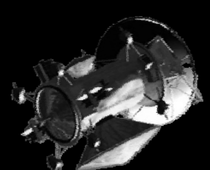
TSSM

Titan Saturn System Mission

“…oh brave new world…”



<u>*TSSM JSDT*</u>

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Study managers: Ch. Erd, K. Reh

TSSM Agenda

- Overview and
  Orbiter Science J. Lunine
- In situ Science A.
  Coustenis
- Mission Implementation K. Reh
- In situ Elements C. Erd
- Summary

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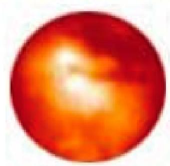
Features

Titan Triple Threat



Summary (Nov 06, 2008): The Cassini-Huygens mission has given us our best view yet of Titan, but this moon of Saturn still remains shrouded in mystery. A proposed future mission takes a three-tiered approach – using an orbiting spacecraft, a surface probe, and a hot air balloon -- to further explore the enigmatic moon.

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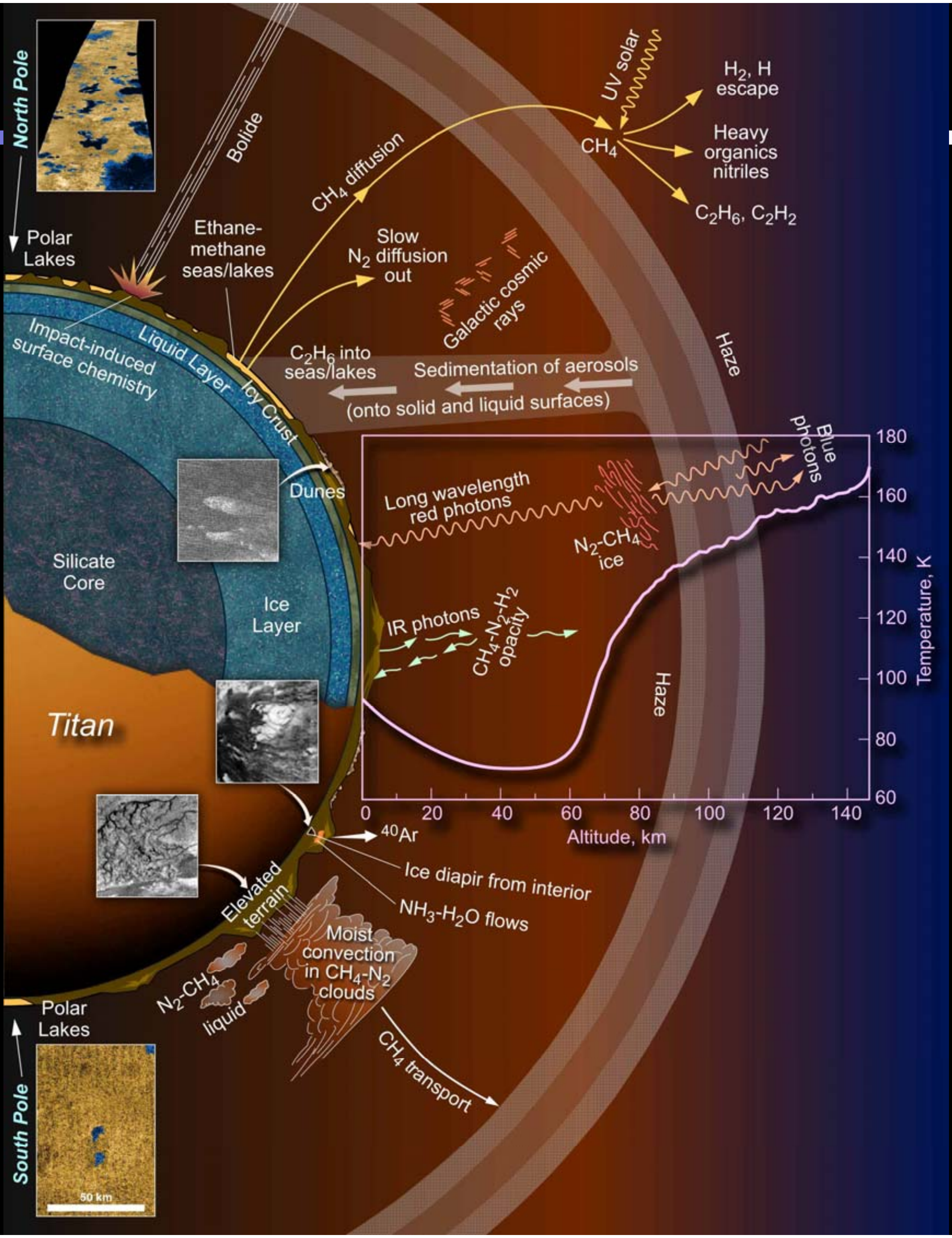
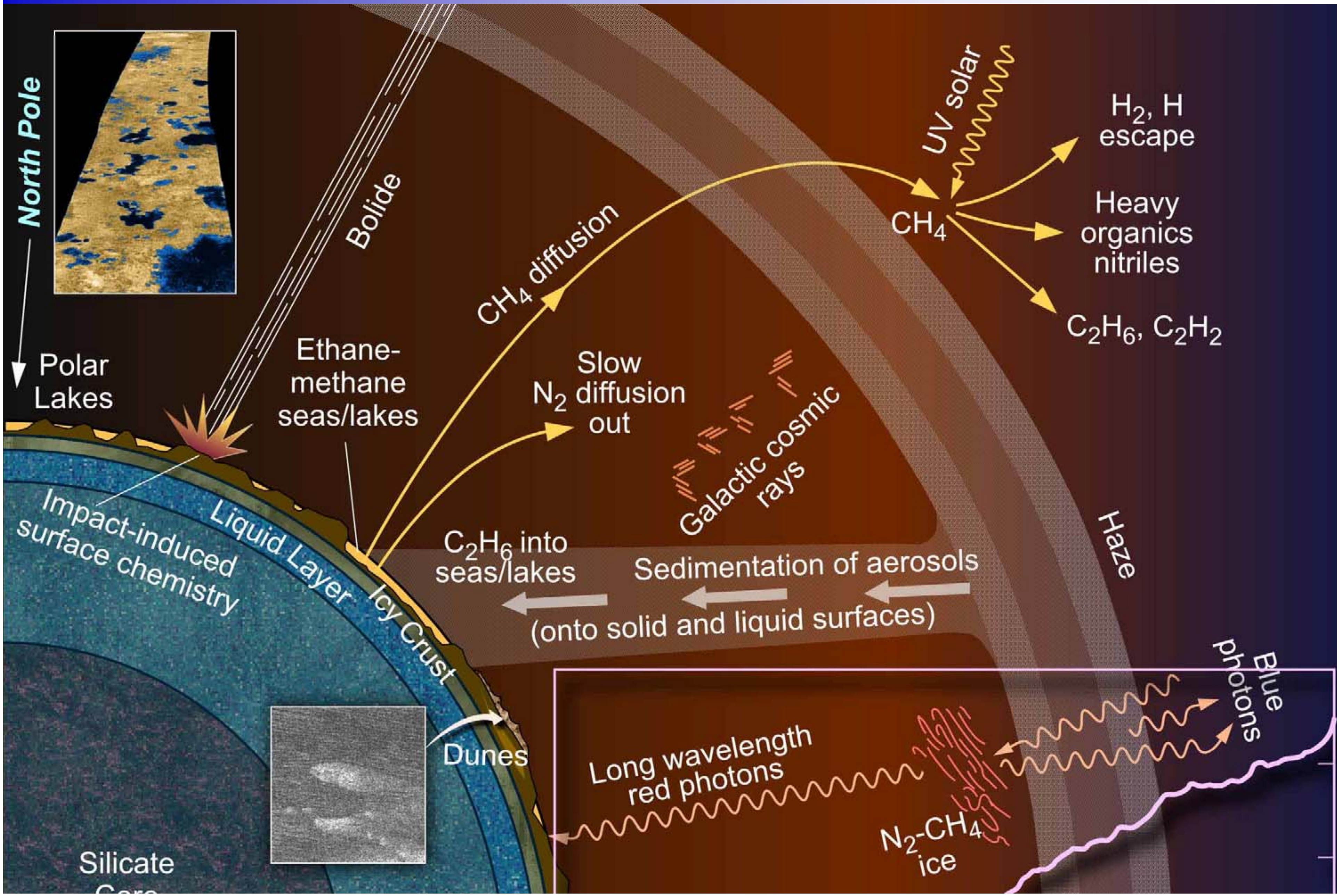
Titan Triple Threat

