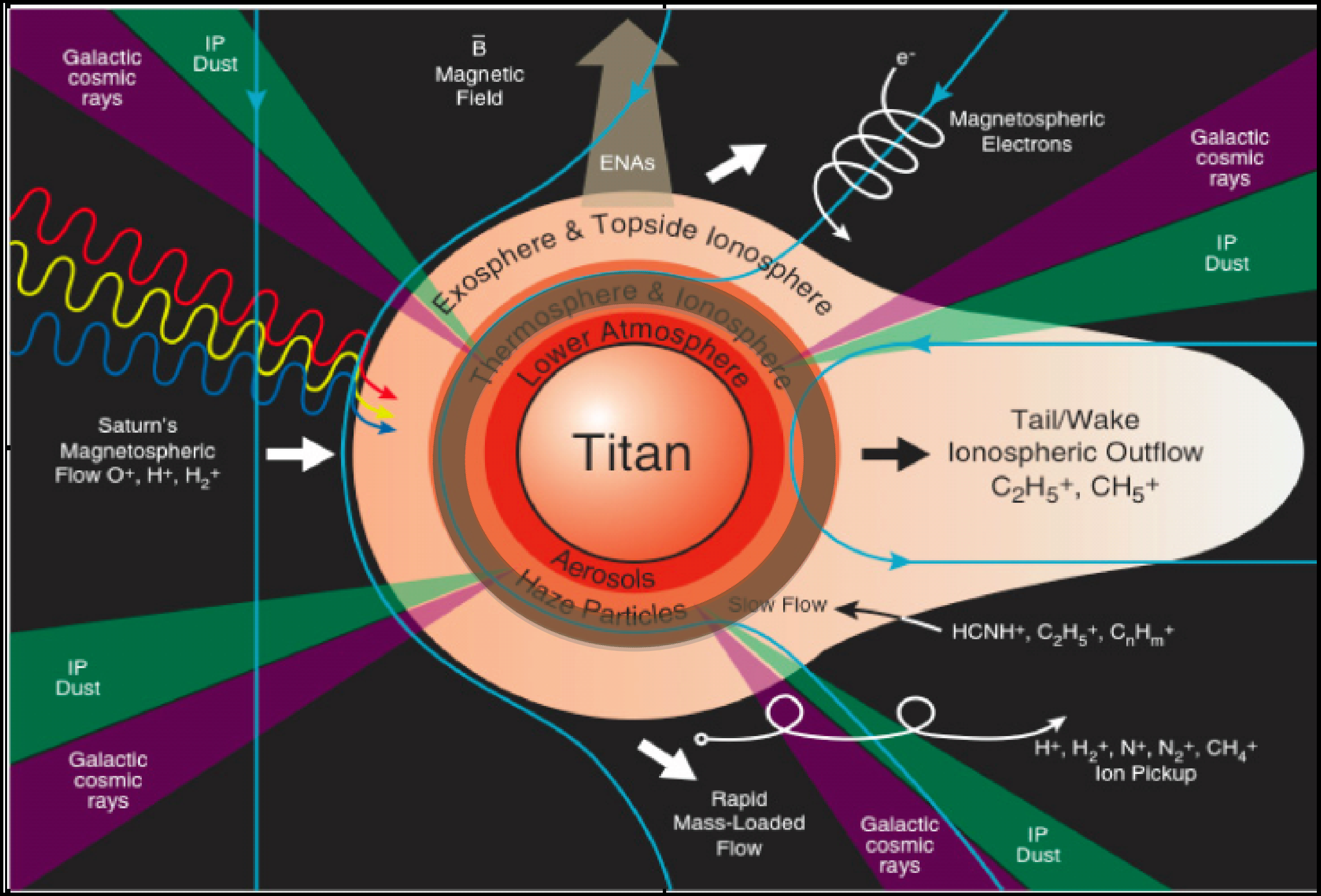
Schaller et al. 2009

c. Temporal resolution and range. ii: TSSM launched in 2020 meshes very well with Cassini in terms of seasonal coverage



Orbital motion of Titan and Saturn around the Sun during one Saturn year. L_s denotes the Kronocentric (Saturnicentric) orbital longitude of the Sun that characterizes the season.

