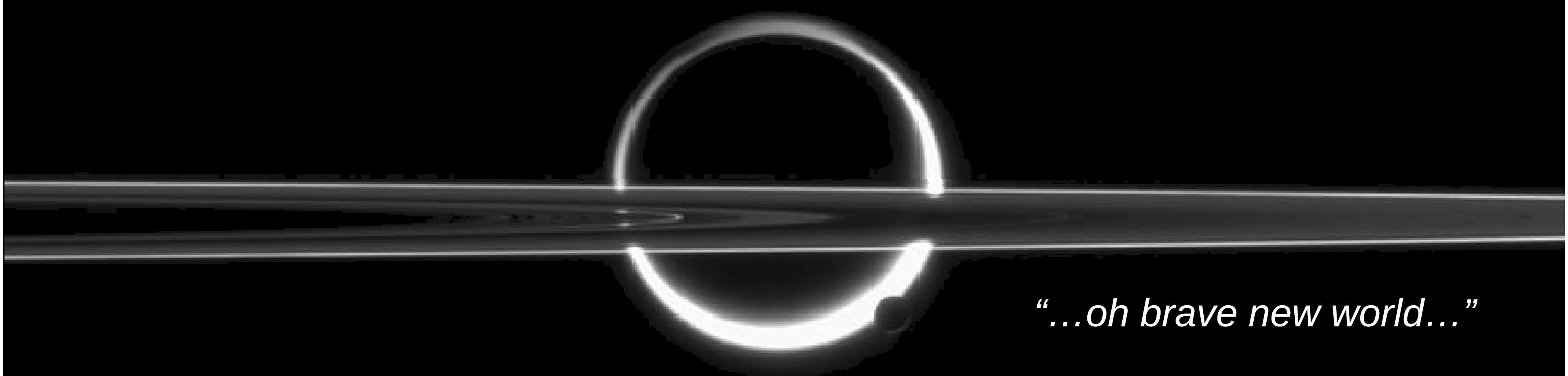
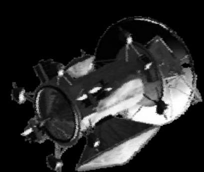
TSSM

Titan Saturn System Mission



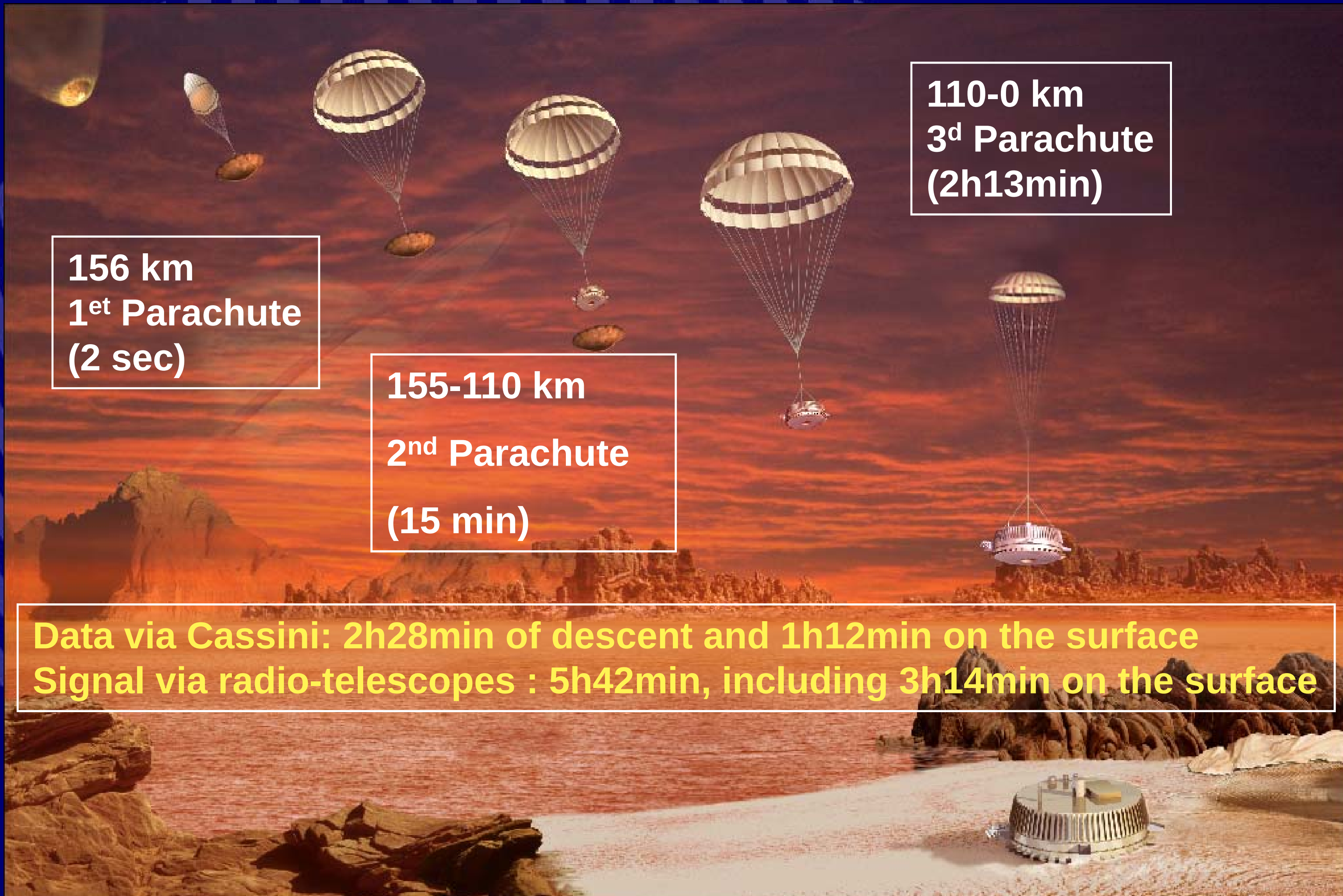
"…oh brave new world…"

The in situ elements of TSSM



A. Coustenis, J. Lunine, D. Matson, J-P. Lebreton,
K. Reh, Ch. Erd, P. Beauchamp, N. Strange

and the Joint Science Definition Team



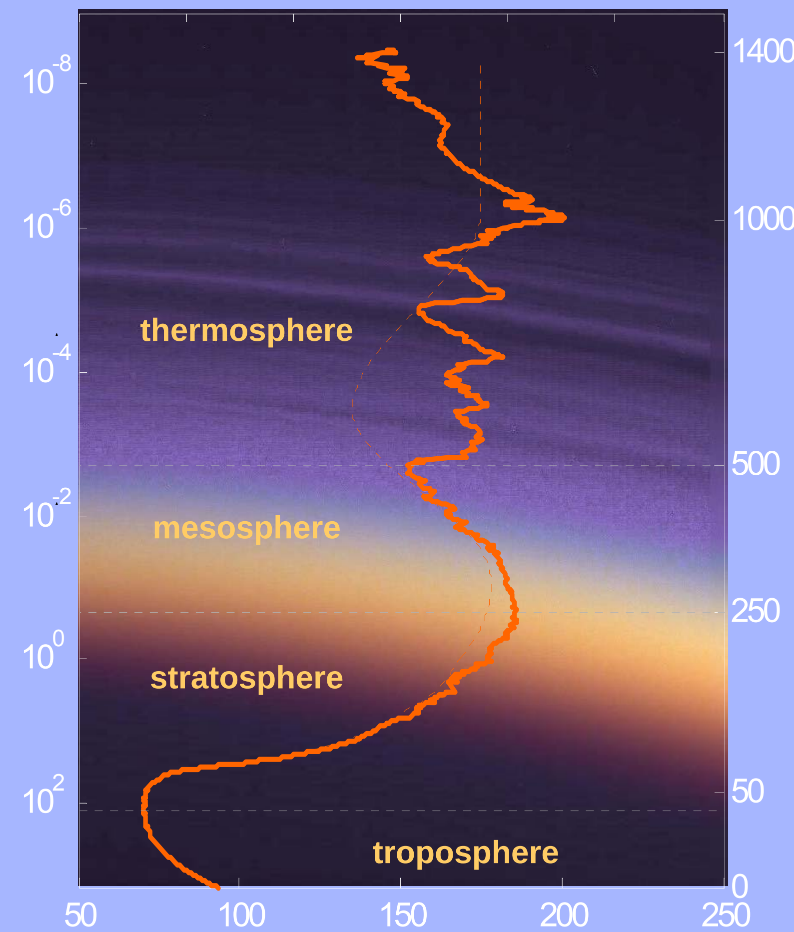
Lebreton et al., 2005; Bird et al., 2005

itan's

- In the **upper atmosphere** density & temperature higher than expected. Wave-like nature of thermal profile => atmosphere is highly stratified and variable in time.
  Stratopause 180 K at 250 km

- **Lower stratosphere** & **tropopause**: very good agreement with Voyager 1 temperature.
  Tropopause 71 K at 44 km