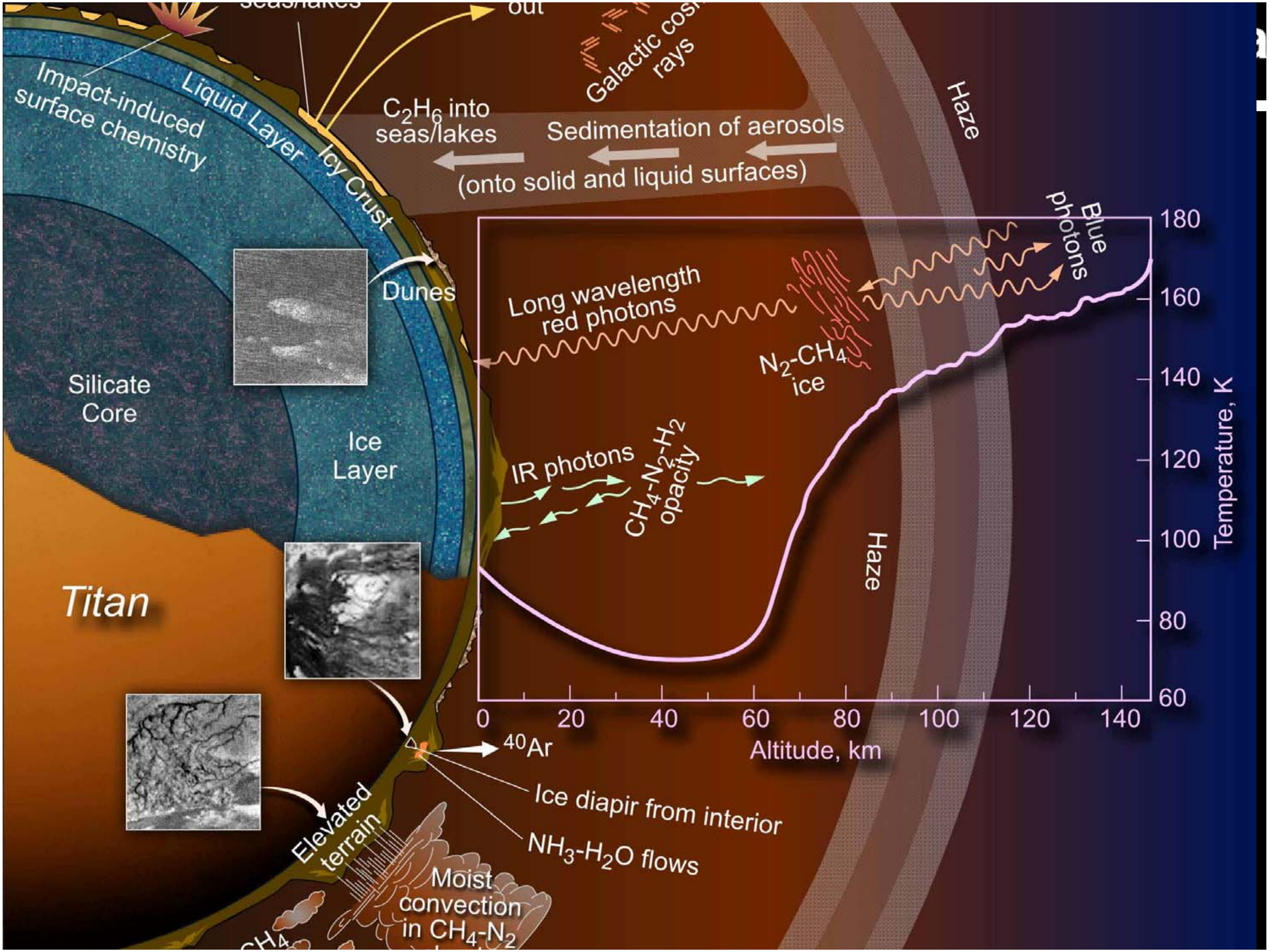
By *Leslie Mullen*

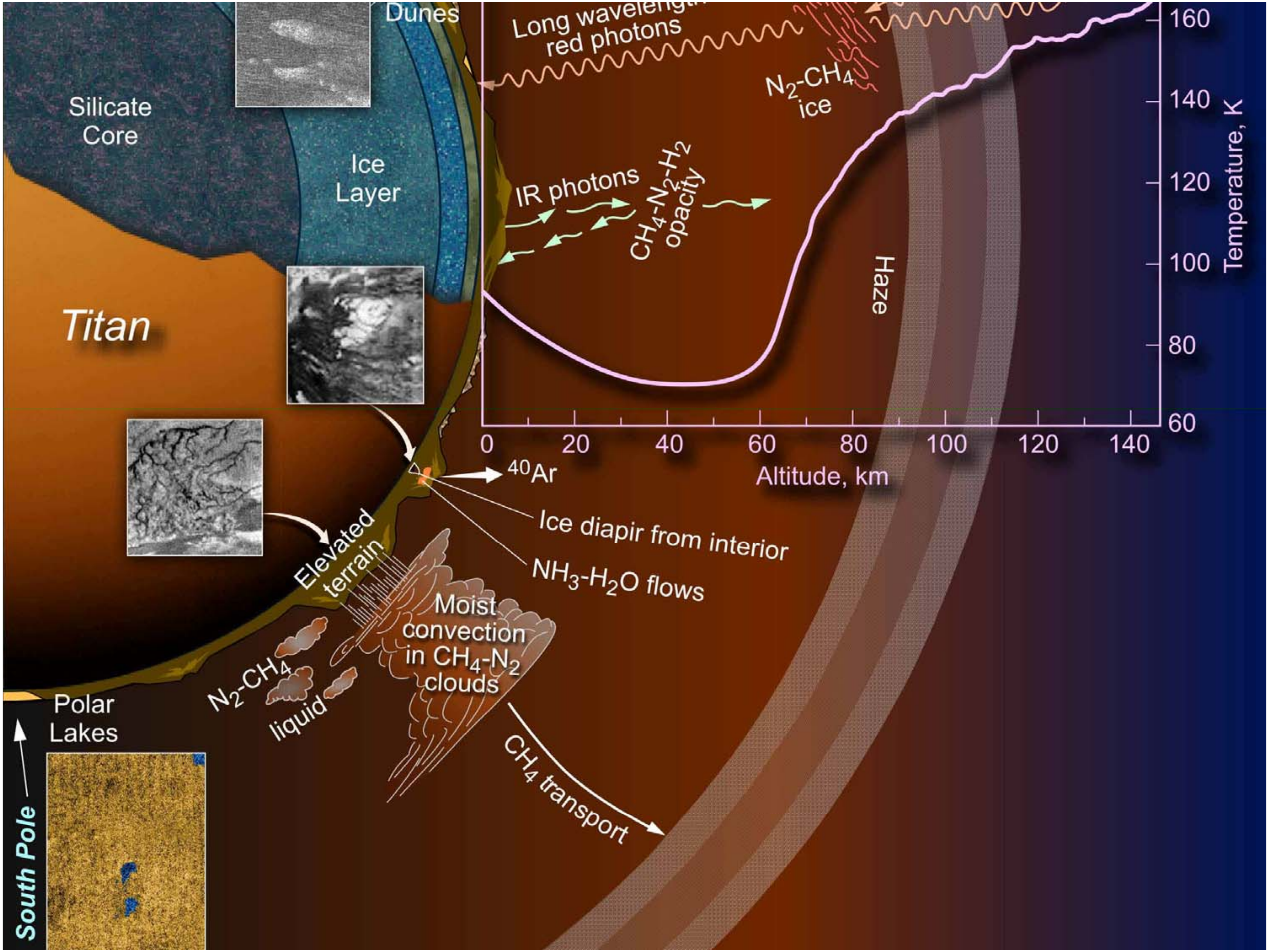
A hot air balloon drifts gently in the breeze, gliding over mountain ranges and vast lakes. Thick clouds extend over the entire horizon, threatening rain. The meager light that filters through illuminates one side of the balloon,

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




North Pole
Polar Lakes
Bolide
Ethane-methane seas/lakes
Impact-induced surface chemistry
Liquid Layer
Icy Crust
CH_4 diffusion
Slow N_2 diffusion out
UV solar
CH_4
H_2, H escape
Heavy organics nitriles
C_2H_6, C_2H_2
Galactic cosmic rays
Haze
C_2H_6 into seas/lakes
Sedimentation of aerosols
(onto solid and liquid surfaces)
Dunes
Long wavelength red photons
Blue photons
N_2-CH_4 ice
Silicate Core


seas/lakes
out
Galactic cosmic rays
Impact-induced surface chemistry
Liquid Layer
Icy Crust
C_2H_6 into seas/lakes
Sedimentation of aerosols
(onto solid and liquid surfaces)
Haze
Blue photons
Dunes
Long wavelength red photons
N_2-CH_4 ice
Silicate Core
Ice Layer
IR photons
CH_4-N_2-H_2 opacity
Haze
Titan
Temperature, K
180
160
140
120
100
80
60
0
20
40
60
80
100
120
140
Altitude, km
^{40}Ar
Ice diapir from interior
NH_3-H_2O flows
Elevated terrain
Moist convection in CH_4-N_2
CH_4