d.Altitude range: Thermosphere and ionosphere: not accessible to Cassini-Huygens



TSSM

Science Team

Jonathan Lunine, Co-Chair (University of Arizona)
Jean-Pierre Lebreton, Co-Chair (ESA/ESTEC)
Athéna Coustenis, Lead Scientist for ESA Study (Observatoire de Paris-Meudon)
Dennis Matson, NASA Study Scientist (JPL)
Lorenzo Bruzzone, University of Trento
Maria-Teresa Capria (Instituto di Astrofisica Spaziale, Rome)
Julie Castillo-Rogez (JPL)
Andrew Coates (Mullard Space Science Laboratory, Dorking)
Michele K. Dougherty (Imperial College London)
Candice Hansen, NASA Deputy Study Scientist (JPL)
Andy Ingersoll (Caltech)
Ralf Jaumann (DRL Institute of Planetary Research, Berlin)
William Kurth (University of Iowa)
Luisa M. Lara (Instituto de Astrofísica de Andalucía, Granada)
Rosaly Lopes (JPL)
Ralph Lorenz (JHU/APL)
Chris McKay (ARC)
Ingo Muller-Wodarg (Imperial College London)
Olga Prieto-Ballesteros (Laboratorio de Geologia Planetaria, Madrid)
François Raulin (LISA Universités Paris 12 & Paris 7)
Amy Simon-Miller (GSFC)
Ed Sittler (GSFC)
Jason Soderblom (University of Arizona)
Frank Sohl (DLR Institute of Planetary Research, Berlin)
Christophe Sotin (JPL)
Dave Stevenson (Caltech)
Ellen Stofan (Proxemy Research)
Gabriel Tobie (Université de Nantes)
Tetsuya Tokano (Universität zu Köln)
Paolo Tortora (Università di Bologna)
Elizabeth Turtle (JHU/APL)
Hunter Waite (SwRI)

Kim Reh: JPL Study Lead Christian Erd: ESA Study Lead

Pat Beauchamp, Nathan Strange, Tom Spilker, John Elliot,… (JPL)…
Mark Perry, Michael Paul…(APL

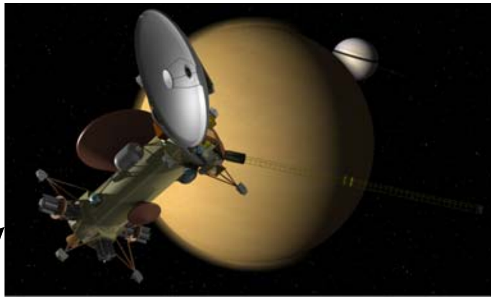
Traceability matrix (sample page)

MISSION GOALS	SCIENCE OBJECTIVES	SCIENCE INVESTIGATIONS	REQUIRED MEASUREMENTS/ DETERMINATIONS	PLANNING MEASUREMENT APPROACH	PLAN INSTR.	DATA PRODUCTS	MISSION REQUIREMENTS
Goal A: How does Titan function as a system; to what extent are there similarities and differences with Earth and other solar system bodies?	**O8:** Determine the state of internal differentiation, whether Titan has a metal core and an intrinsic magnetic field, and constrain the crustal expression of thermal evolution of Titan's interior.	**I1:** Map interior structure of Titan.	**M1:** Global gravity field to at least degree six. Doppler accurate to 50 μm/s with 60 s integration periods.	**A1:** Relative velocity between the spacecraft and ground station determined from Doppler tracking with an accuracy up to 50 μm/s with 60 s integration periods. (Ka-band link stability ~10^{-15} after all calibrations including accelerometer for non-gravitational forces).	RSA	Coefficients of spherical harmonic expansion of gravity field for further analysis and interpretation in terms of internal structure. The static degree-two gravity field will lead to constraints on the global density structure of the interior. Time variations of the degree-two field will lead to investigating the tidal response of the satellite and constraining its viscoelastic structure and crustal structure.	Prefer mapping phase orbit height of 1500 km
Goal A: How does Titan function as a system; to what extent are there similarities and differences with Earth and other solar system bodies?	**O8:** Determine the state of internal differentiation, whether Titan has a metal core and an intrinsic magnetic field, and constrain the crustal expression of thermal evolution of Titan's interior.	**I2:** Determine whether Titan has a dynamo.	**M1:** Detect or set limits on the intrinsic magnetic field of Titan. Measure vector magnetic field perturbations of order a few nT (with a resolution of order 0.04 nT). Thermal and magnetospheric plasma measurements will provide supportive role with regard to external currents from magnetospheric measurements.	**A1:** Vector Magnetometry (part of a combined instrument).	MAPP	Magnetic field vector at 1 s resolution from both sensors Ion and electron thermal and suprathermal velocity moments of density, temperature and magnetosphere-ionosphere winds.	Continuous measurements, globally distributed at varying altitudes. Knowledge of orbiter attitude and location, and a rigid magnetometer boom. Consideration of magnetic cleanliness requirements vs. boom length.
Goal B: To what level of complexity has prebiotic chemistry evolved in the Titan system?	**O1:** Determine the processes leading to formation of complex organics in the Titan atmosphere and their deposition on the surface.	**I1:** Assay the speciation and abundances of atmospheric trace molecular constituents.	**M1:** Abundances of monomer and polymer organic species and inorganic species with a detectability of <1 ppb and an accuracy of better than 3% over an altitude range from 30–1500 km.	**A1:** Passive Thermal-infrared Fourier Transform spectrometry, in the region from 30–1400 wavenumbers (7–333 μm); resolution 0.1–3.0 wavenumber.	TIRS	Thermal and compositional maps and profiles of the stratosphere (50–450 km) with altitude and latitude	Limb and nadir viewing on polar orbit, rotation in
Goal B: To what level of complexity has prebiotic chemistry evolved in the Titan system?	**O1:** Determine the processes leading to formation of complex organics in the Titan atmosphere and their deposition on the surface.	**I1:** Assay the speciation and abundances of atmospheric trace molecular constituents.	**M1:** Abundances of monomer and polymer organic species and inorganic species with a detectability of <1 ppb and an accuracy of better than 3% over an altitude range from 30–1500 km.	**A2:** Submillimeter sounding at 540–640 GHz with resolution 300 khz and 10% precision in retrieved abundances.	SMS	Alt/lat maps of selected organics	Limb viewing from polar orbit, in-track and off-track orientation