- At **surface**:
  Temperature 93.4 K
  Pressure ~1.5 bar



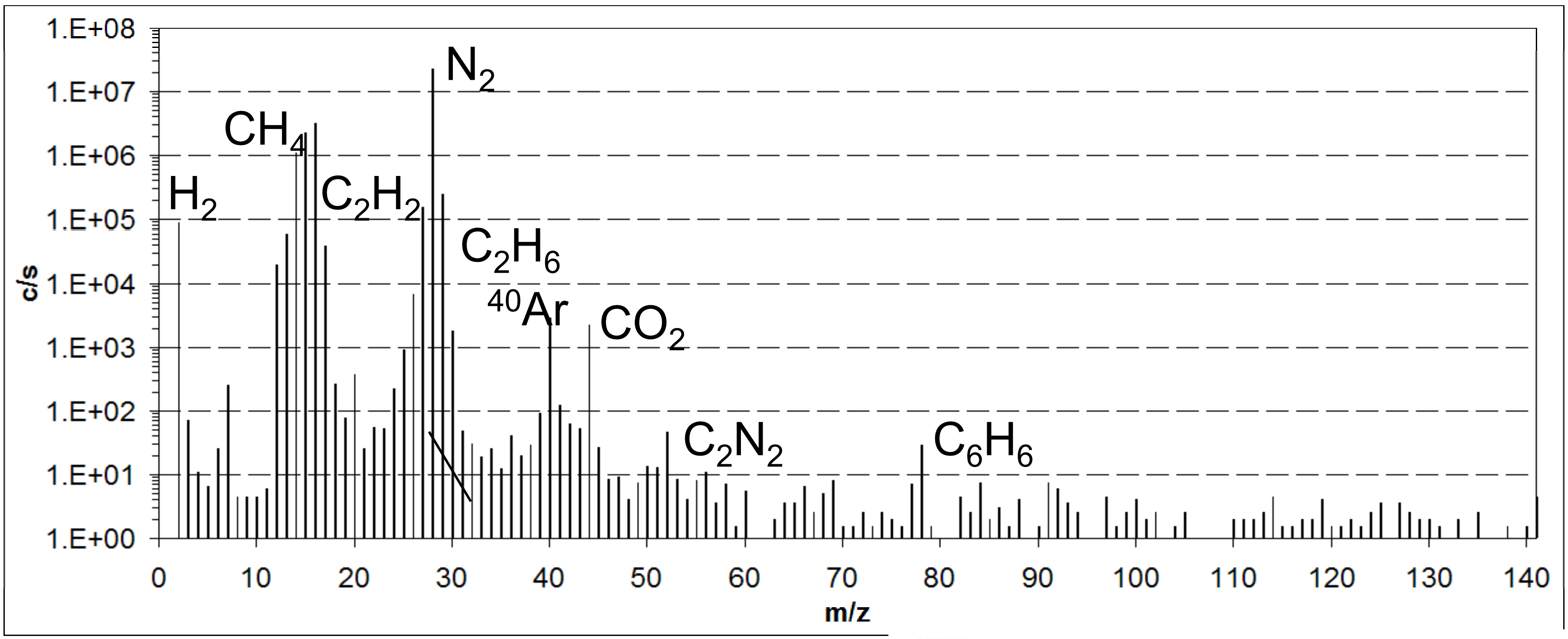
Fulchignoni et al., 2005

Surface Observations and Composition of aerosols with GCMS & ACP

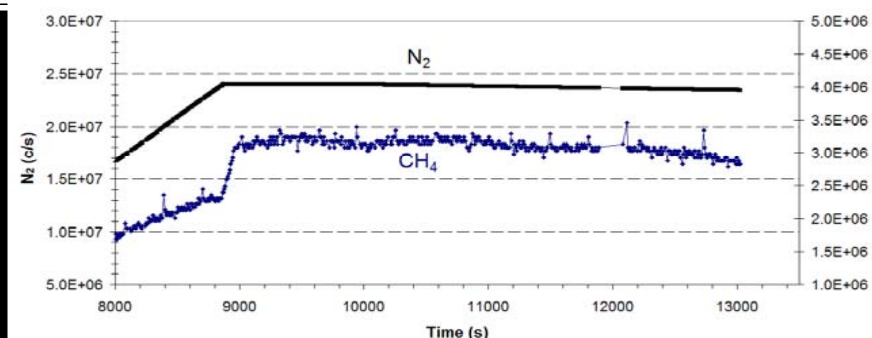
(Niemann et al., Israel et al., Nature, 438, 779-784, 2005)

Detection of various organic compounds on the surface but limited m/z range.

Aerosols: NH3 and HCN primary pyrolysis products.

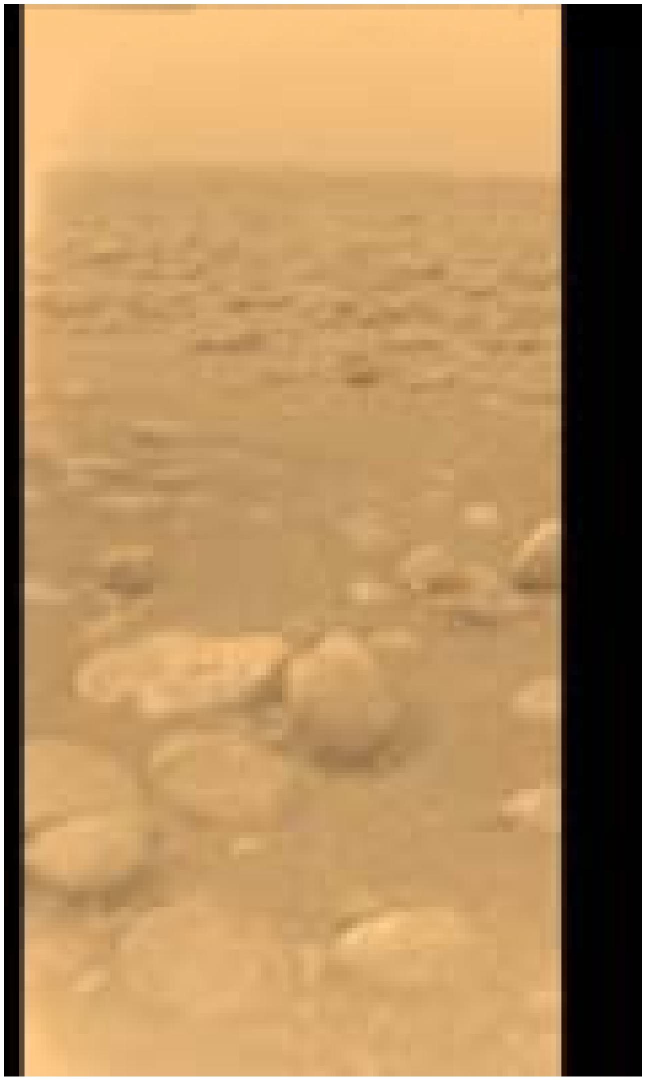


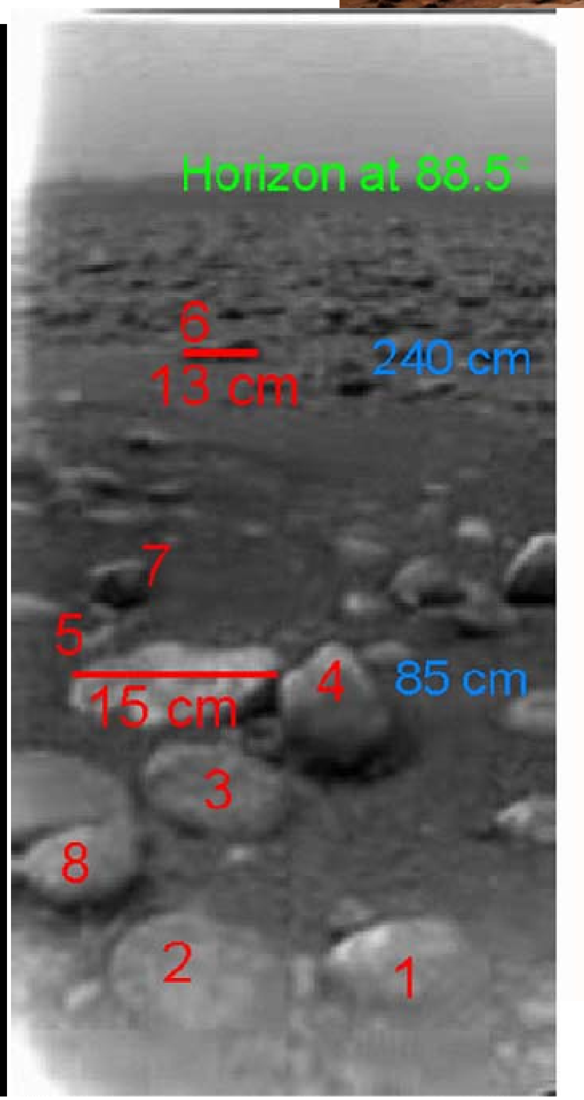
Methane evaporated from the surface after warming from the heated sample inlet as observed by an increase of the methane signal after impact. A moist area with liquid methane in the near sub-surface is indicated.