Dunes
Long wavelength red photons
Silicate Core
Ice Layer
N_2-CH_4 ice
IR photons
CH_4-N_2-H_2 opacity
Haze
Titan
160
140
120
100
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Temperature, K
0
20
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60
80
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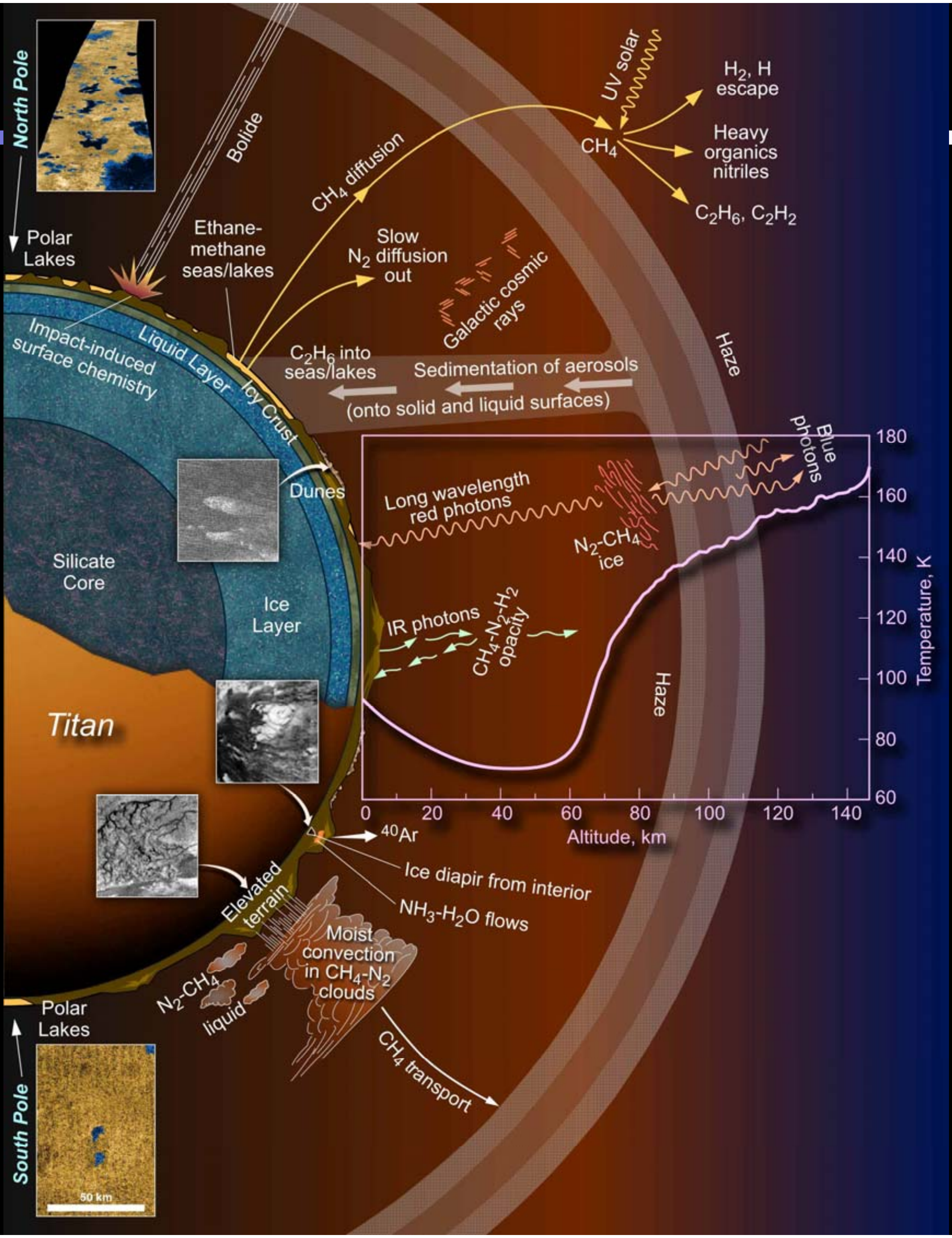
140
Altitude, km
^{40}Ar
Ice diapir from interior
NH_3-H_2O flows
Elevated terrain
Moist convection in CH_4-N_2 clouds
N_2-CH_4 liquid
Polar Lakes
South Pole
CH_4 transport

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



Science Goals

- **Goal A:** How does Titan function as a system; to what extent are there similarities and differences with Earth and other solar system bodies?

- **Goal B:** To what level of complexity has prebiotic chemistry evolved in the Titan system?

- **Goal C:** What could be learned from Enceladus and Saturn's magnetosphere about the origin and evolution of Titan?

TM Road from Goals to Instruments

Table 2.3-1. Science traceability matrix: orbiter, cont'd.

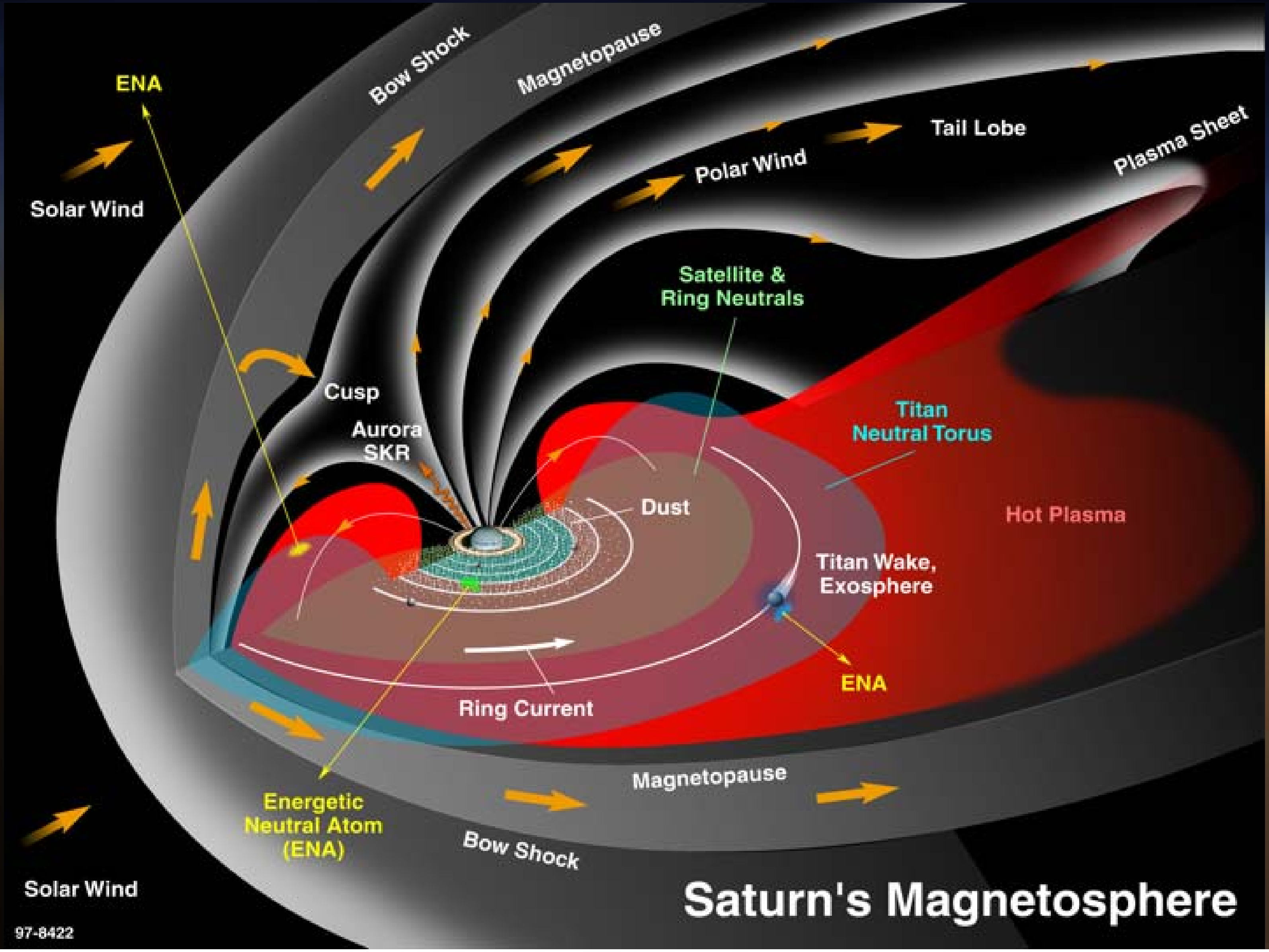
MISSION GOALS	SCIENCE OBJECTIVES	SCIENCE INVESTIGATIONS	REQUIRED MEASUREMENTS/ DETERMINATIONS	PLANNING MEASUREMENT APPROACH	PLAN INSTR.	DATA PRODUCTS	MISSION REQUIREMENTS
Goal A: How does Titan function as a system; to what extent are there similarities and differences with Earth and other solar system 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
		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 form-ation 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
				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