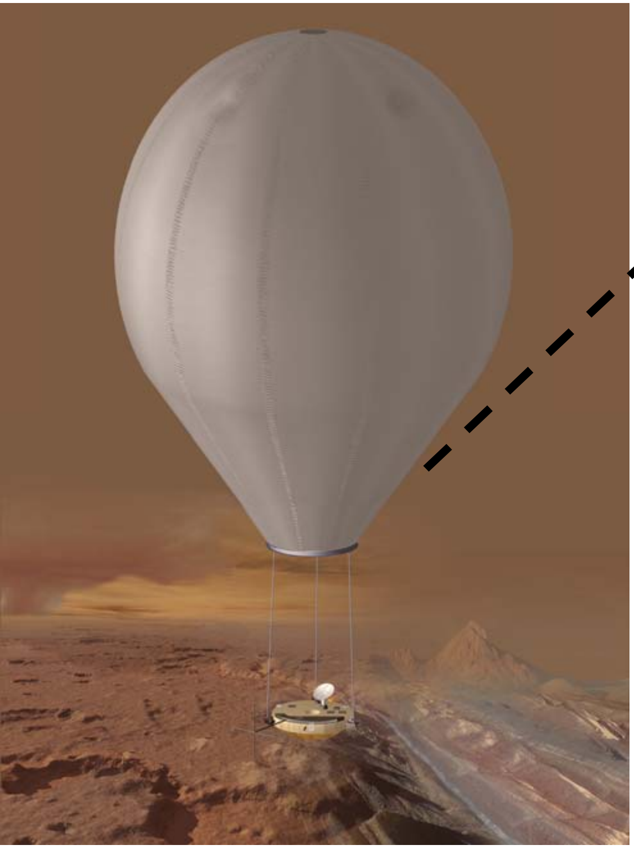
Baseline mission architecture

Combining

- An orbiter (Titan+Enceladus)
- A hot-air balloon/montgolfière on Titan and one North-pole lake-landing probe

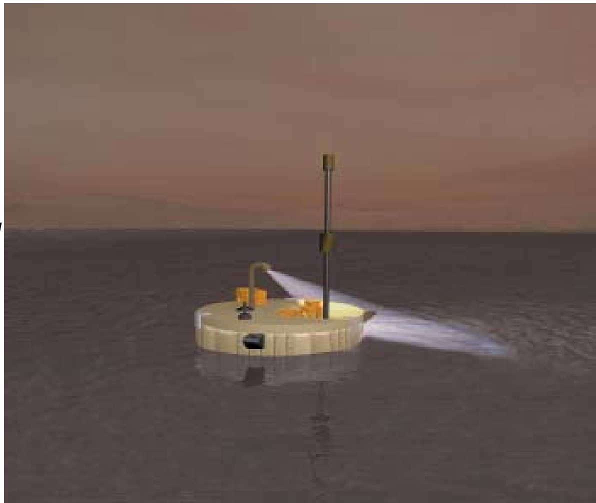


Dedicated Titan orbiter would be used also for relay after several Enceladus flybys