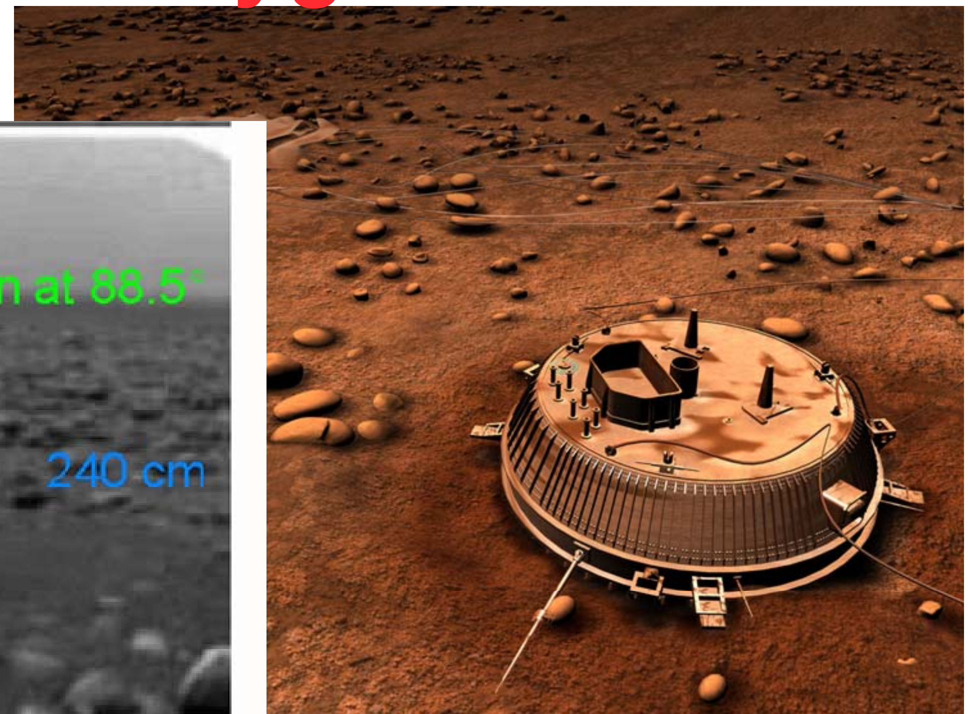


DISR-based reconstructed view of Titan landscape from the Huygens landing site

Titan's surface with Huygens

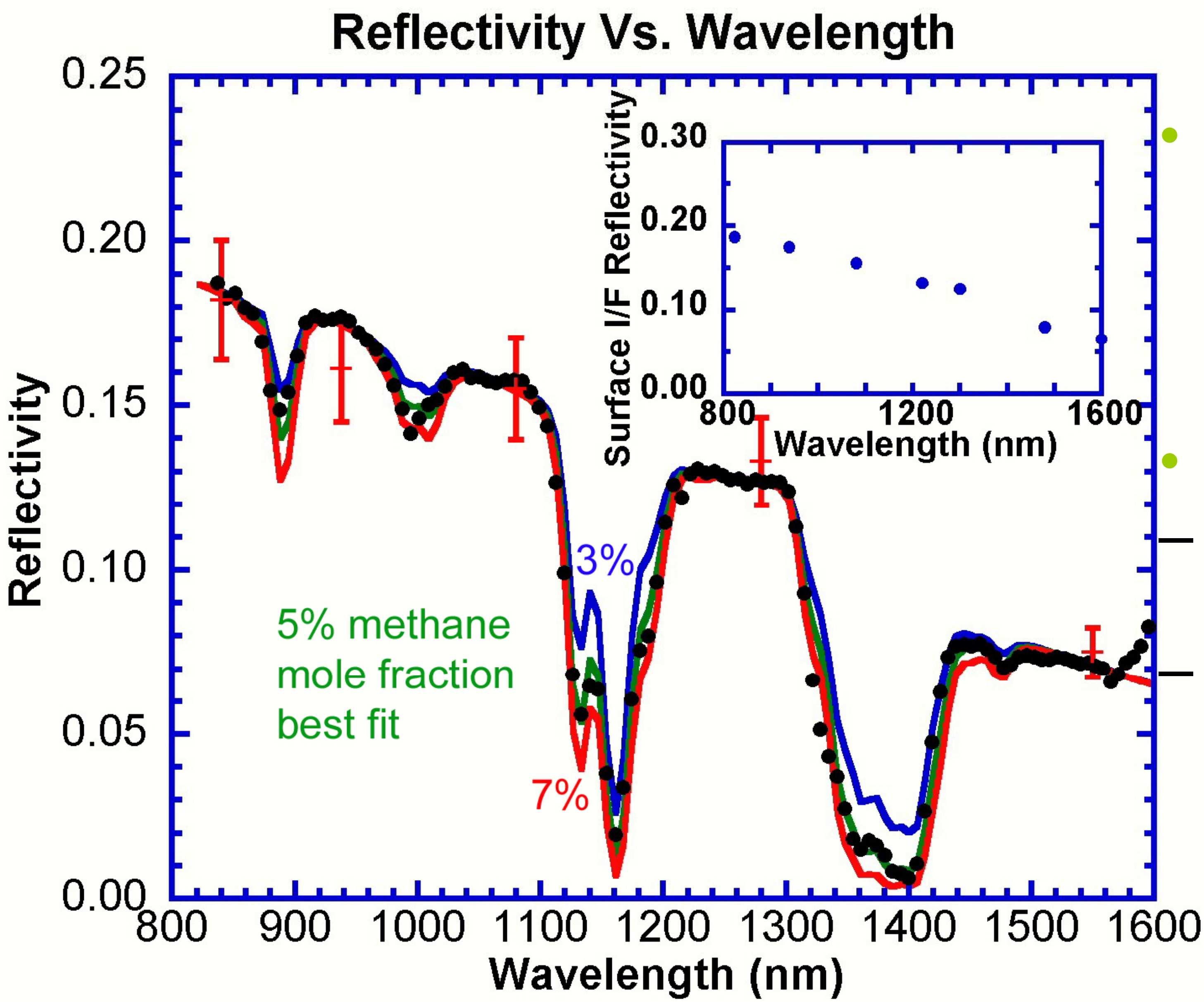






Tomasko et al., 2005

DLIS spectrum at 20 m



- Methane : about 5% at the surface
- Surface :
  – Dark material
  – Probable water ice absorption

Tomasko et al., 2005

TSSM in situ elements

TSSM science goals addressed by ISE’s

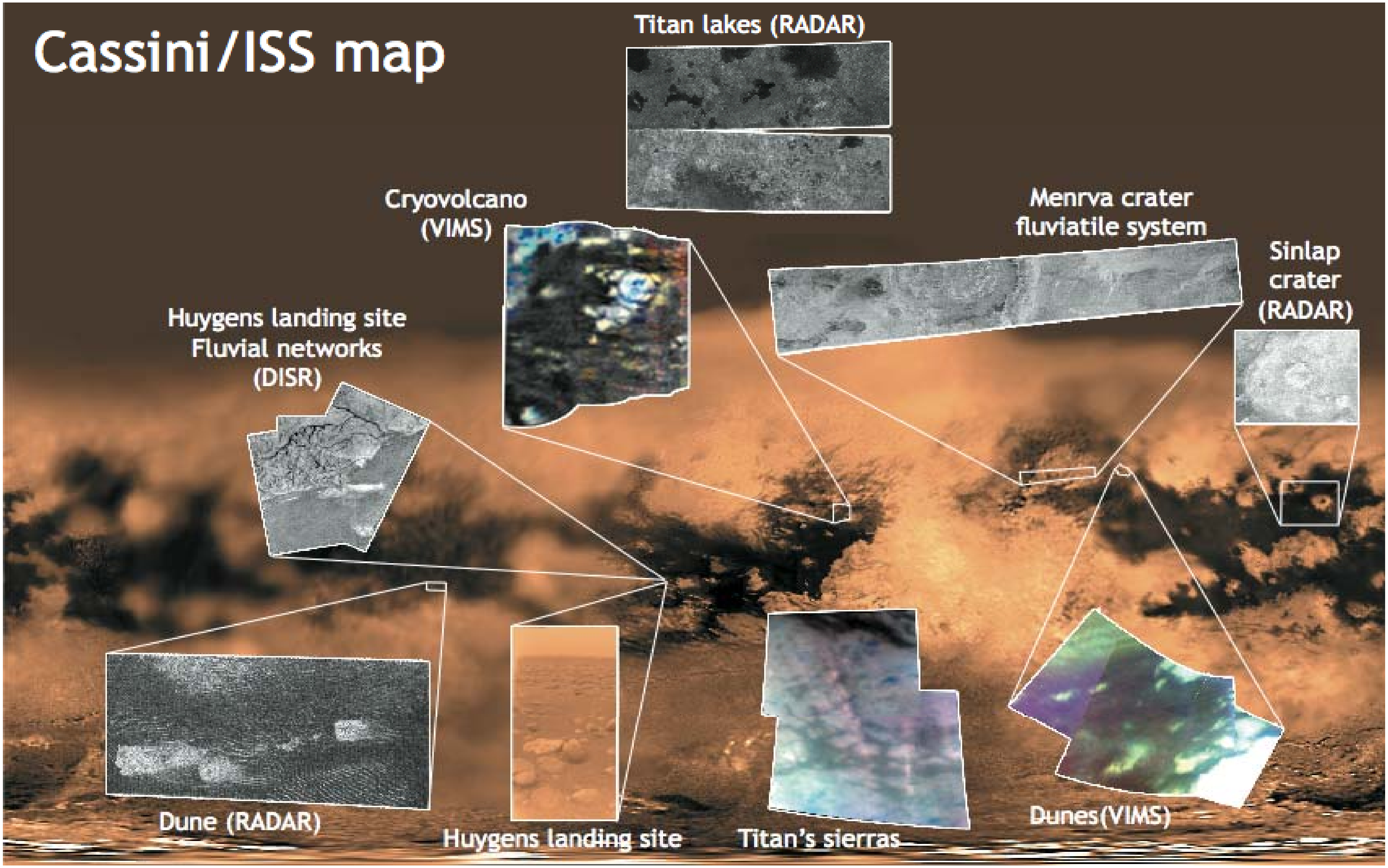
- Goal A: Explore Titan an Earth-Like System:
  - How does Titan function as a system? How are the similarities and differences with Earth, and other solar system bodies, a result of the interplay of the geology, hydrology, meteorology, and aeronomy present in the Titan system?

- Goal B: Examine Titan’s Organic Inventory - A Path to Prebiological Molecules:
  - What is the complexity of Titan’s organic chemistry in the atmosphere, within its lakes, on its surface, and in its putative subsurface water ocean and how does this inventory differ from known abiotic organic material in meteorites and therefore contribute to our understanding of the origin of life in the Solar System?

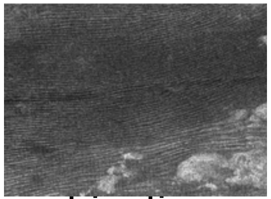
- Goal C: Explore Enceladus and Saturn’s r origin and evolution
  - What is the exchange of energy and material wit What is the source of geysers on Enceladus? Do source?

http://www.lesia.obspm.fr/cosmicvision/tssm/tssm-public

Titan : Cassini-Huygens images of Titan's surface



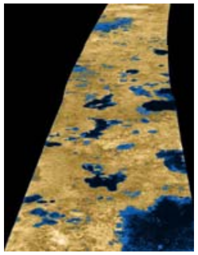
QuickTime™ et un
décompresseur TIFF (non compressé)
sont requis pour visionner cette image.