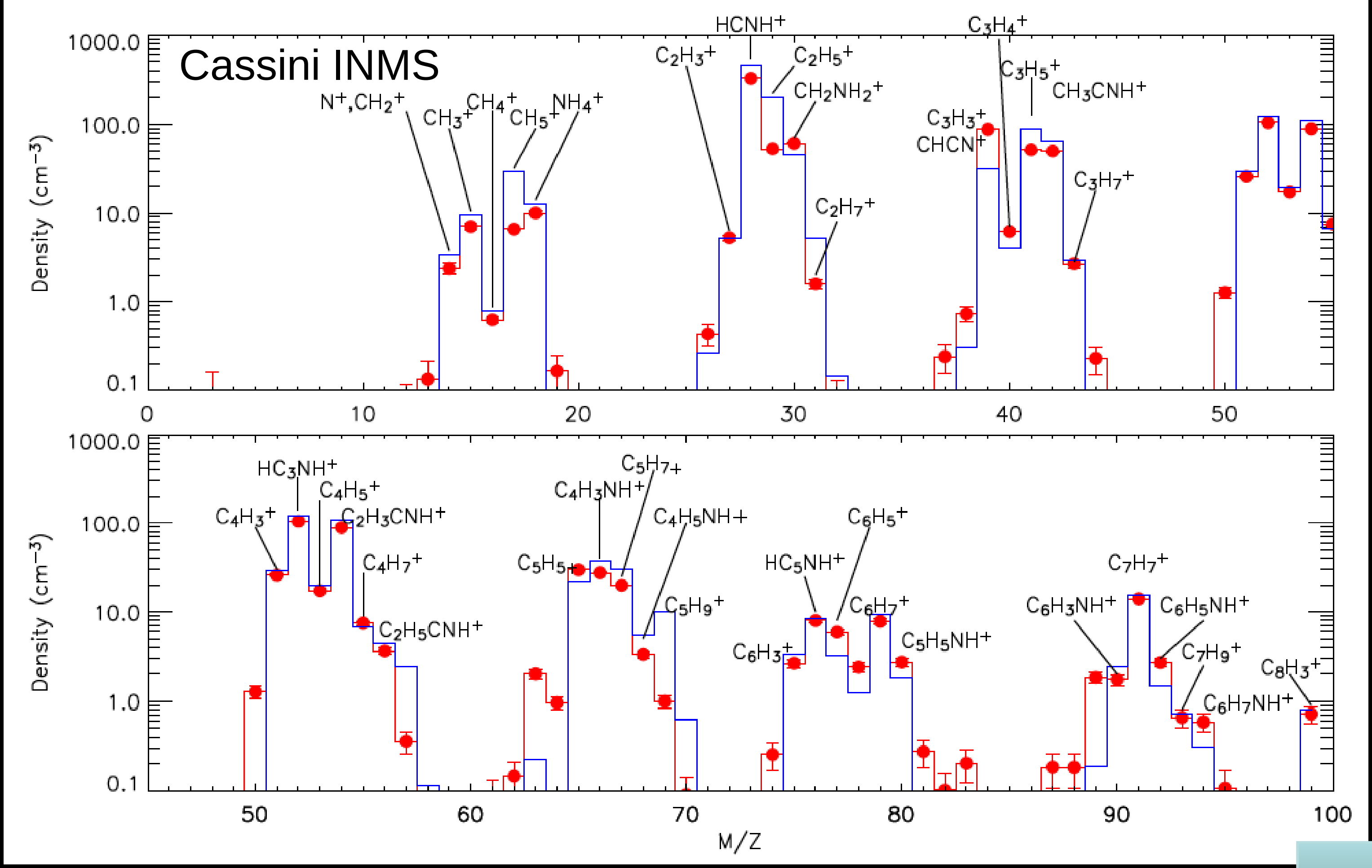
TSSM Planning Payload
NASA Orbiter

	Planning Science Instruments	Instrument Capabilities
HiRIS	High-Resolution Imager and Spectrometer (near IR)	Global surface mapping at 50 m/pixel in three colors (~2.0, 2.7, and 5–6 µm). Two spectral mapping bands 0.85 to 2.4 µm (5 nm spectral resolution) and 4.8 to 5.8 m supporting surface/atmosphere studies
TiPRA	Titan Penetrating Radar and Altimeter	>20 MHz global mapping of subsurface reflectors with 10 m height resolution in altimetry mode and better than 10 m in depth resolution. Lower data rate depth sounding mode with ~100 m depth resolution. Approximately 1 km x 10 km spatial resolution.
PMS	Polymer Mass Spectrometer	Upper atmospheric *in situ* analysis of gases and aerosol precursors—M/ΔM ~10,000 for masses up to 10,000 Da. Focus instrument for aerosampling down to 600 km. Better than 10^4 particles/cm^3
SMS	Sub-Millimeter Spectrometer	Direct winds from Doppler and temperature mapping from ~200–1000 km altitude; CO, H_2O, nitrile and hydrocarbon profiles; heterodyne spectrometer with scanned mirror.

TIRS	Thermal Infrared Spectrometer	Organic gas abundance, aerosol opacity and temperature mapping 30–500 km. Passively cooled Fourier Spectrometer 7–333 µm. Spectral resolution 0.125-15 cm^{-1}.
MAPP	Magnetometer	Interaction of field with ionosphere: internal and induced field.
	Energetic Particle Spectrometer	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 system, with a linear electric field (LEF) time-of-flight mass spectrometer. Measures ion and electron fluxes at few eV to a few keV. M/ΔM~10.
RSA	Radio Science and Accelerometer	Lower stratosphere and troposphere temperature profile. Gravity field. Mass and power are zero because all hardware components are part of the spacecraft bus: USO, UST, and accelerometers.

Titan's link to Saturn and Enceladus: A rich magnetospheric mission





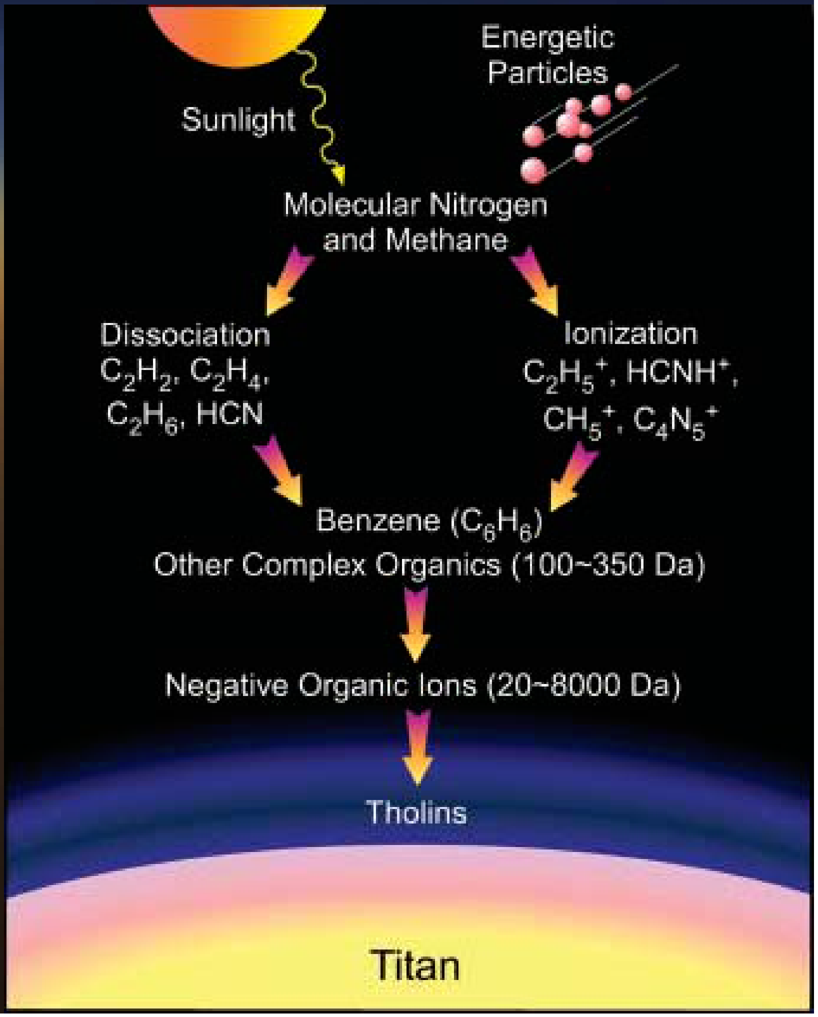
Upper atmosphere complex polymers higher than eight carbon atoms cannot be analyzed by Cassini

?