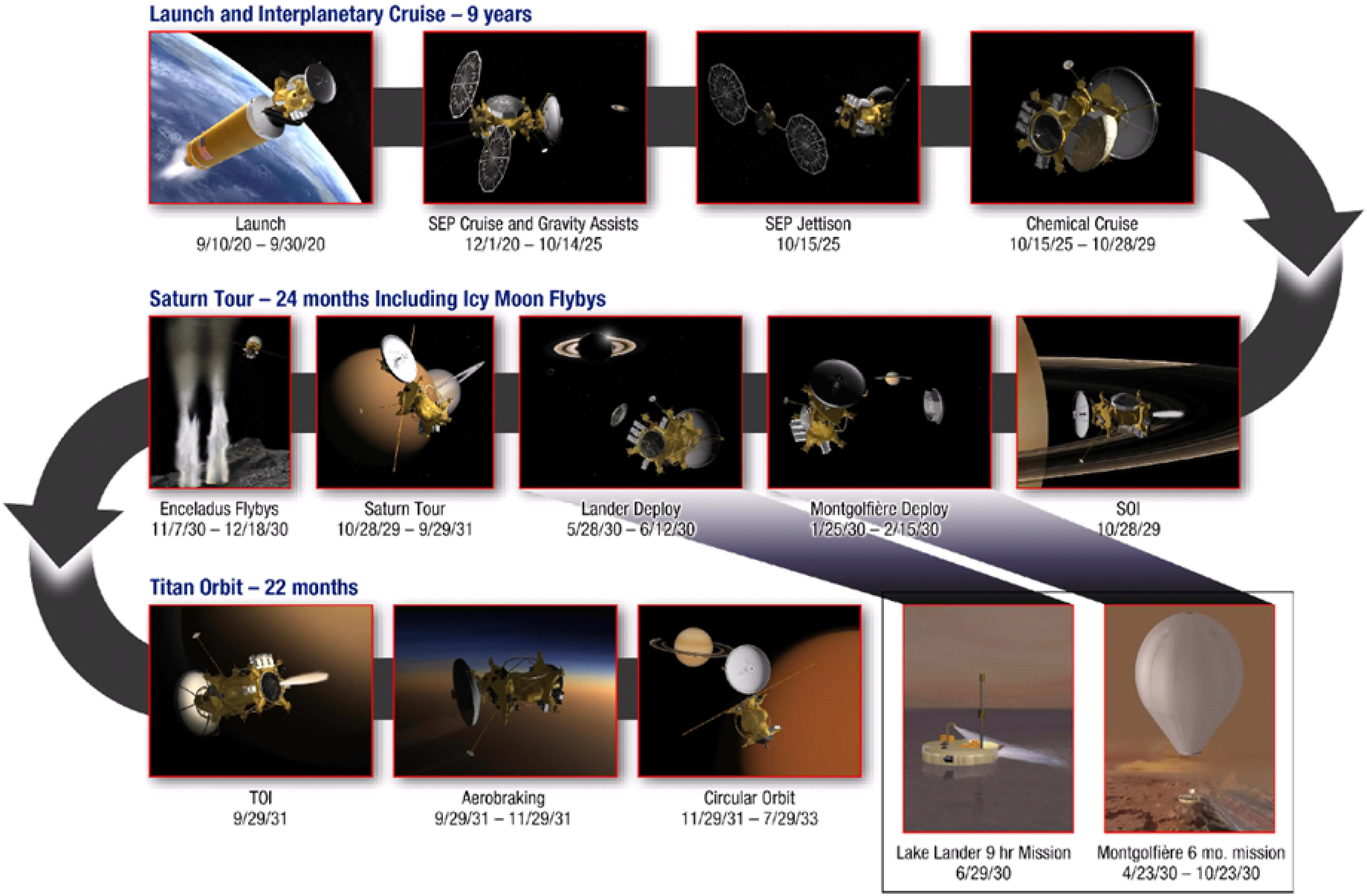


A hot-air balloon (Titan Montgolfière) would float at 10 km above the surface around the equator with some altitude control