First order targets:

(D) Brownish **dune units e.g. Belet dunefield** (can be hit by 15x40° ellipse (600x1600km)); coordinates: 255°W 5°S (center of ellipse)

Reason: fits most of engineering requirements and addresses most of science objectives



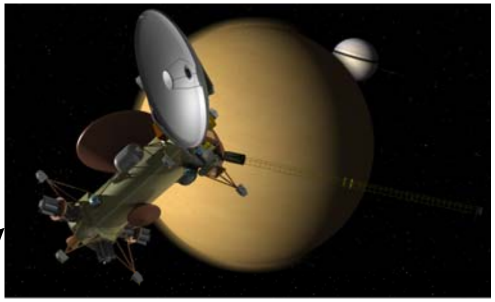
(E) **North Polar Lakes** above 65°N (200km circular delivery error can be accomodated in Kraken Mare) coordinates: > 72°

Reason: fits the most exciting science goals of the methanological cycle and productions of organics

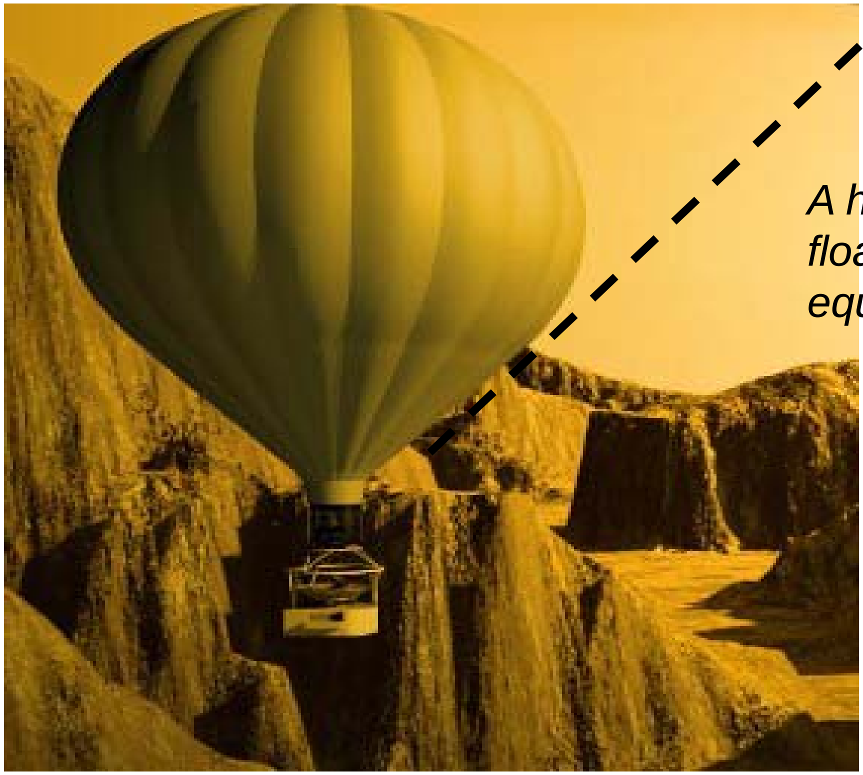
Baseline mission architecture

Combining

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

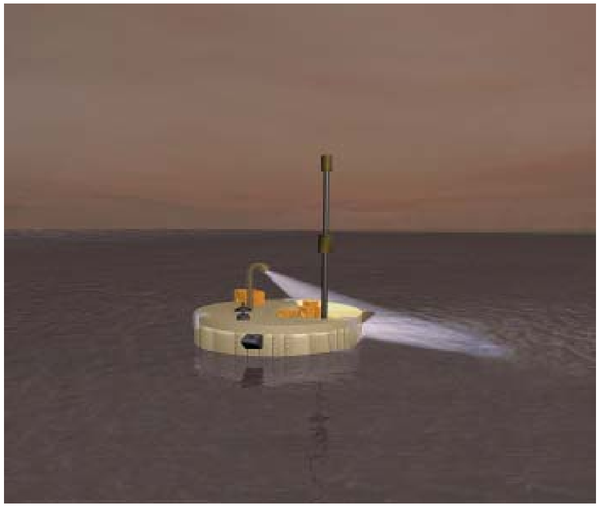


Dedicated Titan orbiter will be used also for relay after several Enceladus flybys



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

A short-lived Probe/Lander with liquid surface package will land in northern lake



Primary in situ science objectives

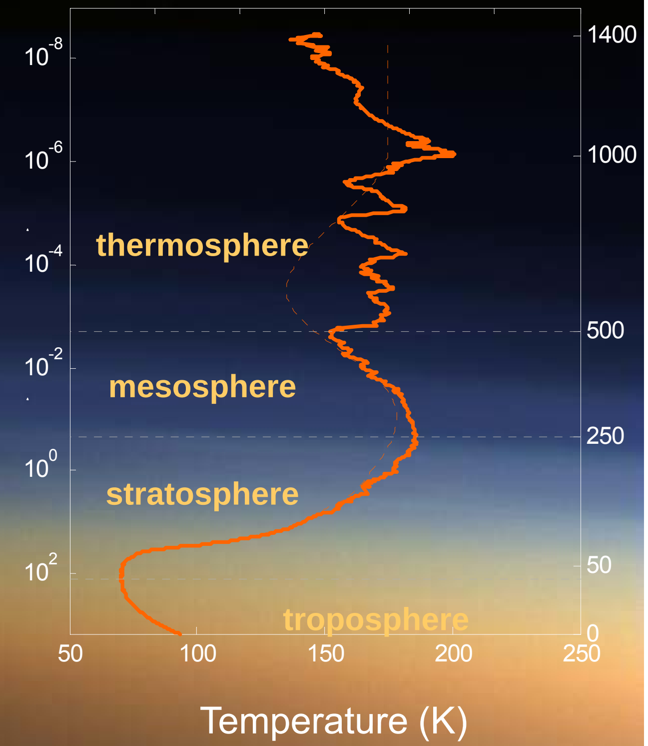
- Perform chemical analysis, both in the atmosphere and in the liquid of the lake, the latter to determine the kinds of chemical species that accumulate on the surface, to describe how far such complex reactions have advanced and define the rich inventory of complex organic molecules that are known or suspected to be present at the surface. New astrobiological insights will be delivered through the montgolfière and the lander investigations.
- Analyze the composition of the surface, in particular the liquid material and in context, the ice content in the surrounding areas.
- Study the forces that shape Titan's diverse landscape. This objective benefits from detailed investigation at a range of locations, a demanding requirement anywhere else, but that is uniquely straightforward at Titan with the montgolfière high-resolution cameras and subsurface-probing radar.

Titan's neutral atmosphere: *understand how it works*

- **Atmospheric structure & chemistry**

–Define locally the atmospheric parameters and properties (T, r, heat balance, electricity…) from the ground up to 1600 km during lander's entry and descent phases and the balloon's cruising phase

–Detremine local thermal and chemical structure of the lower atmosphere (0->130 km) at different latitudes and longitudes



- **Atmospheric dynamics**

–Determine locally the dynamics and heat balance of the atmosphere (circulation, tides, wave, eddies, turbulence, radiation, etc…)

- **Origin and evolution**

–Measure the abundances in noble gases and isotopic ratios in major species in order to constrain the origin and the evolution of the atmosphere though photochemistry , escape and ourgassing processes

- **Climate and alkanological cycle**

–Measure climatic (seasonal and long term) variations and CH4 and C2H6 abundances in the lower atmosphere and surface (compare with Huygens)

–Determine the meteorology (dynamics, rain, clouds, evaporation, atmospheric electricity, etc)

- **Quantify the coupling of the surface and atmosphere in terms of mass & energy balance**

Titan‘s surface and subsurface

.... In general

Surfaces are the boundary layer between interiors and atmospheres and record all processes passing this transition.

Surfaces and sub-surfaces are accessible for measurements and thus can constrain theoretic models

Zur Anzeige wird der QuickTime™
Dekompressor „TIFF (Unkomprimiert)“
benötigt.

The geological context will provide the current state of surfaces and sub-surfaces as well as their evolution as a function of time.

Basic surface science -> characterize the boundary layer

<u>atmosphere/surface interaction</u> (exchange of components)

<u>surface</u> (geology, composition, lateral exchange of materials)

<u>surface/sub-surface</u> (physical properties, exchange of components)

Titan's surface

Understand Titan's Geological System

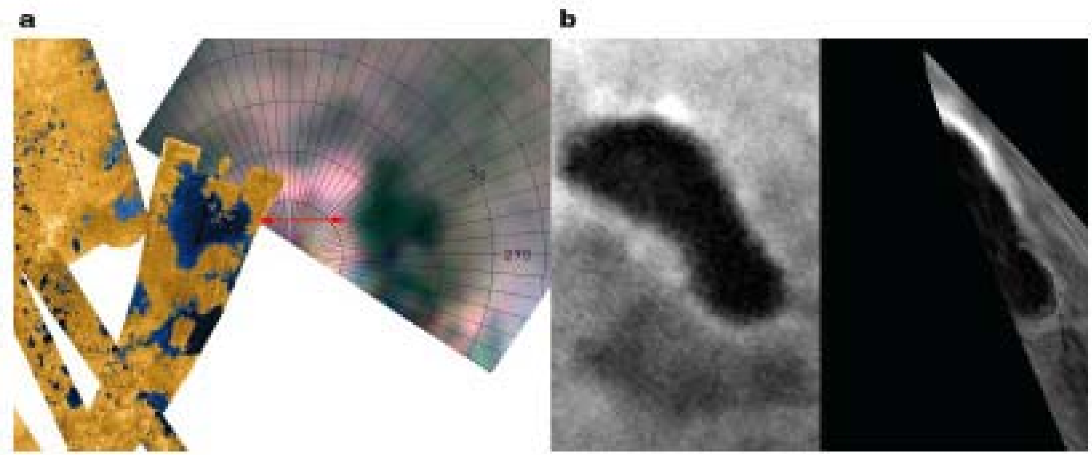
Map the surface at equatorial and mid-latitudes, as well as above the probe's landing location, at optical, near-IR, and radar wavelengths with resolution <2.5 m (and in stereo where possible).

Determine the surface material from high-resolution *in situ* measurements and compositional mapping of the surface from the montgolfière.

Zur Anzeige wird der QuickTime™ Dekompressor „TIFF (Unkomprimiert)“ benötigt.

Detect recent surface changes including cryovolcanic and alluvial flows, variation in lake levels, and evidence of tectonic and erosion processes.

Zur Anzeige wird der QuickTime™ Dekompressor „TIFF (Unkomprimiert)“ benötigt.



(Brown et al., Nature, July 2008)

Titan's surface

Understand Titan's Geological System

Map the surface at equatorial and mid-latitudes, as well as above the probe's landing location, at optical, near-IR, and radar wavelengths with resolution <2.5 m (and in stereo where possible).

Determine the surface material from high-resolution *in situ* measurements and compositional mapping of the surface from the montgolfière.

Zur Anzeige wird der QuickTime™ Dekompressor „TIFF (Unkomprimiert)“ benötigt.

