IPPW-11 Short Course

Science Highlights, Experience and Future Goals : Titan

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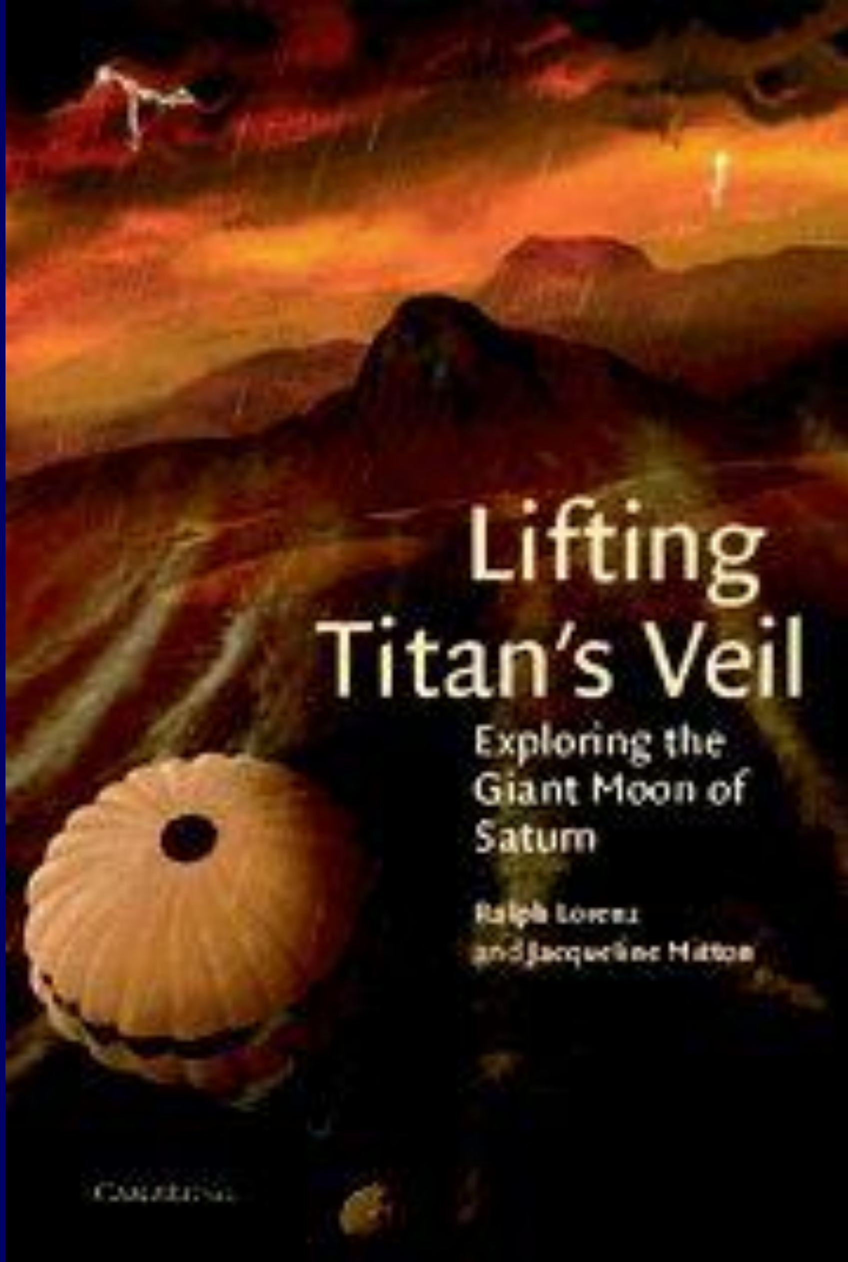