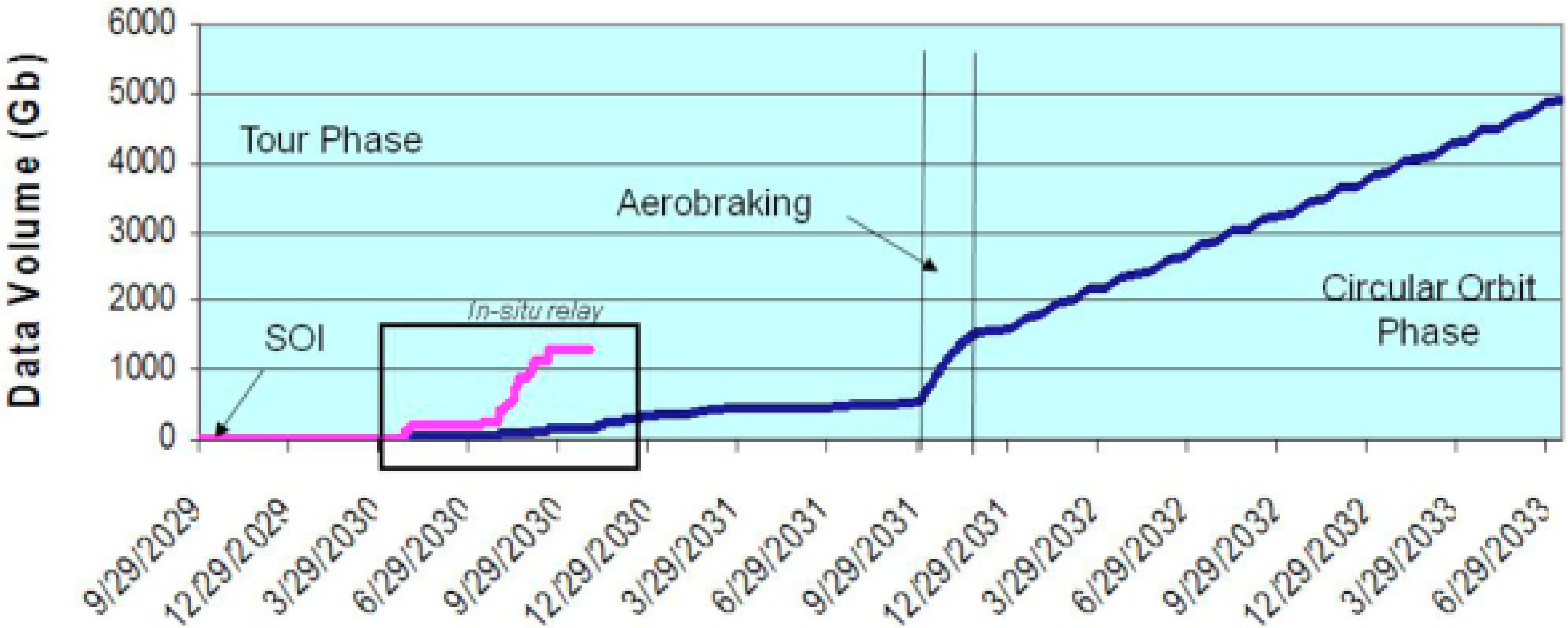
A short-lived Probe/Lander with liquid surface package would land in a northern sea



TSSM Phases (assumes 2020 launch)



Data Volume Acquired Throughout Mission



Planning Payload

Orbiter

	Orbiter Planning Payload	Instrument Capabilities
HiRIS	High-Resolution Imager and Spectrometer (near IR)	1–6 μm global mapping at 50 m/pixel in three colors. Adjustable spectral editing for surface/atmosphere studies.
TiPRA	Titan Penetrating Radar and Altimeter	>20 MHz global mapping of subsurface reflectors with 10 m altitude resolution in altimetry mode & >10 m depth resolution. Lower data rate sounding mode with ~100 m depth resolution. ~1 km x 10 km spatial resolution.
PMS	Polymer Mass Spectrometer	TOF MS with M /ΔM ~10,000 for masses up to 10,000 Da. From 600 km to upper atmospheric *in situ* analysis of gases and aerosol precursors.
SMS	Sub-Millimeter Spectrometer	Heterodyne spectrometer with scanning mirror. Direct winds from Doppler and temperature mapping from ~200-1000 km altitude; carbon dioxide and nitrile profiles.
TIRS	Thermal Infrared Spectrometer	Passively cooled Fourier spectrometer, 7–333 μm. Organic gas abundance, aerosol opacity and temperature mapping 30–500 km.
MAPP	Magnetometer	Tri-axial fluxgate sensors. Noise level ~11pT$_{rms.}$ Interaction of field with ionosphere: internal and induced field.
	Energetic Particle Spectrometer	TOF Analyzer w/ss detectors to measure magnetospheric particle fluxes, ~10 keV to >MeV with 150° x 15° FOV.
	Langmuir Probe	Swept voltage/current probe. *In situ* electron density and temperature, ion speed constraint, including during aerosampling.
	Plasma Spectrometer	Electrostatic analyzer with Linear electric field TOF MS. Measures ion and electron fluxes at ~5 eV to ~5 keV. M/ΔM~10.
RSA	Radio Science and Accelerometer	All components part of spacecraft telecom system. Lower stratosphere and troposphere T profile. Gravity field.

Montgolfière

Montgolfière Planning Payload (10 km altitude in equatorial region)	
BIS	Balloon Imaging Spectrometer (1–5.6 μm)
VISTA-B	Visual Imaging System for Titan Balloon
ASI/MET	Atmospheric Structure Instrument/ Meteorological Package
TEEP-B	Titan Electric Environment Package
TRS	Titan Radar Sounder (>150 MHz)
TMCA	Titan Montgolfière Chemical Analyzer (1–600 Da Mass Spectrometer)
MAG	Magnetometer
MRST	Radio Science using spacecraft / montgolfière telecom system