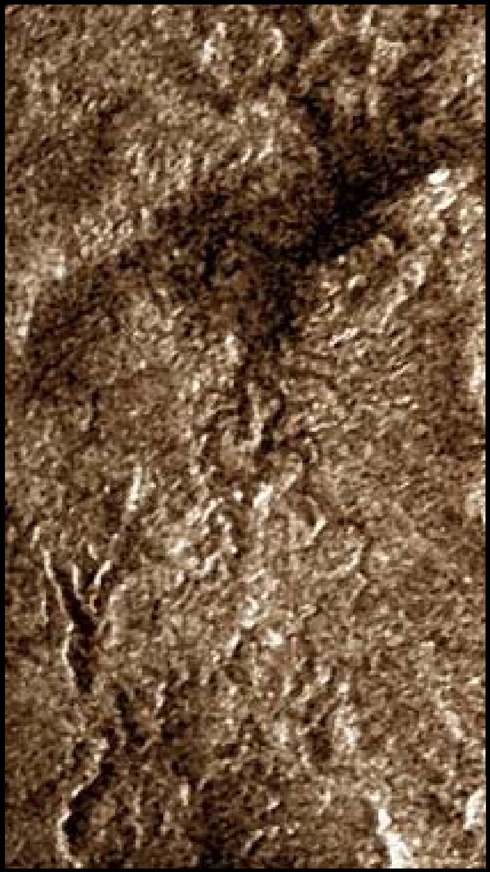
Detect recent surface changes including cryovolcanic and alluvial flows, variation in lake levels, and evidence of tectonic and erosion processes.

> need to obtain imaging and topography with resolutions <100 m;
-> need highest-resolutions for specific sites (< 1 m);
-> need global compositional mapping with resolutions < 1 km;
-> need to determine the depth and vertical structure of surface and subsurface deposits and methanifers

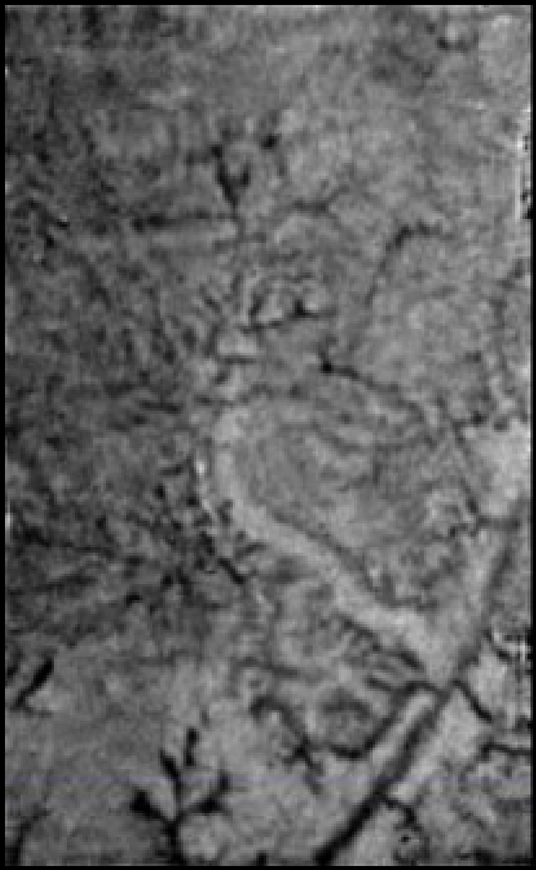
Zur Anzeige wird der QuickTime™ Dekompressor „TIFF (Unkomprimiert)“ benötigt.

-> need to obtain mapping with resolutions <100 m;
-> need highest-resolutions for specific sites (< 1 m);
-> need global compositional mapping with resolutions < 1 km;
-> need to determine the depth and vertical structure of surface and subsurface deposits and methanofers;
-> need measures of the gravity field

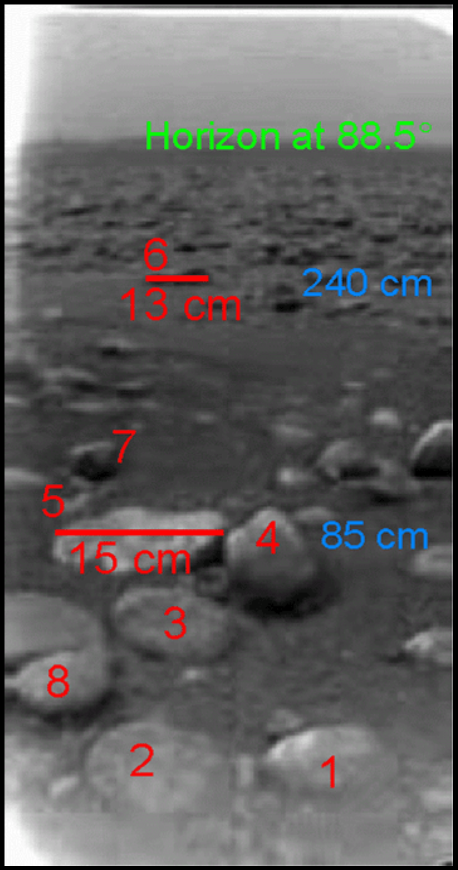
Titan: A mystery unveiled but not solved



500 meter resolution
Broad fluvial channels
(Cassini Radar)

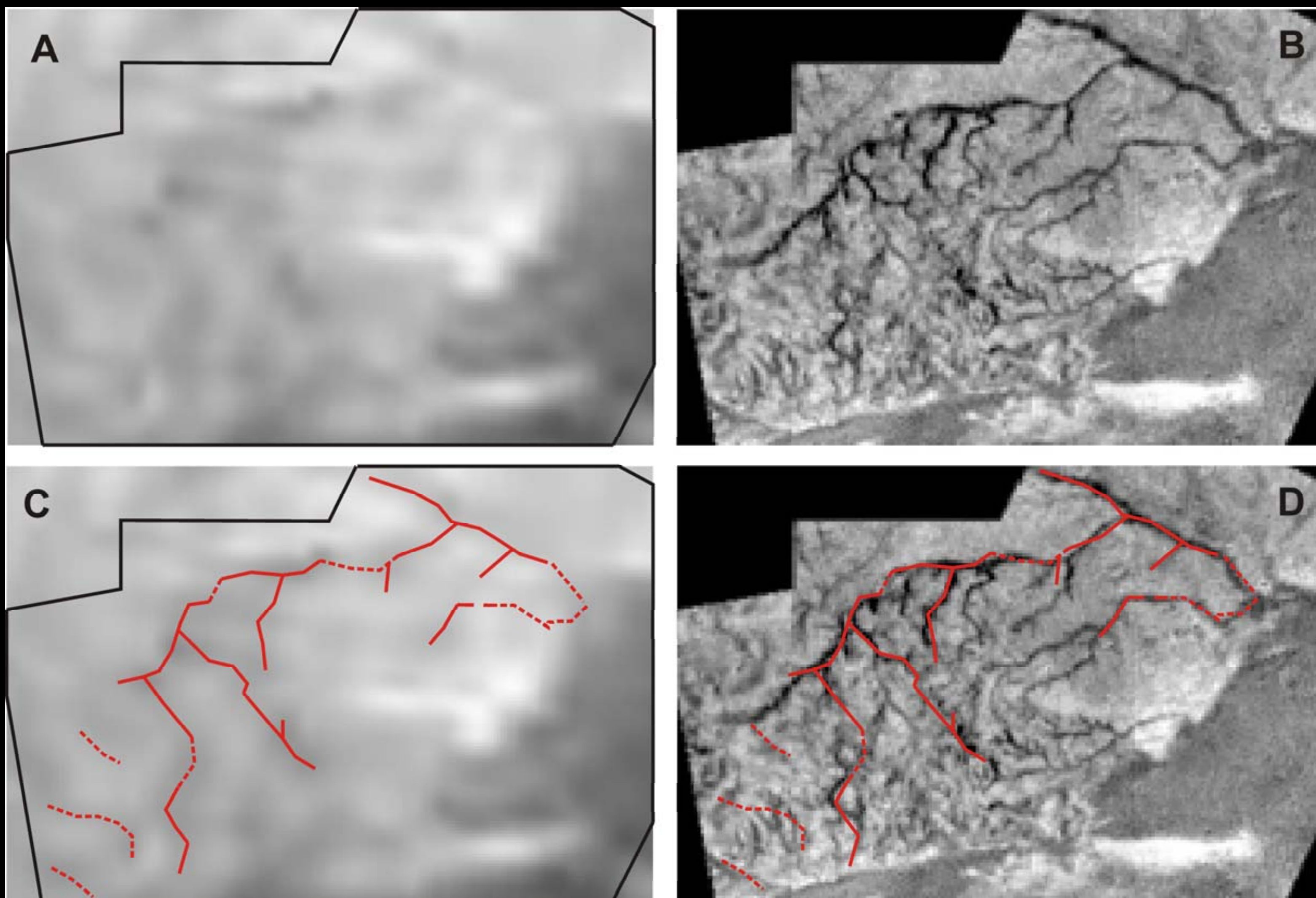


50 meter resolution
Small-scale sapping
(Huygens DISR)



5 cm resolution
Fluvial outflow
(Huygens DISR)

Erosion on Titan



HLS DISR 01/14/2005 at VIMS Resolution

Science Objectives: Titan Surface

Science Goals	Observables	Lander/Balloon Gondola	Orbiter
Geology Characterize geologic (volcanism, tectonism, impact cratering, stratigraphy) and geomorphologic (erosion, sediment transport, aeolian, fluvial, marin) surface processes	• IR imaging (global, regional, local) • Altimetry	• IR imager (Balloon) • Radar altimeter (Balloon) • Stereo Imaging (Lander/Balloon)	• NIR imager and spectrometer • Radar and altimeter
Surface Composition Characterize composition (organics, volatiles, condensates, searching for NH_3) and physical properties of the surface → relation to geological and geomorphological surface processes	• in-situ analysis • IR spectral mapping (global, regional, local) • Radiometer	• close up imager • IR imaging spectrometer (Balloon Gondola) •In-situ Analysis (Lander)	• NIR – MIR imaging spectrometer

Zur Anzeige wird der QuickTime™ Dekompressor „TIFF (Unkomprimiert)“ benötigt.