Titan Upper Atmosphere/ Induced Magnetosphere

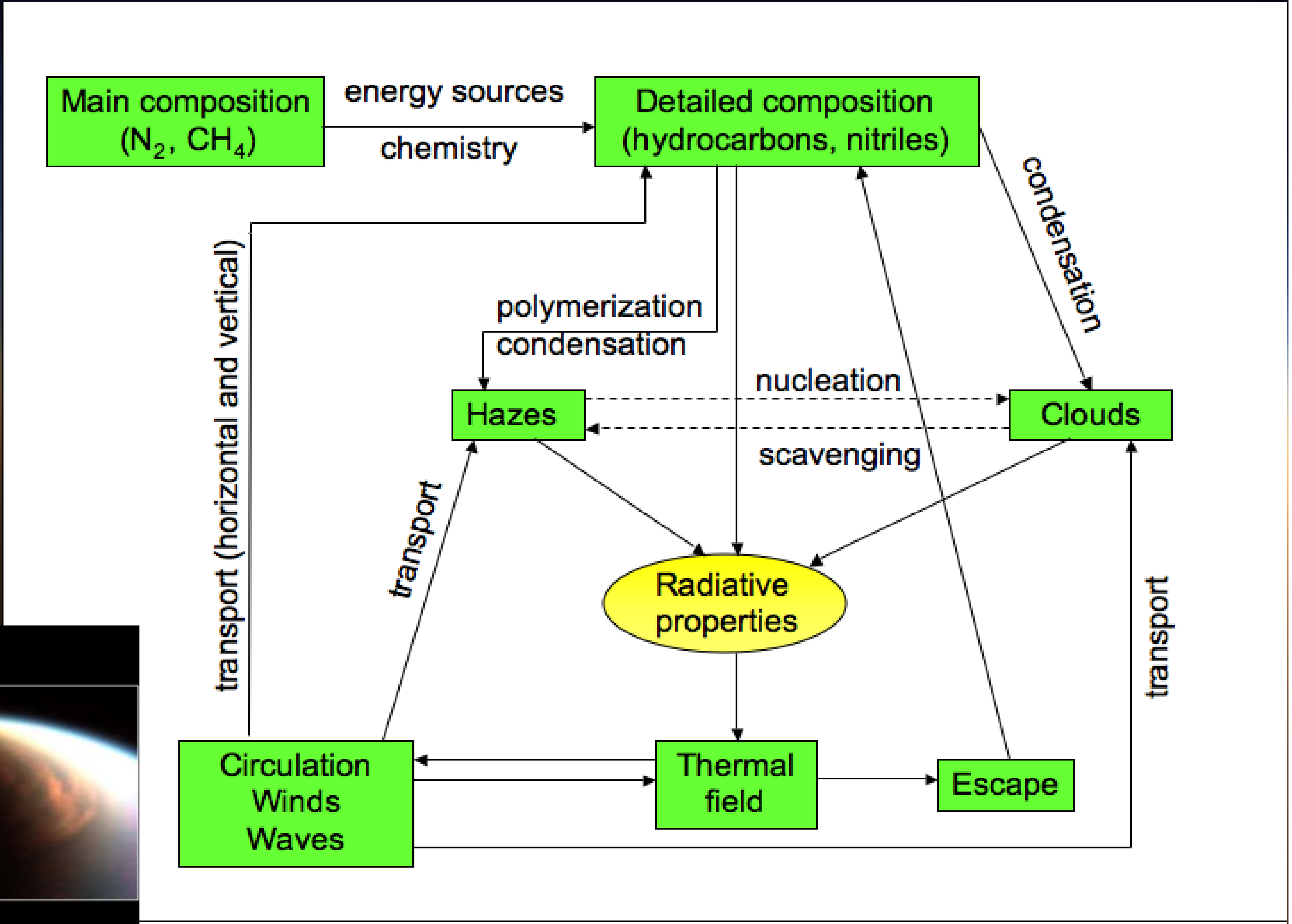
- **Agnostosphere (400-950 km) not reached by most measurements**
  – Important region for complex organic ion-molecule & aerosol synthesis with relevance for the entire atmosphere and astrobiology: Cassini-Huygens not equipped to study much of Agnostosphere/ Thermosphere/Ionosphere chemistry

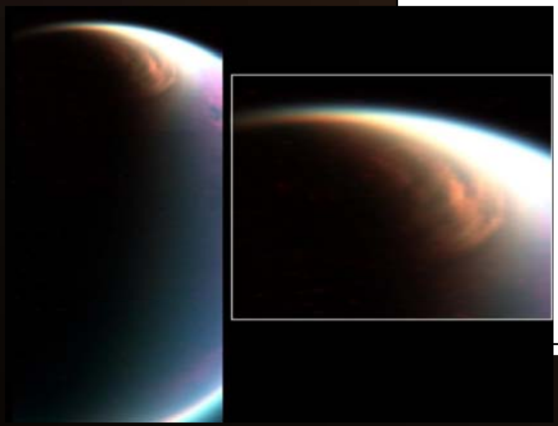
- **Dedicated orbiter and improved and new instrumental payload & configuration necessary to answer new questions raised during Cassini-Huygens mission**
  - –Advanced INMS to measure the very heavy neutrals and positive/ negative ions
  - –DC electric field (plasma speed) for studying electrodynamic coupling
  - –Millimetre & Sub-mm spectrometer for neutral wind



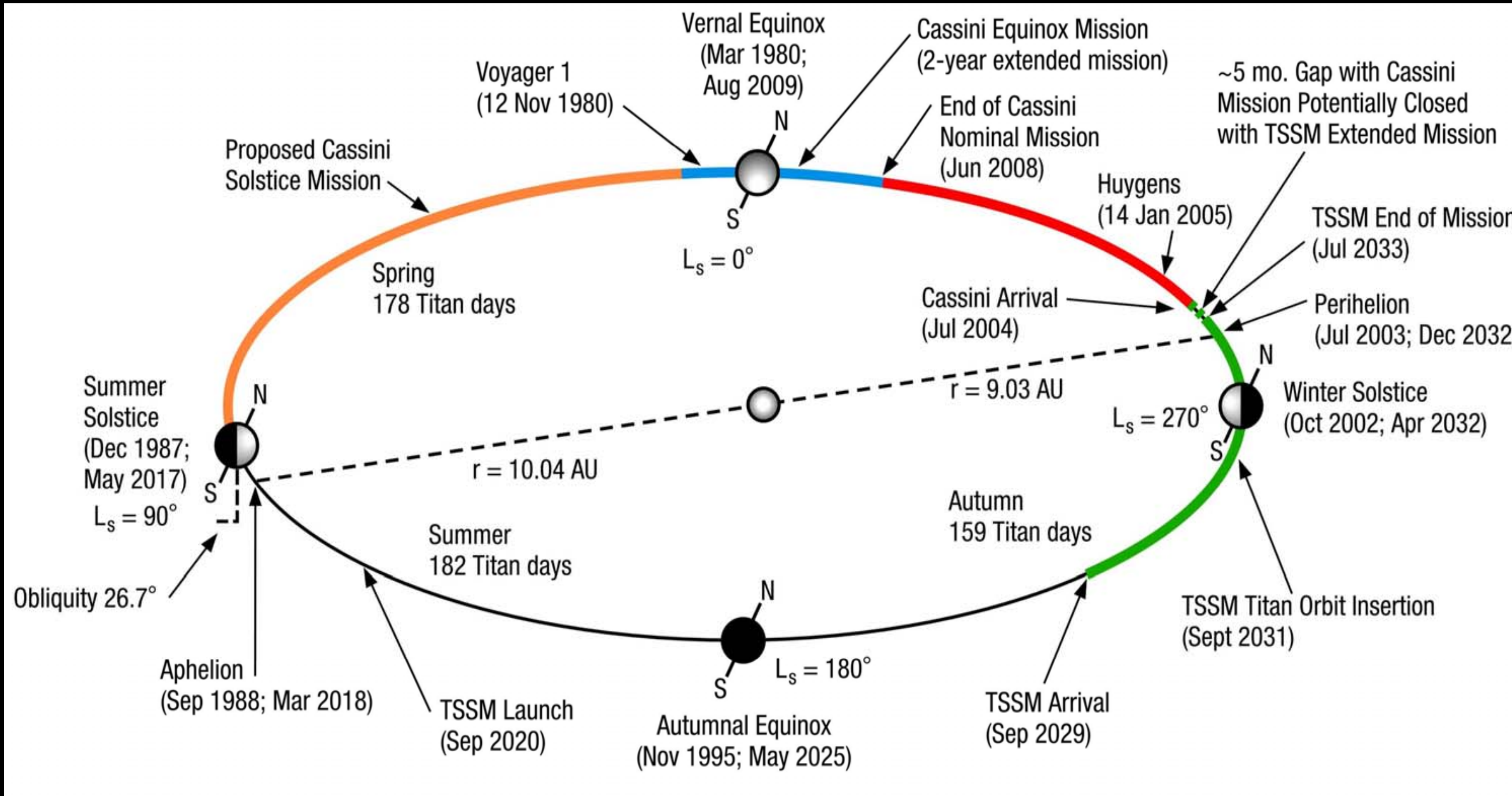
Titan's neutral atmosphere

Densest N_2 atmosphere in solar system.