Lander

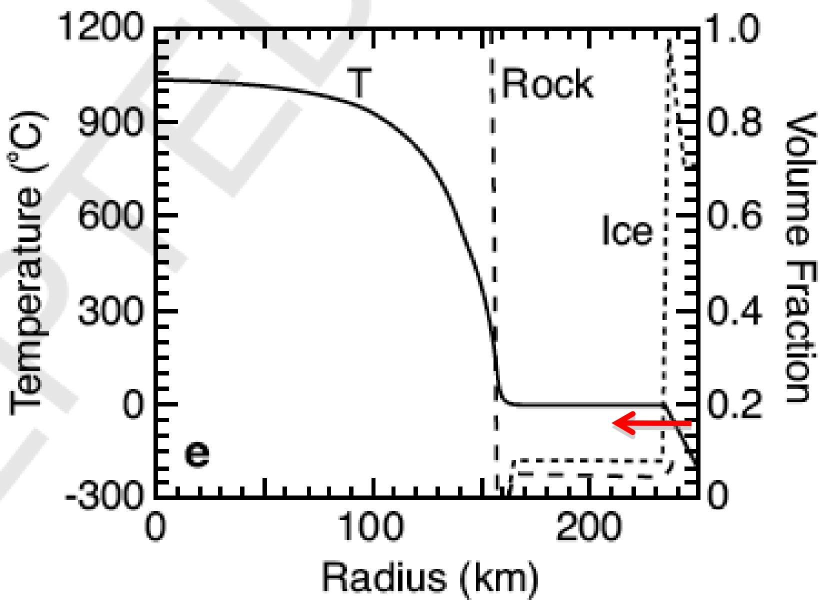
Lake Lander Planning Payload	
TLCA	Titan Lander Chemical Analyzer (GCMS)
TiPI	Titan Probe Imager + Lamp
ASI/MET-TEEP	Atmospheric Structure Instrument/ Meteorological Package + Titan Electric Environment Package
SPP	Surface Properties Package + Acoustic Sensor Package with Magnetometer
LRST	Radio Science using spacecraft/lander telecom system

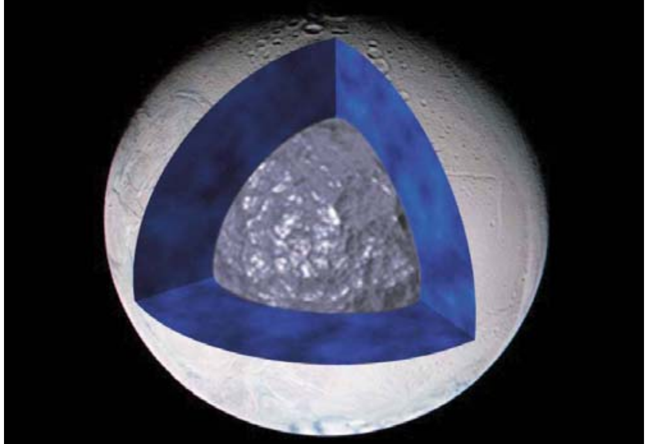
TSSM orbiter maps well to decadal objectives

Decadal Survey p. 138	Cassini	TSSM
What are the chemistry, distribution and cycling of organic materials on Titan?	Methane/ethane sensed at Huygens site; high altitude polymers; lakes, fluvial	High molecular weight mass spectroscopy; hi-res imaging at 5 µm; near-IR spectra
Is Titan internally active, producing water-rich environments with potential habitability?	Spin rate evidence for ocean; radar images of cryovolcanic features; near-IR spectra of carbon dioxide patches	Accelerometry-enhanced gravity; hi-res surface imaging; surface temperature monitoring in thermal IR; 5–6 µm spectra
What are the current state and the history of Titan's surface?	Radar and VIMS show dearth of craters; fluvial transport at Huygens site	High resolution imaging; radar altimetry and sounding; near-IR spectra
What drives the meteorology of Titan?	Huygens wind and CIRS temperature data provide crude basis for GCM	Sub-millimeter wind/thermal mapping; IR mapping; near-IR cloud sounding
Has there been climate change on Titan?	Fluvial erosion at desert Huygens site; extensive dunes; missing ethane	High resolution imaging; radar sounding; near-IR spectra
Could Titan support life forms that do not require liquid water?	High latitude lakes found, as well as environments where active fluvial flow may occur, and cryovolcanism	Hi-res spectra over 5–6 µm; repeat surface coverage; high molecular weight sampling of upper atmosphere organics


"The Titan mission would also offer technological firsts, including the floating lander and that undeniably romantic hot air balloon."
Nature editorial 22/1/09.