Instrument Request for
GEOLOGY and GEOMORPHOLOGY

IR-imaging in
CH_4 windows : at least 1.3, 2 and 5 µm
resolution: Orbit 50 m @ 1500 km
Balloon 5m @ 15 km
Lander 1mm - 1m @ 1m - 1.5 km
S/N > 100

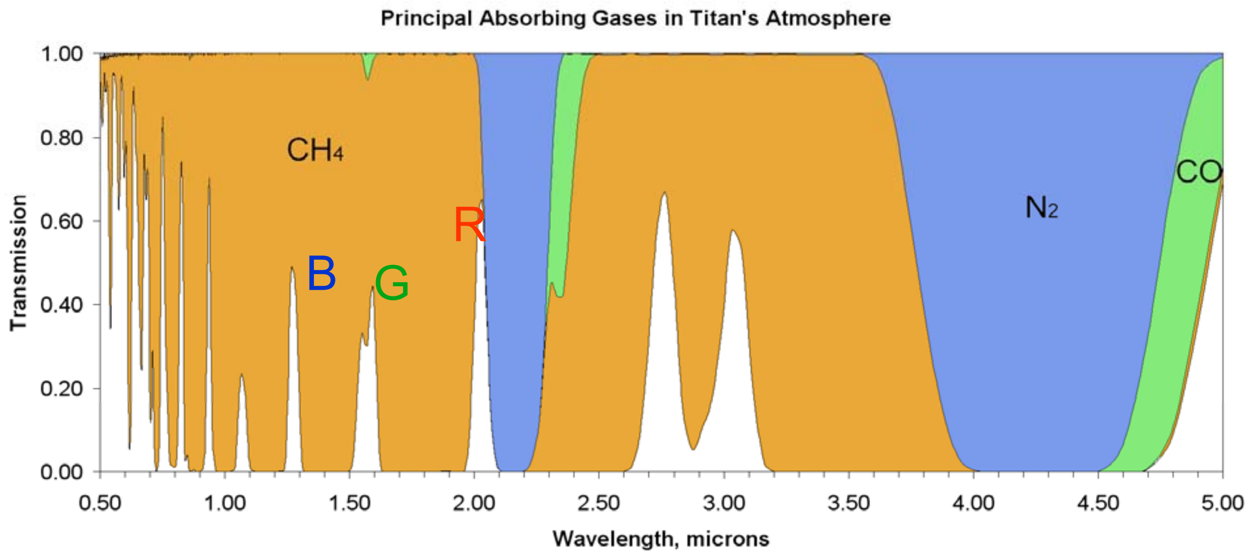
Zur Anzeige wird der QuickTime™
Dekompressor „TIFF (Unkomprimiert)“
benötigt.

options: stereo capabilities
limb sounding capabilities

additional science capabilities:
Mapping spectral units
Estimation of cloud altitude and haze distribution
(cross calibration from orbit, balloon and ground)

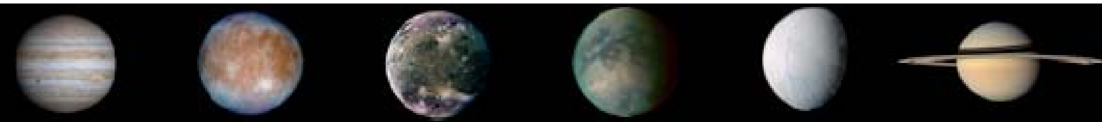
Instrument Request for COMPOSITION

Near-IR-spectrometer: Wavelength range : near-IR (1-5.6 μ)

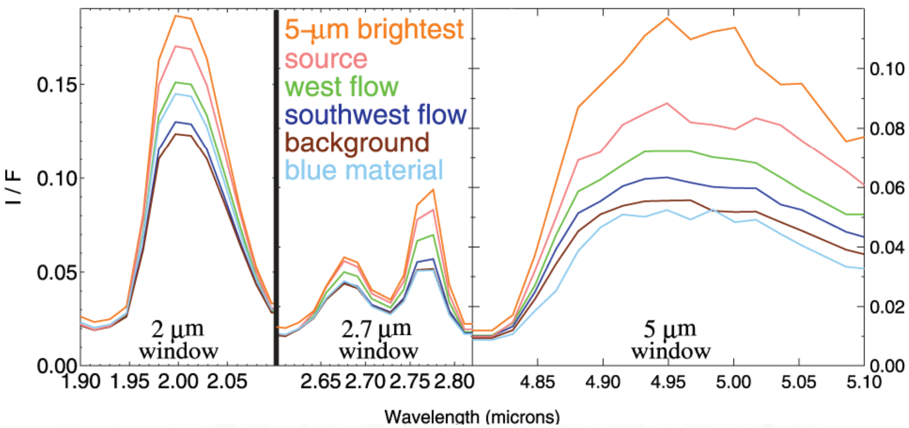


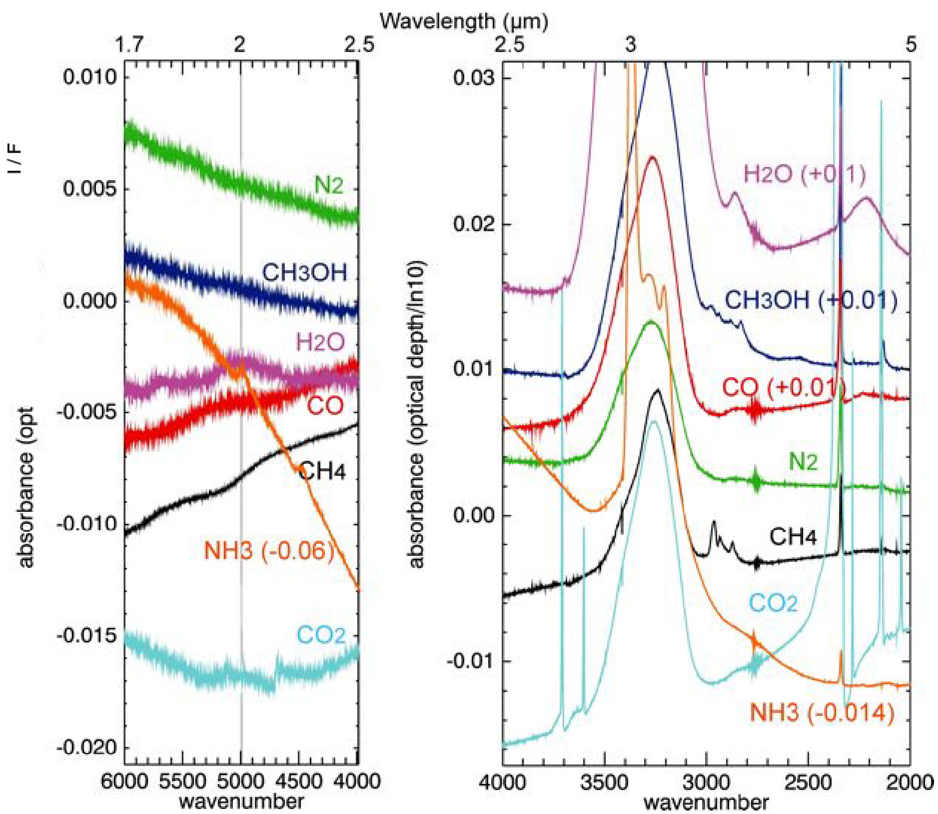
Species	IUPAC name	Common name	Molar mass (g mol^{-1})[b]
C_2H_4	ethene	ethylene	28.0532
C_2H_2	ethyne	acetylene	26.0373
CH_3C_2H	propyne	methyl-acetylene	40.0639
C_4H_2	1,3-butadiyne	diacetylene	50.0587
C_6H_6	cyclohexatriene	benzene	78.1118
HCN	formonitrile	cyanide	27.0254
CH_2NH	methyleneimine	-	29.0413
CH_3CN	ethanenitrile	acetonitrile	41.0520
C_2H_3CN	2-propenenitrile	acrylonitrile	53.0627
HC_3N	2-propynenitrile	cyanoacetylene	51.0468
C_2N_2	ethanedinitrile	cyanogen	52.0349
C_4N_2	2-butynedinitrile	dicyanoacetylene	76.0563

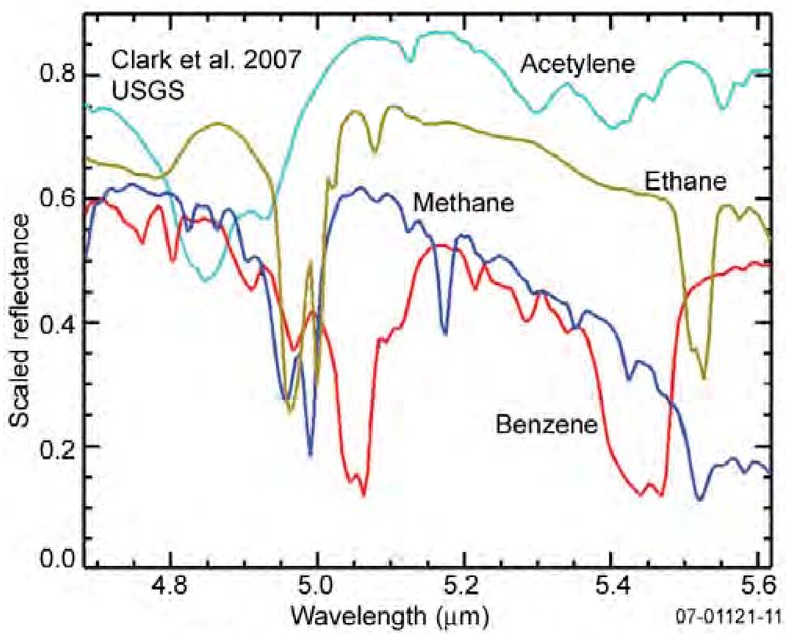
Zur Anzeige wird der QuickTime™ Dekompressor „TIFF (Unkomprimiert)“ benötigt.