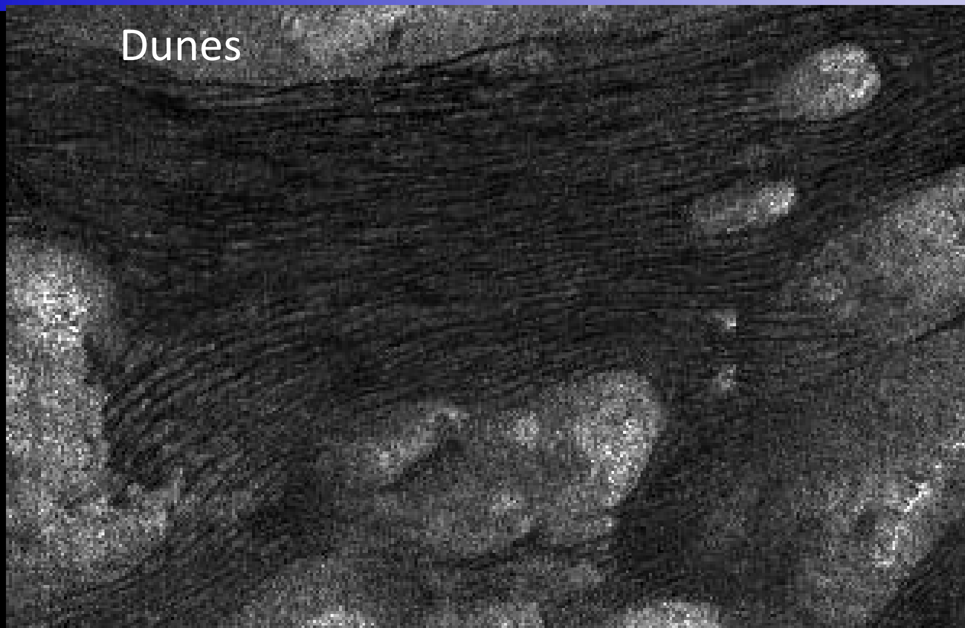


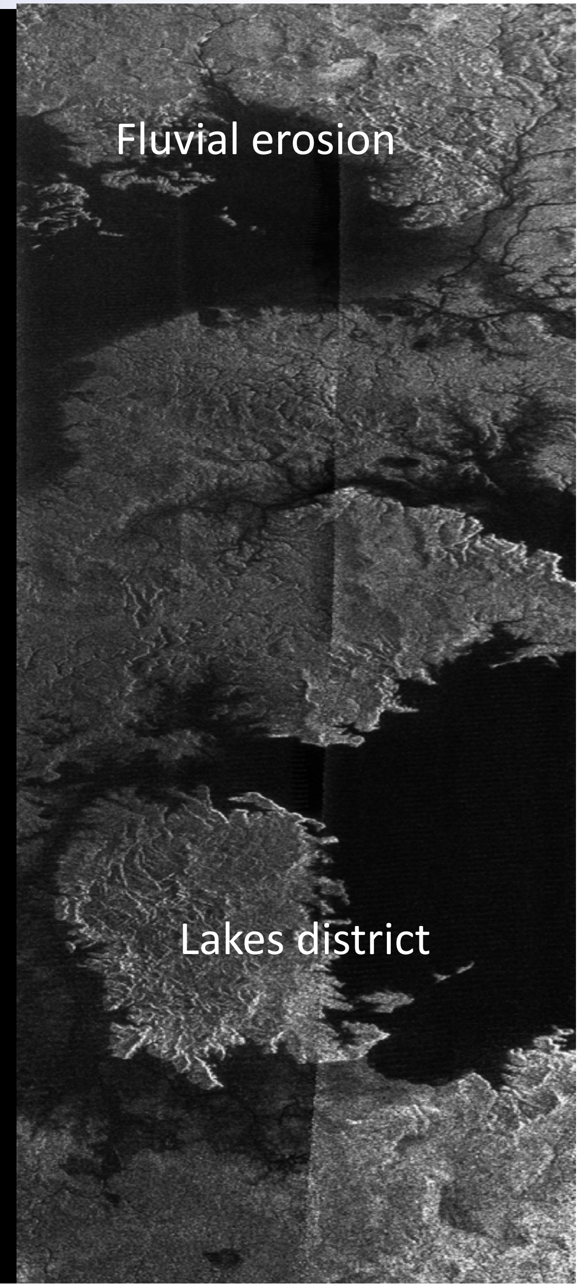
Titan seasonal cycle: exploration coverage

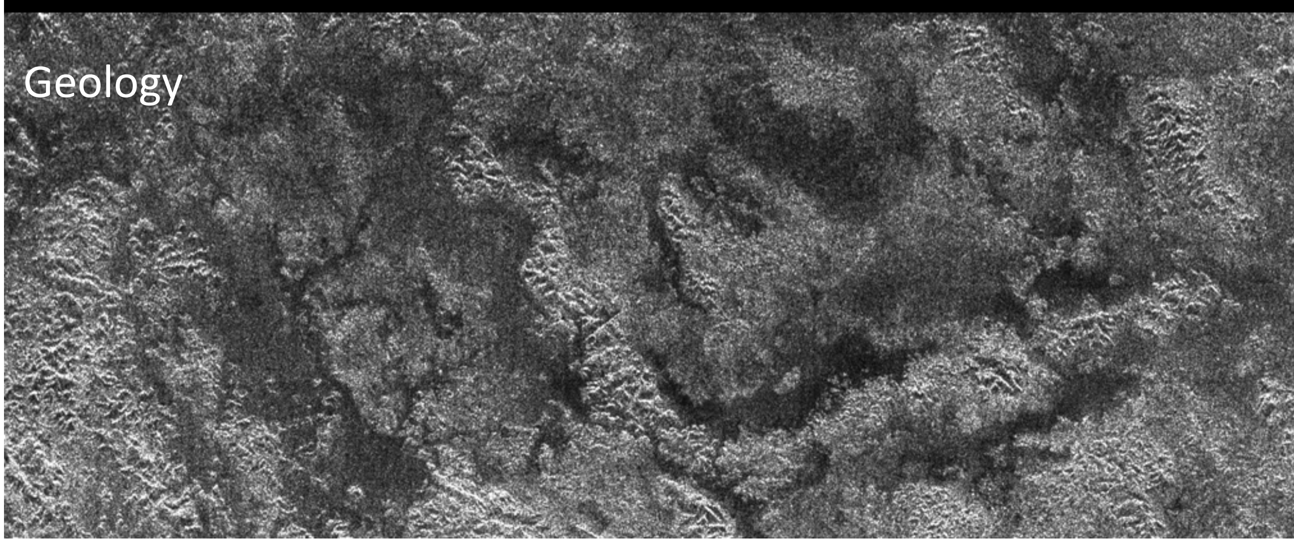


Orbital motion of Titan and Saturn around the Sun during one Saturn year. L_s denotes the Kronocentric (Saturnicentric) orbital longitude of the Sun that characterizes the season.