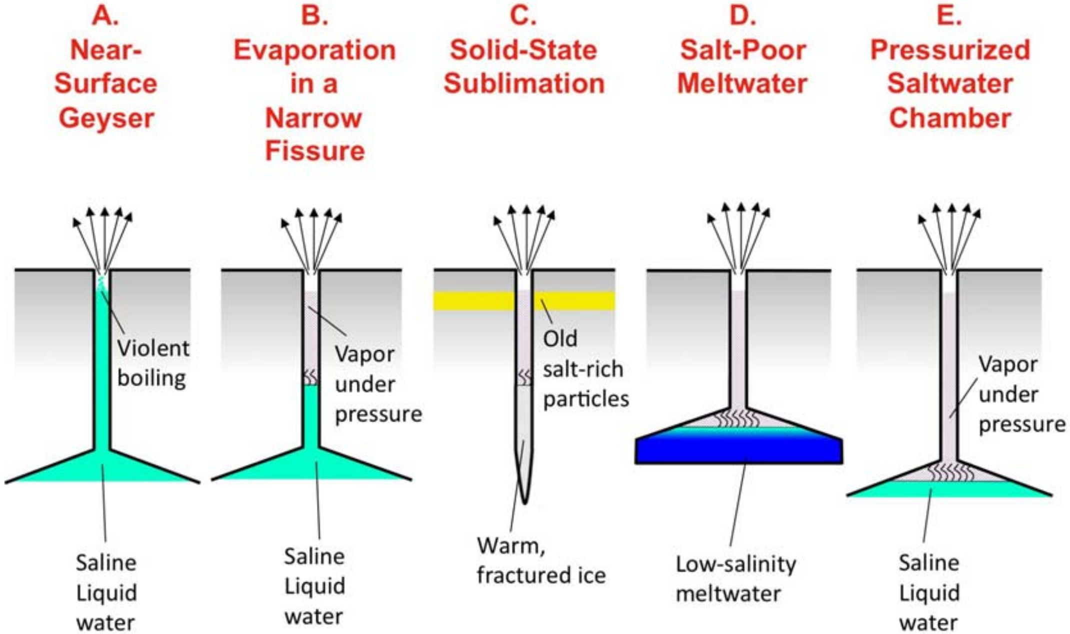
Ground-penetrating radar on Enceladus

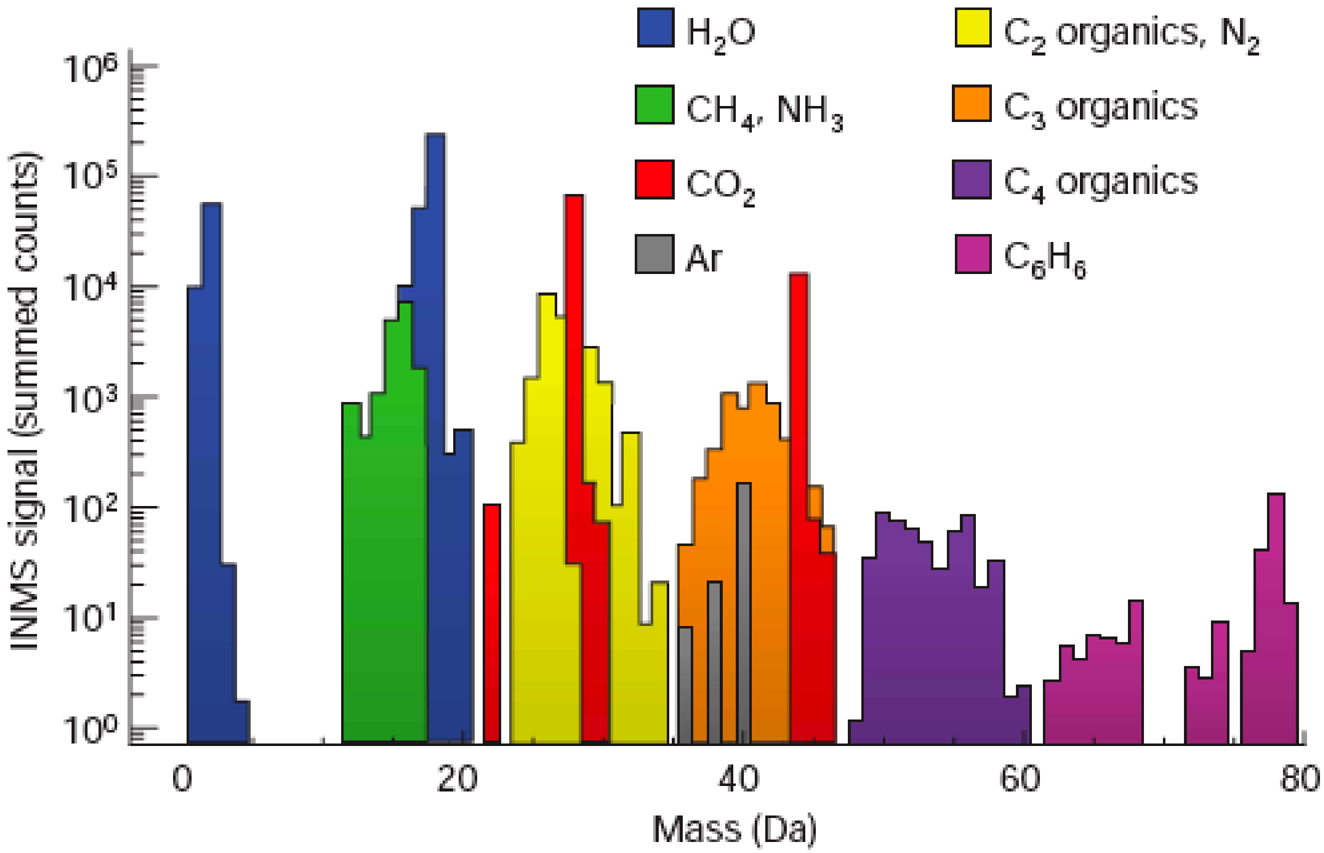




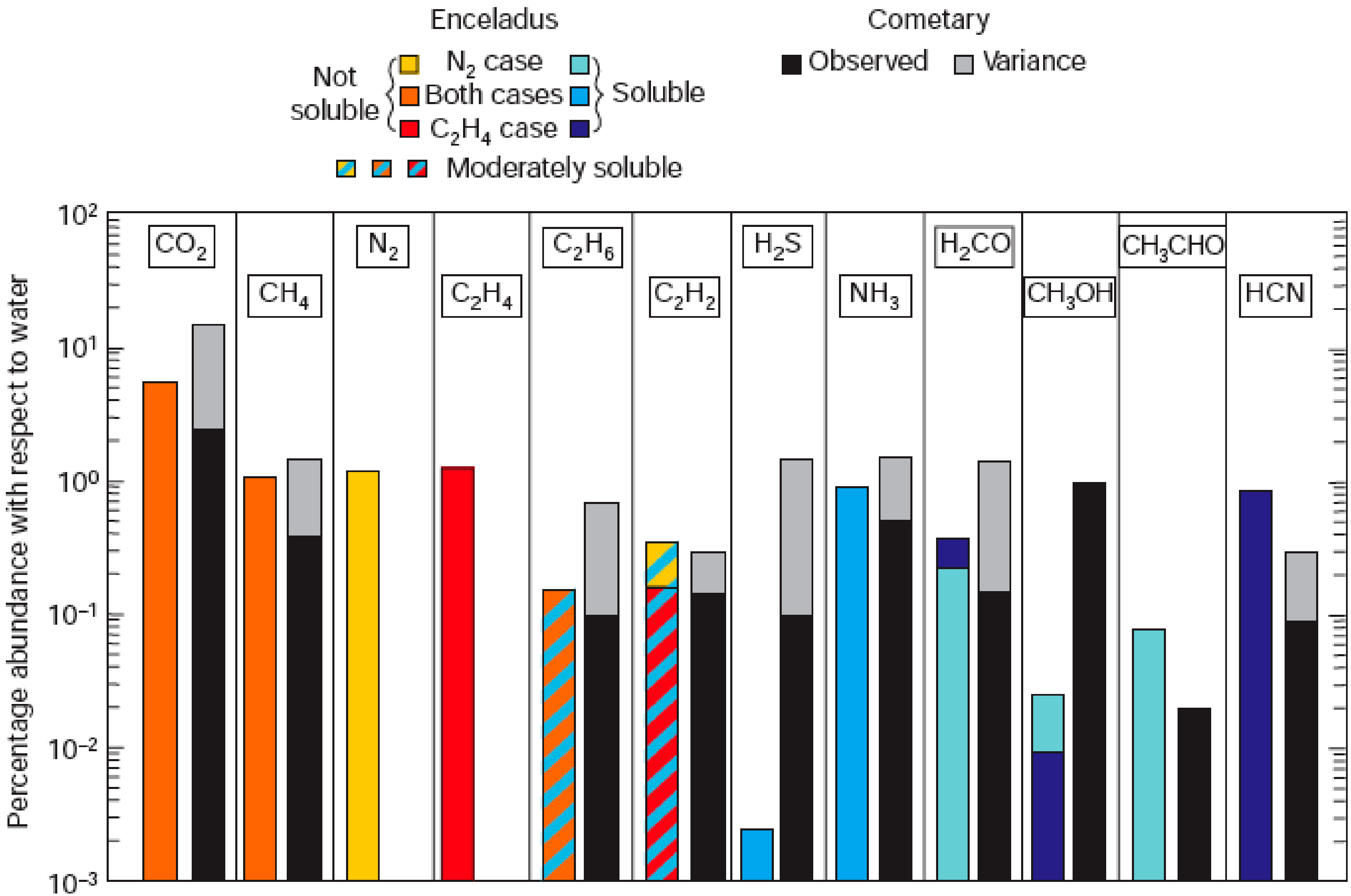
Schubert et al 2007. Superposed arrow indicates maximum radar penetration depth

Plume Vent Models (SWRI)





Waite et al., 2009



Waite et al., 2009