λ resolution & range



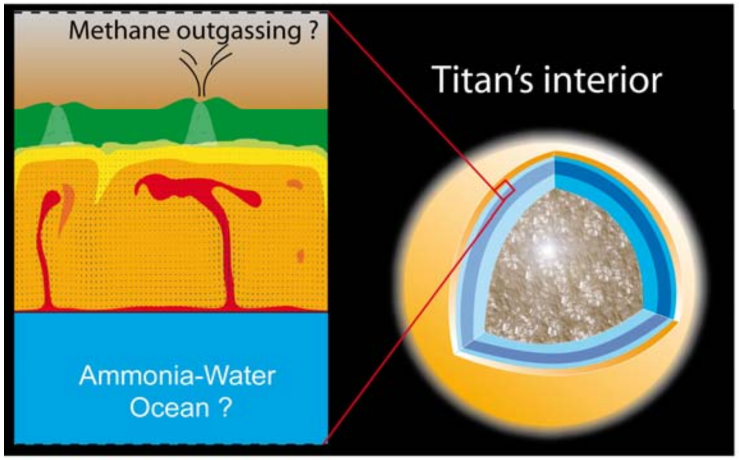




Reflectance spectra of organic ices

Interior & early evolution Science Goals

- *Present interior structure (subsurface profiles at very high resolution ~few hundred meters spot size and a vertical resolution < 3 m)* to
    - detect sedimentary processes and to reconstruct their history;
    - detect structures of tectonic, impact, or cryovolcanic origin, and correlate these structures with the surface morphology for understanding the geologic history;
    - detect subsurface structures of cryovolcanic origin (e.g. channels, chambers, etc.).
- *Heat sources, cryovolcanism and eruptive processes*
    - Intrinsic heatflow, near-surface thermal gradient.
    - Delivery of nitrogen and methane to the surface.
    - Geochemical and geophysical constraints on bulk composition and internal differentiation
- *Interior-surface interactions*
    - Size and state of the rocky core, structure of the crust and depth of the “methanifer”,
    - sources of atmospheric methane
    - What is the crustal history?
- *Early Evolution*
    - Noble gas isotopic ratios (Ar, Kr, Xe, Ne) of surface materials and aerosol depositions, $^{14}N/^{15}N$ isotopic ratios, presence of H_2, N_2 or CO at mass 28, presence of NH_3, gas/dust ratio of plumes.



- *Detect and measure the depth of shallow subsurface reservoirs of liquid (hydrocarbons) where the probe lands*
- *Titan’s spin rate, tidally-induced deformation, magnetic field and seismicity* ***(“geosaucer”)***
    - Depth to liquid water reservoirs, radial extent and electrical conductivity.
    - Lateral variations in thickness and rigidity of the overlying icy crust.

Exploring Titan's subsurface with a « geosaucer » on HEAT SHIELD

Additional long-term (1 month, possibly more) investigations relevant to geophysical aspects of Titan's surface and interior could be performed thanks to an Instrumented Heat Shield of the montgolfière which would carry a geophysical package (to be studied in the next phase) allowing for a number of additional investigations to be performed, including measurements of

QuickTime™ et un
décompresseur TIFF (non compressé)
sont requis pour visionner cette image.

a) the induced and inducing magnetic fields of Titan and their variation as Titan orbits Saturn with a magnetometer (additional to the balloon one), providing clues on the magnetic environment and possibly on the location and thickness of Titan's internal ocean;

b) the tidally-induced solid crustal displacements and forced librations of the outer ice shell through the radio science equipment;

c) the level of seismic activity on the surface, the structure of the outer ice shell and hence the internal ocean with a micro-seismometer (Lognonné 2005);

d) the environment through an acoustic experiment.

Science Implementation for the TSSM/ISE

Montgolfiere Science Traceability Matrix flows from the three goals to measurements

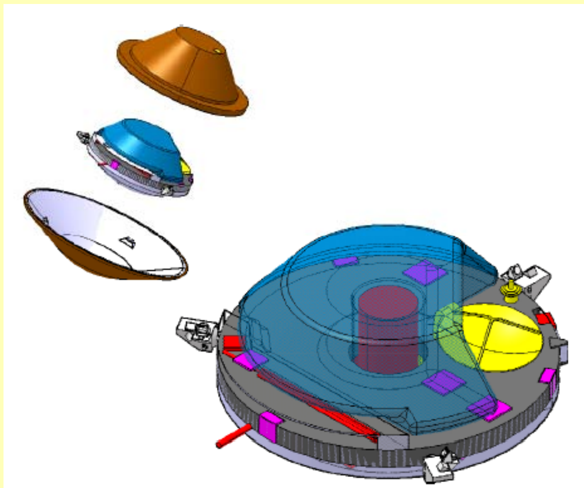
MISSION GOALS	SCIENCE OBJECTIVES	SCIENCE INVESTIGATIONS	REQUIRED MEASUREMENTS/ DETERMINATION	PLANNING MEASUREMENT APPROACH	PLAN. INSTR.	DATA PRODUCTS	MISSION REQUIREMENTS
			M2: Global electric circuit and fair-weather electric field in the range from 0–10 kHz. With a height resolution of 1 km				
			M3: Extra low and low frequency (ELF-VLF) magnetic components of the atmospheric				
				optical sensors	B	spectra	
				A1: Relaxation probe to measure the conductivity of all charged species	TEEP-B	Time series of conductivity (all charged species)	Time series of conductivity (all charged species)
				A2: Mutual impedance probe which measures the conductivity of electronics only	TEEP-B	Amplitude and phase of electric signal	Amplitude and phase of electric signal
				A1: Use the infrared images at different incidence angles to	BIS	Infrared maps of the surface between 1 and 5.6 µm with a spectral sampling of 10.5	Adapt the observation strategy to the motion of the montgolfière. Coordination with VISTA-B for

SCIENCE OBJECTIVES	SCIENCE INVESTIGATIONS	REQUIRED MEASUREMENTS/ DETERMINATION	PLANNING MEASUREMENT APPROACH	PLAN. INSTR.	DATA PRODUCTS	MISSION REQUIREMENTS
O5: Characterize the amount of liquid on the Titan surface today.	I3: Determine surface composition that might reveal the presence of liquids.	M1: Optical maps in the methane windows at 2.5 m resolution	A1: Use the infrared images at different incidence angles to determine the nature of the surface (liquid or solid)	BIS	Infrared maps of the surface between 1 and 5.6 µm with a spectral sampling of 10.5 nm.	Adapt the observation strategy to the motion of the montgolfière. Coordination with VISTA-B for context is required.
		M2: Precipitation rate, solid or liquid nature of precipitation	A1: *In situ* monitoring of T and P conditions with reference to the altitude level	ASI/ MET	T and P time series	1 km and 5° attitude knowledge of montgolfière
			A3: *In situ* observations at all wavelengths.	VISTA-B	1360 x1024 multispectral images 48°FOV	Precise location of montgolfière to 1 km and 5° attitude knowledge of montgolfière

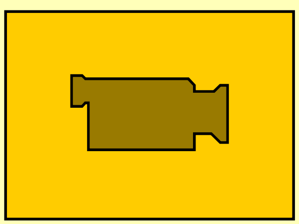
SCIENCE OBJECTIVES	SCIENCE INVESTIGATIONS
O5: Characterize the amount of liquid on the Titan surface today.	**I3:** Determine surface composition that might reveal the presence of liquids.

REQUIRED MEASUREMENTS/ DETERMINATION	PLANNING MEASUREMENT APPROACH	PLAN. INSTR.	DATA PRODUCTS	MISSION REQUIREMENTS
M1: Optical maps in the methane windows at 2.5 m resolution	**A1:** Use the infrared images at different incidence angles to determine the nature of the surface (liquid or solid)	BIS	Infrared maps of the surface between 1 and 5.6 µm with a spectral sampling of 10.5 nm.	Adapt the observation strategy to the motion of the montgolfière. Coordination with VISTA-B for context is required.
M2: Precipitation rate, solid or liquid nature of precipitation	**A1:** *In situ* monitoring of T and P conditions with reference to the altitude level	ASI/ MET	T and P time series	1 km and 5° attitude knowledge of montgolfière
	A3: *In situ* observations at all wavelengths.	VISTA-B	1360 x1024 multispectral images 48°FOV	Precise location of montgolfière to 1 km and 5° attitude knowledge of montgolfière

montgolfière Scientific Payload



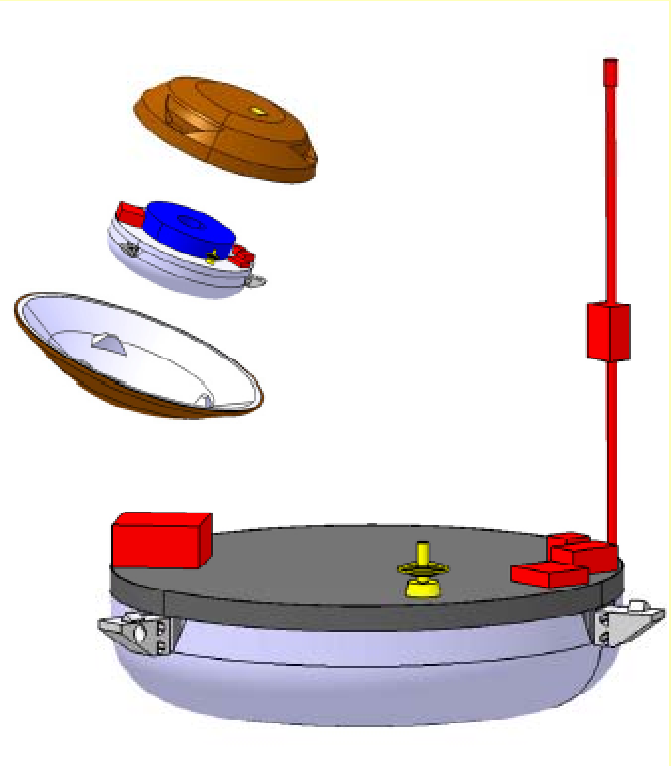
Conceptual design
of the Montgolfière



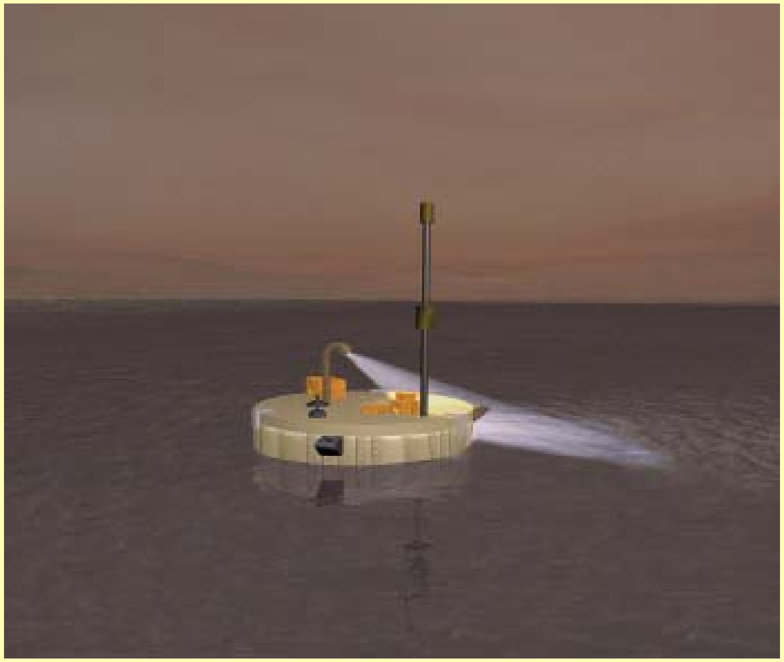
montgolfière floating over the
equatorial region of Titan