Titan’s surface: many questions from radar

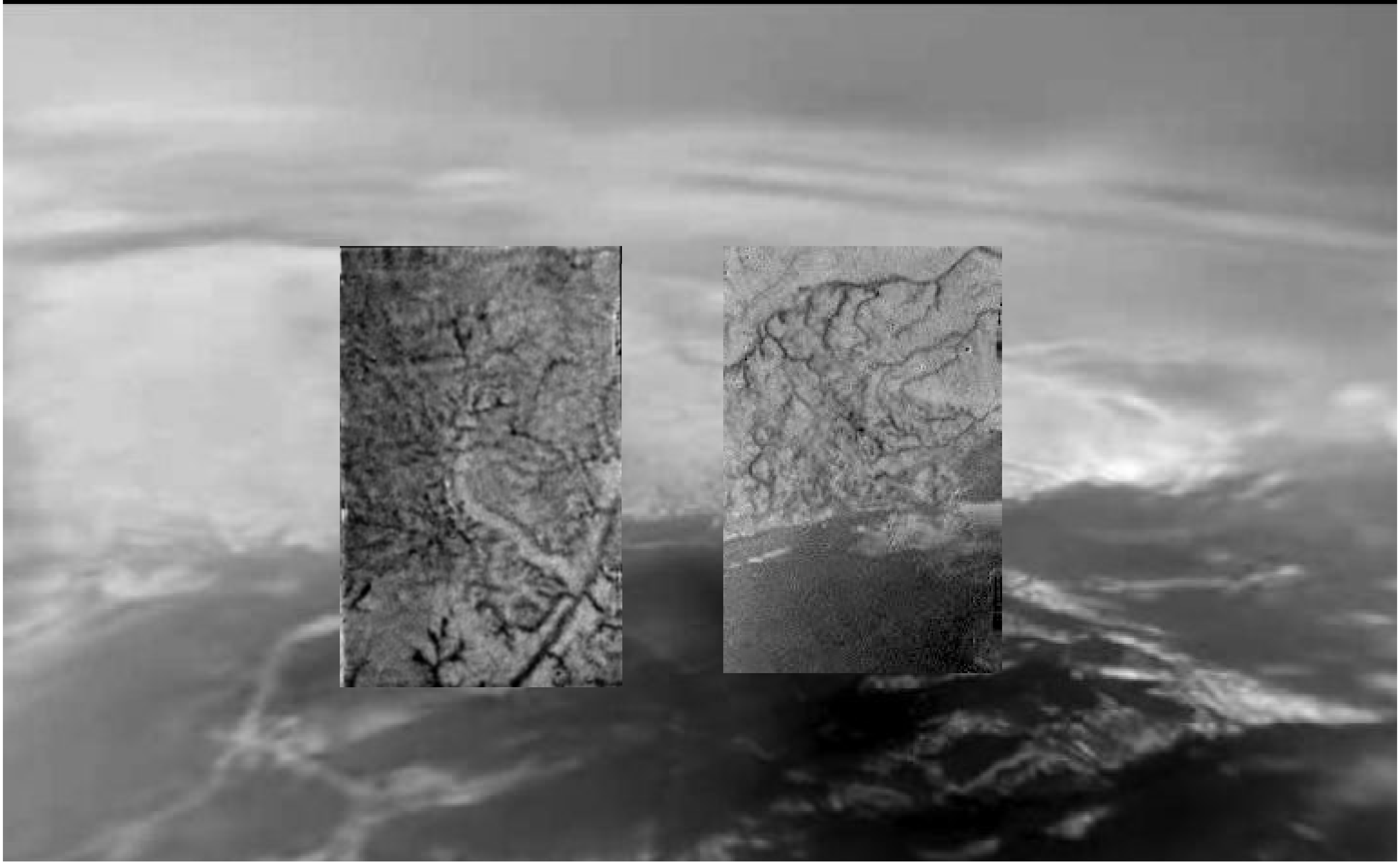






Titan’s surface

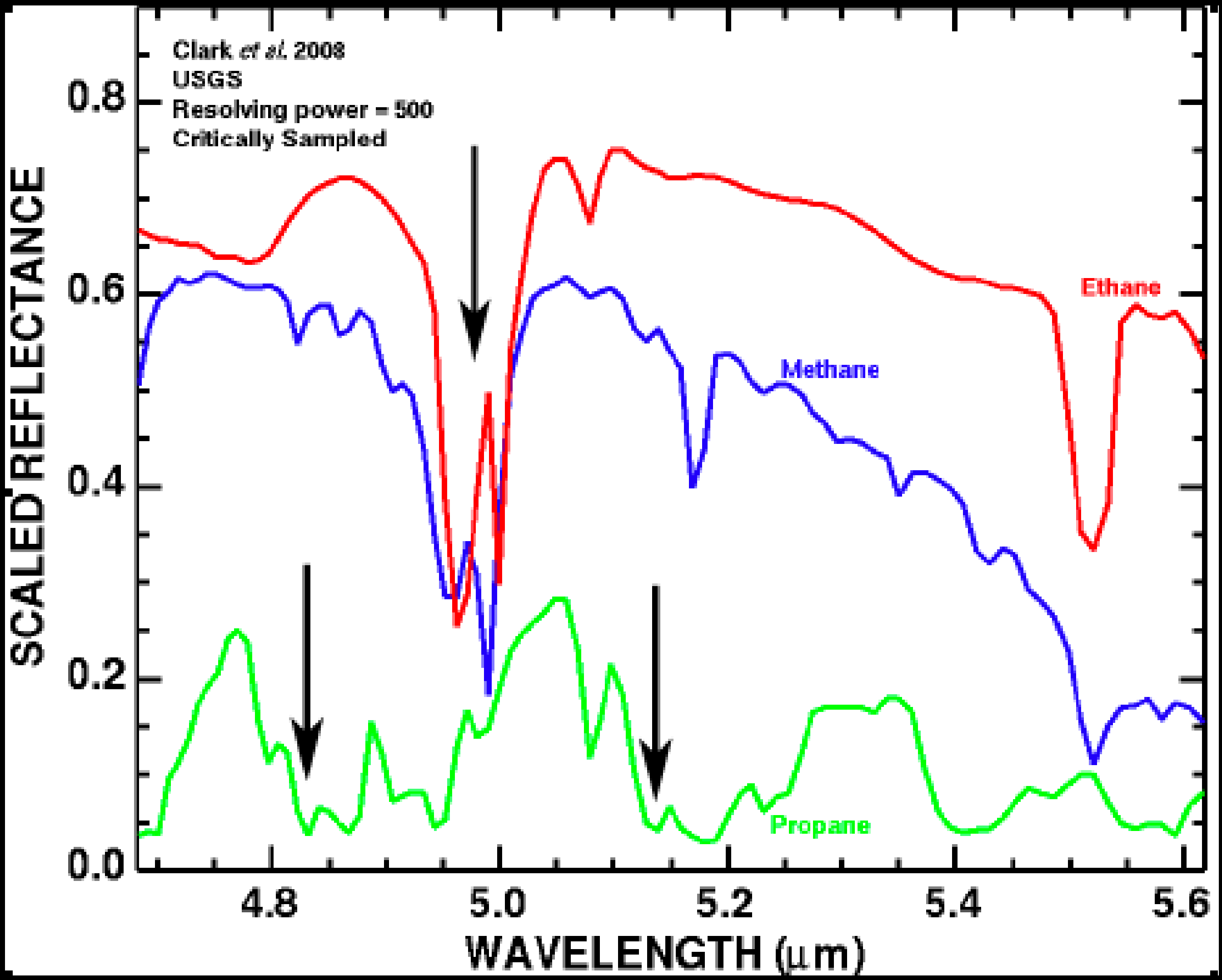
One site well understood from Huygens



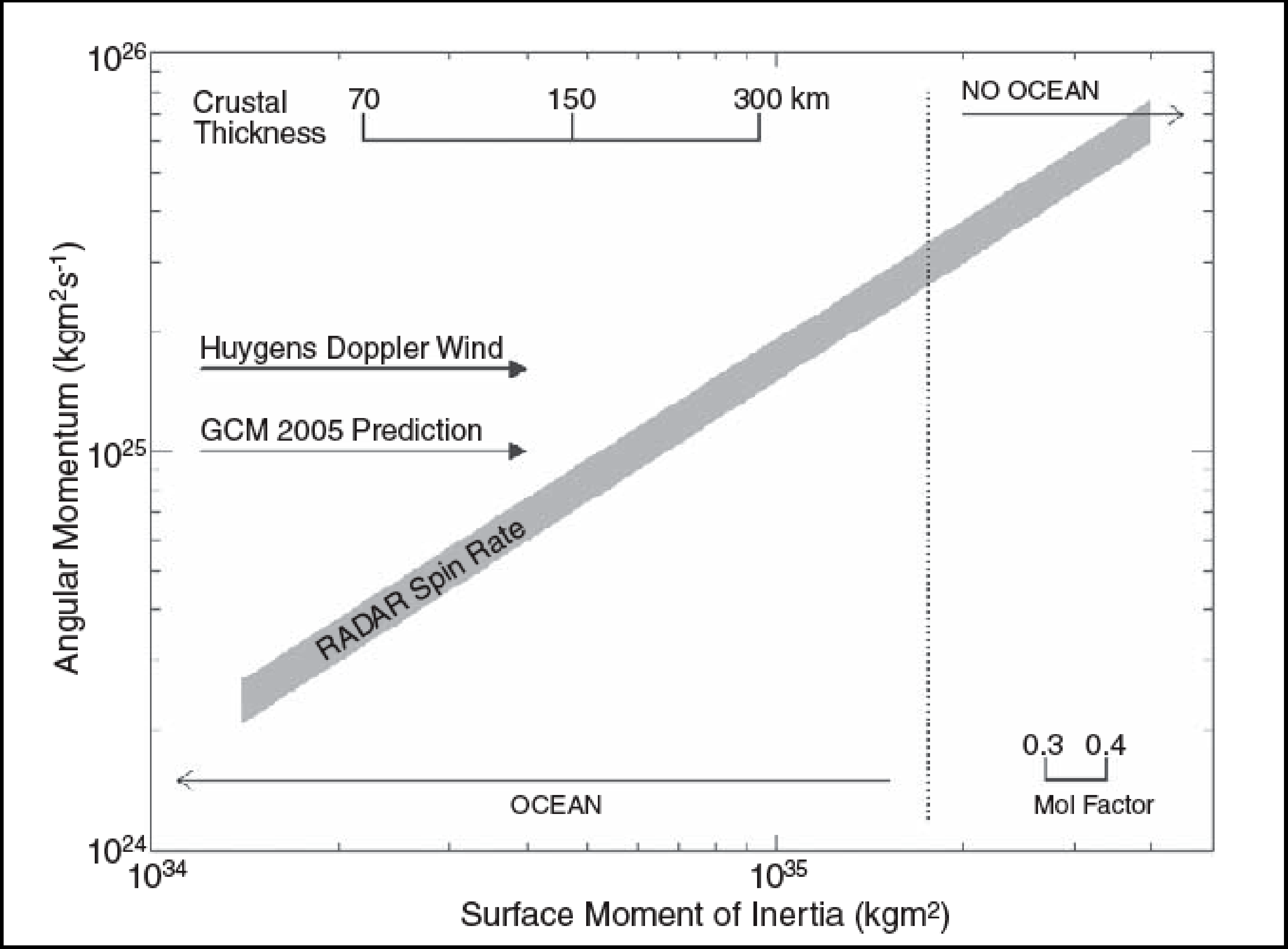
Landing site most resembles a desert bajada on Earth

Titan Earth (Desert bajada, Tucson)