Model instruments in the planning payload on the montgolfière which will circumnavigate Titan at ~10 km altitude at mid-latitudes for 6 months

Instrument	Description	Science Contributions	Mass (kg)
BIS	Balloon Imaging Spectrometer (1–5.6 μm).	Mapping for troposphere and surface composition at 2.5 m resolution	3.0
VISTA-B	Visual Imaging System with two wide angle stereo cameras & one narrow angle camera.	Detailed geomorphology at 1 m resolution	2.0
ASI/MET	Atmospheric Structure Instrument and Meteorological Package.	Record atmosphere characteristics & determine wind velocities in the equatorial troposphere	1.0
TEEP-B	Titan Electronic Environment Package	Measure electric field in the troposphere (0-10 kHz) and determine connection with weather.	1.0
TRS	> 150 MHz radar sounder	Detection of shallow reservoirs of hydrocarbons, depth of icy crust and better than 10 m resolution stratigraphic of geological features.	8.0
TMCA	1-600 Da Mass spectrometer	Analysis of aerosols and determination of noble gases concentration and ethane/methane ratios in the troposphere	6.0
MAG	Magnetometer	Separate internal and external sources of the field and determine whether Titan has an intrinsic and/or induced magnetic field.	0.5
MRST	Radio Science using s/c telecom system	Precision tracking of the montgolfière	0.0
			TOTAL 21.5



Conceptual design of the lander in floating configuration



Lander in deployed configuration as it would be floating in Kraken Mare

Lander Scientific Payload

Model instruments in the planning payload for the probe, which will land in a northern Titan lake.

Instrument	Description	Science Contributions	Mass (kg)
TLCA	Titan Lander Chemical Analyzer with 2-dimensional gas chromatographic columns and TOF mass spectrometer. Dedicated isotope mass spectrometer.	Perform isotopic measurements, determination of the amount of noble gases and analysis of complex organic molecules up to 10,000 Da.	23.0
TiPI	Titan Probe Imager using Saturn shine and a lamp	Provide context images and views of the lake surface.	1.0
ASI/MET-TEEP	Atmospheric Structure Instrument and Meteorological Package including electric measurements	Characterize the atmosphere during the descent and at the surface of the lake and to reconstruct the trajectory of the lander during the descent.	1.5
SPP	Surface properties package	Characterize the physical properties of the liquid, depth of the lake and the magnetic signal at the landing site.	1.5
LRST	Radio Science using spacecraft telecom system	Precision tracking of lander	0

Total = 27.0 kg

Ile Flottante:

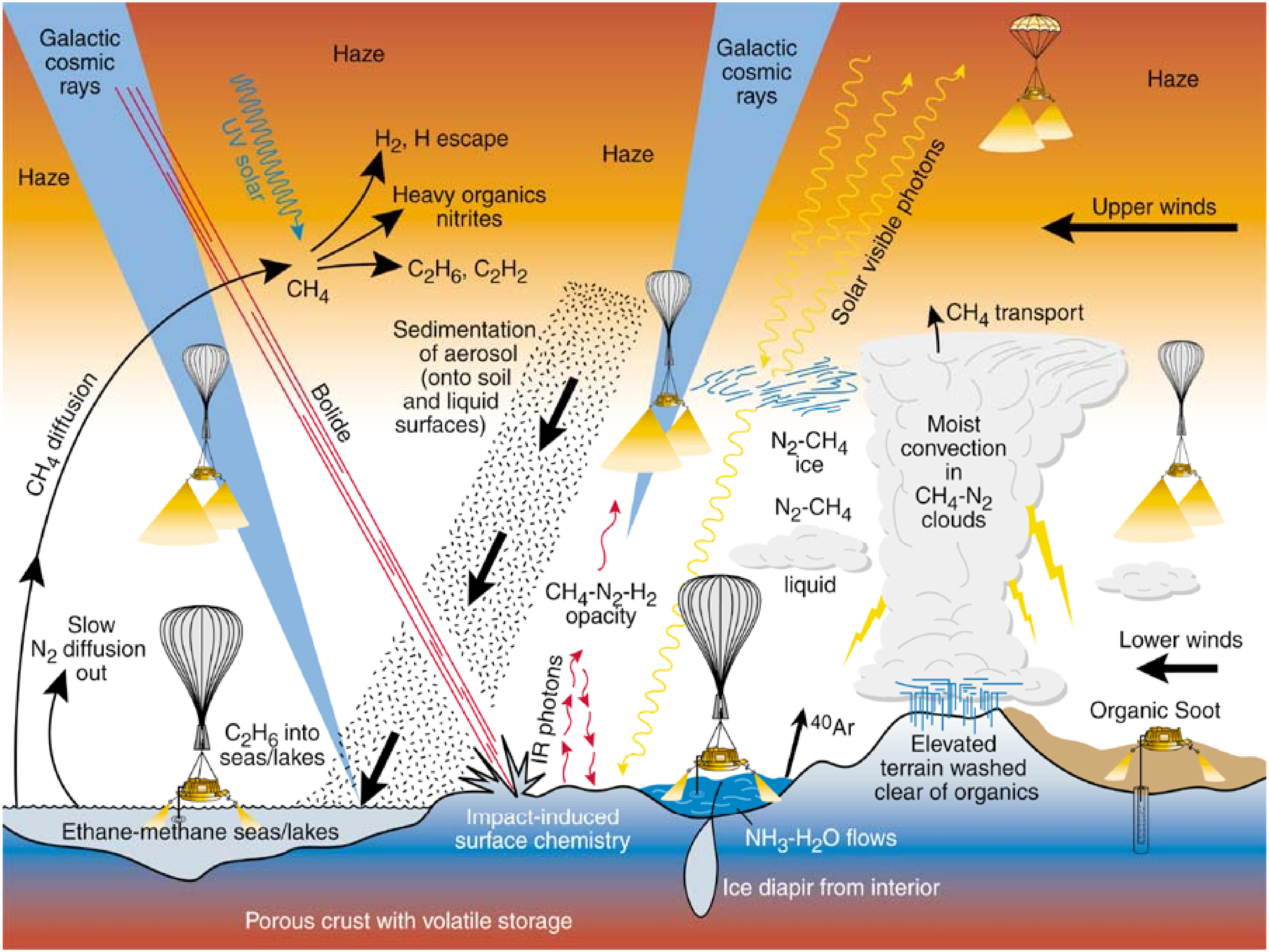
a floating island on Titan's Kraken Mare

http://frenchdesire.com/recipes/ile/

So, as I was told by french people, this desert, called "Floating island", is trully french one :) Of course, I had to taste it and I did so…Yeah, it's delicious! But what is it?
This 'floating island' desert is one of the great desserts of classic French cuisine with its light meringue floating on a sea of custard sauce.

Top 10 *in situ* first-time investigations

1. First direct *in situ* exploration of the northern seas of Titan—the only known surface seas in the solar system besides Earth.
2. Detailed images of thousands of kilometers of Titan terrain, with image quality comparable to that of Huygens during its descent will test the extent of fluvial erosion on Titan at Huygens spatial scales, well matched to the scales mapped globally by the orbiter.
3. First analysis of the detailed sedimentary record of organic deposits and crustal ice geology on Titan, including the search for porous environments ("caverns measureless to man") hinted at by Cassini on Xanadu.
4. Direct test through *in situ* meteorological measurements of whether the large lakes and seas control the global methane humidity—key to the methane cycle.
5. First *in situ* sampling of the winter polar environment on Titan—vastly different from the equatorial atmosphere explored by Huygens.
6. Compositional mapping of the surface at scales sufficient to identify materials deposited by fluvial, aeolian, tectonic, impact, and/or cryovolcanic processes.
7. First search for a permanent magnetic field unimpeded by Titan's ionosphere.
8. First direct search for a subsurface water ocean suggested by Cassini.
9. First direct, prolonged exploration of Titan's complex lower atmosphere winds.
10. Exploration of the complex organic chemistry in the lower atmosphere and surface liquid reservoirs discovered at high altitude by Cassini.



Galactic cosmic rays
Haze
UV solar
H$_2$, H escape
Heavy organics nitrites
C_2H_6, C_2H_2
CH_4
Haze
Haze
Galactic cosmic rays
Solar visible photons
Haze
Upper winds
CH_4 transport
Sedimentation of aerosol (onto soil and liquid surfaces)
CH_4 diffusion
Bolide
N_2-CH_4 ice
Moist convection in CH_4-N_2 clouds
N_2-CH_4
liquid
CH_4-N_2-H_2 opacity
Slow N_2 diffusion out
IR photons
Lower winds
C_2H_6 into seas/lakes
^{40}Ar
Organic Soot
Elevated terrain washed clear of organics
Ethane-methane seas/lakes
Impact-induced surface chemistry
NH_3-H_2O flows
Ice diapir from interior
Porous crust with volatile storage