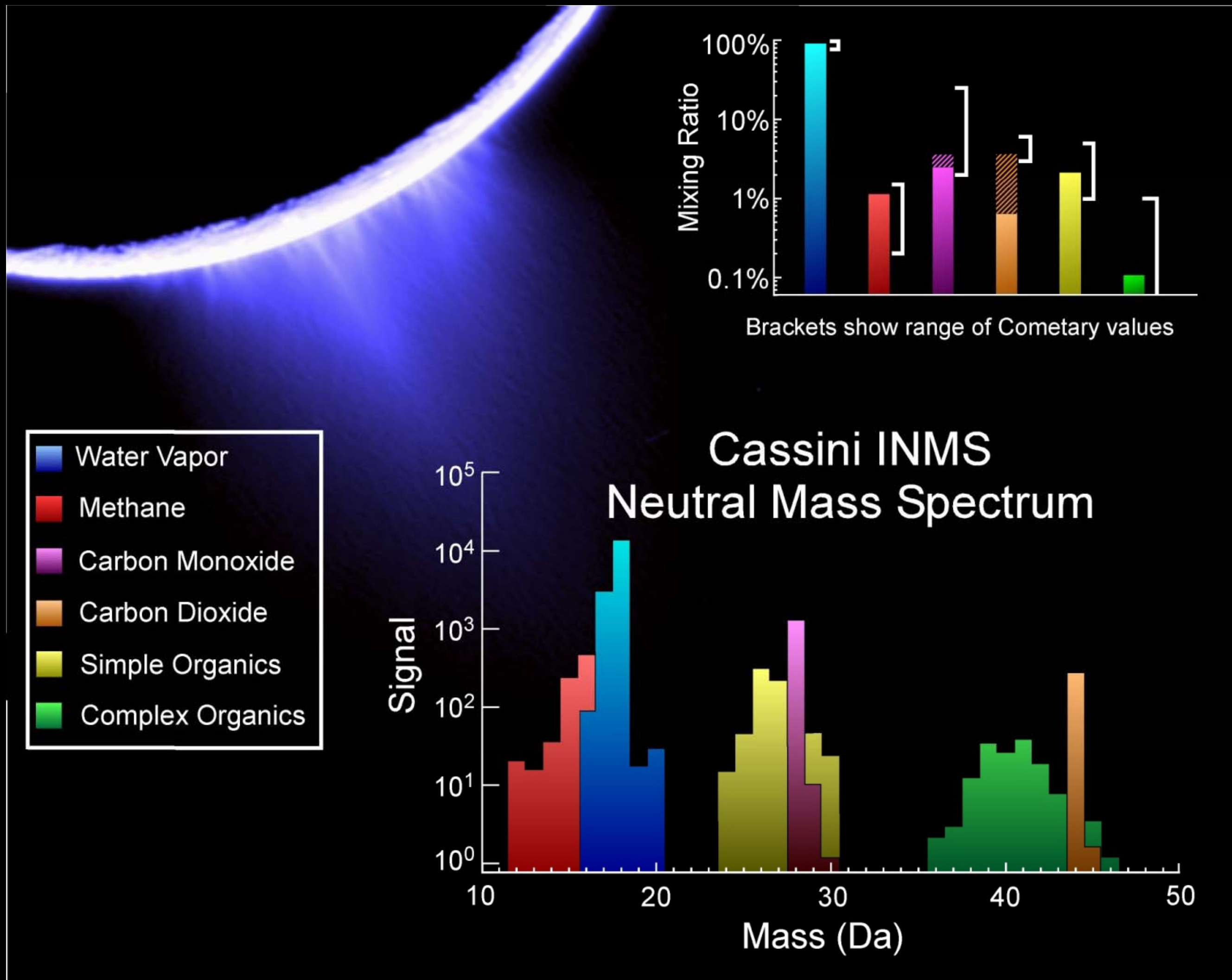
Remote Sensing Diagnosis of Hydrocarbons



Titan's interior includes an ocean



Enceladus: The little moon with active geysers



NASA Titan orbiter maps to decadal objectives

Decadal Survey p. 138	Cassini	TSSM orbiter
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 microns; 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 temp-erature monitoring in thermal IR; 5-5.6 micron 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	Hi 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 cryo-volcanism	Hi-res spectra over 5-5.6 microns; repeat surface coverage; high molecular weight sampling of upper atmosphere organics

Backup charts

Backup charts

Table 2.3-4. Large satellites panel themes and key questions from the 2003 National Research Council (NRC) Decadal Survey.

	Orbiter Only	Orbiter + Lander + Montgolfière	Comments
Theme 1. Origin and Evolution of Satellite Systems			
1. How do conditions in the protoplanetary nebula influence the compositions, orbits, and sizes of the resulting satellites?	3	4	
2. What affects differentiation, outgassing, and the formation of a thick atmosphere? (Why is Titan unique?)	3	5	
3. To what extent are the surfaces of icy satellites coupled to their interiors (chemically and physically)?	4	5	
4. How has the impactor population in the outer solar system evolved through time, and how is it different from the inner solar system?	4	4	Enceladus
5. What does the magnetic field of Ganymede tell us about its thermal evolution, and do other large satellites have intrinsic magnetic fields?	1	3	Comparison of magnetic fields between Ganymede and Titan
Theme 2. Origin and Evolution of Water-Rich Environments			
1. What is the chemical composition of the water-rich phase?	3	4	Enceladus plumes and Titan
2. What is the distribution of internal water in space and in time?	3	4	Both Titan and Enceladus
3. What combination of size, energy sources, composition, and history produce long-lived internal oceans?	3	5	Outstanding pairing of large and small body both with potential internal liquid layers, in the same (Saturn) system.
4. Can and does life exist in the internal ocean of an icy satellite?	2	3	Titan isotopic ratios major gases, and Enceladus plume material
Theme 3. Exploring Organic-Rich Environments			
1. What are the chemistry, distribution, and cycling of organic materials on Titan?	3	4	
2. Is Titan internally active, producing water-rich environments with potential habitability?	3	4	
3. What are the current state and history of Titan's surface?	4	5	
4. What drives the meteorology of Titan?	3	5	Combines seasonal coverage with Voyager and Cassini
5. Has there been climate change on Titan?	3	4	
6. Could Titan support life forms that do not require liquid water?	1	5	
Theme 4. Understanding Dynamic Planetary Processes			
1. What are the active interior processes and their relations to tidal heating, heat flow, and global patterns of volcanism and tectonism?	4	5	Enceladus and Titan
2. What are the currently active endogenic geologic processes (volcanism, tectonism, diapirism) and what can we learn about such processes in general from these active worlds?	4	5	Enceladus and Titan
3. What are the complex processes and interactions on the surfaces and in volcanic or geyser-like plumes, atmospheres, exospheres, and magnetospheres?	4	5	Enceladus and Titan
Average Science Value Score			
	3.1	4.4	

Science Value Scoring Key

5	4	3	2	1
Definitely addresses full science	May address full science	Definitely addresses partial	May address partial science	Touches slightly on science

Backup charts

Table 2.6-3. TSSM mission elements are highly complementary.

Mission Goals	Science Objectives	Science Investigations	Orbiter	Montgolfière	Lake Lander
Goal A: How does Titan function as a system; to what extent are there similarities and differences with Earth and other solar system bodies?	O1: Determine how energy is deposited in the upper atmosphere to drive the chemistry and the escape rate of major atmospheric constituents.	I1: Quantify the deposition of radiation into Titan's atmosphere.	X		x
		I2: Quantify the escape flux of elemental hydrogen, carbon, nitrogen.	X		x
	O2: Characterize the relative importance of exogenic and endogenic oxygen sources.	I1: Quantify the flux of exospheric oxygen into the atmosphere.	X	x	x
		I2: Quantify the flux of endogenic oxygen from the surface and interior.	X		X
	O3: Characterize the major processes controlling the global distribution of atmospheric chemical constituents.	I1: Characterize the major chemical cycles.	X		x
		I2: Determine the relative importance of global transport.	X		
	O4: Characterize the atmospheric circulation and flow of energy and its variability on short-timescales.	I1: Determine the atmospheric thermal and dynamical state.	X	X	x
		I2: Determine the impact of haze and clouds.	x	X	
		I3: Determine the effects of atmospheric composition.	X	X	
		I4: Determine the effects of surface processes on meteorology.	X	X	
		I5: Determine the exchange of momentum, energy and matter between the surface and atmosphere and characterize the planetary boundary layer.		X	x
		I6: Determine the connection between weather, ionosphere, and electricity.		X	x
	O5: Characterize the amount of liquid on the Titan surface today.	I1: Quantify the total major-hydrocarbon (methane/ethane) inventory present in the lakes and seas.	x		X
		I2: Determine the depth of lake	x		X
		I3: Determine surface composition that might reveal the presence of liquids		X	
		I4: Determine the nature of precipitation responsible for the formation of valley networks in the equatorial regions.		X	
	O6: Characterize the major processes transforming the surface throughout time.	I1: Determine the origin of major crustal features; correlate regional elevation changes with geomorphology and compositional variations.	X	x	
		I2: Characterize the origin of major surface features, including the effects of liquid flow, tectonic, volcanic, and impact events.	X		
		I3: Determine the internal magnetic signal of Titan	x	X	x
		I4: Detect and measure the depth of shallow subsurface reservoirs of liquid (hydrocarbons).	x	X	
		I5: Determine the subsurface structures and constrain the stratigraphic history of dunes.		X	