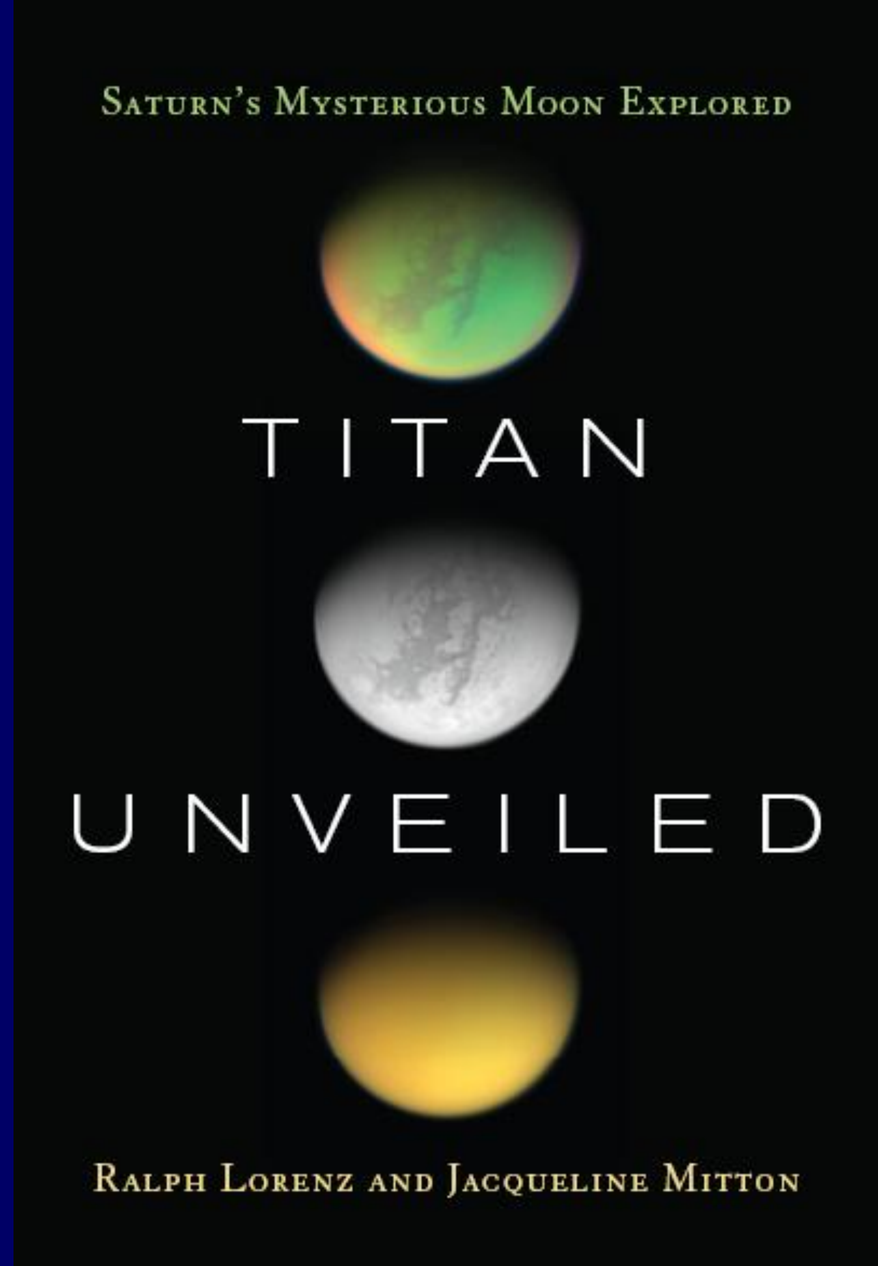
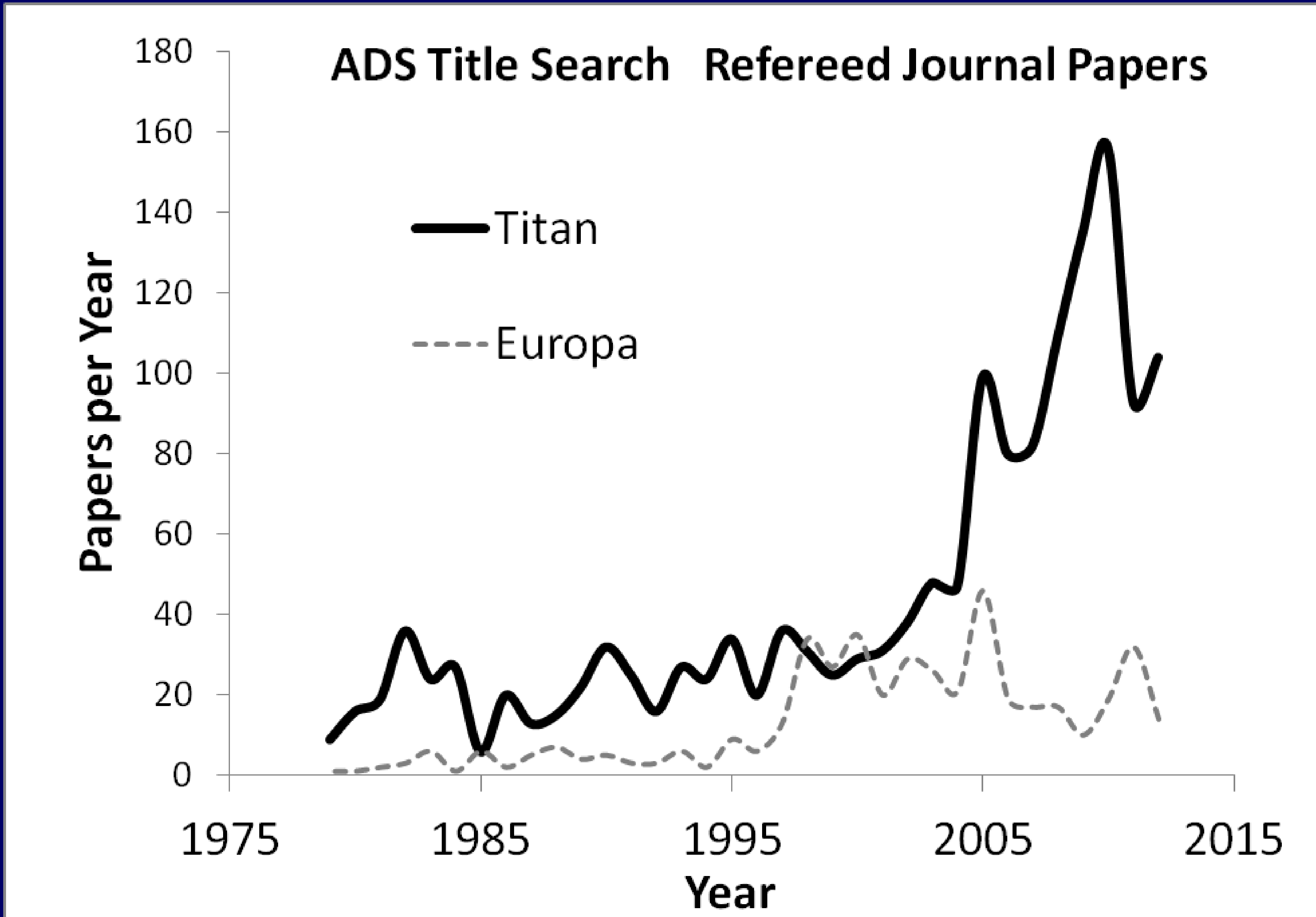
Johns Hopkins Applied Physics Laboratory



CUP, 2002



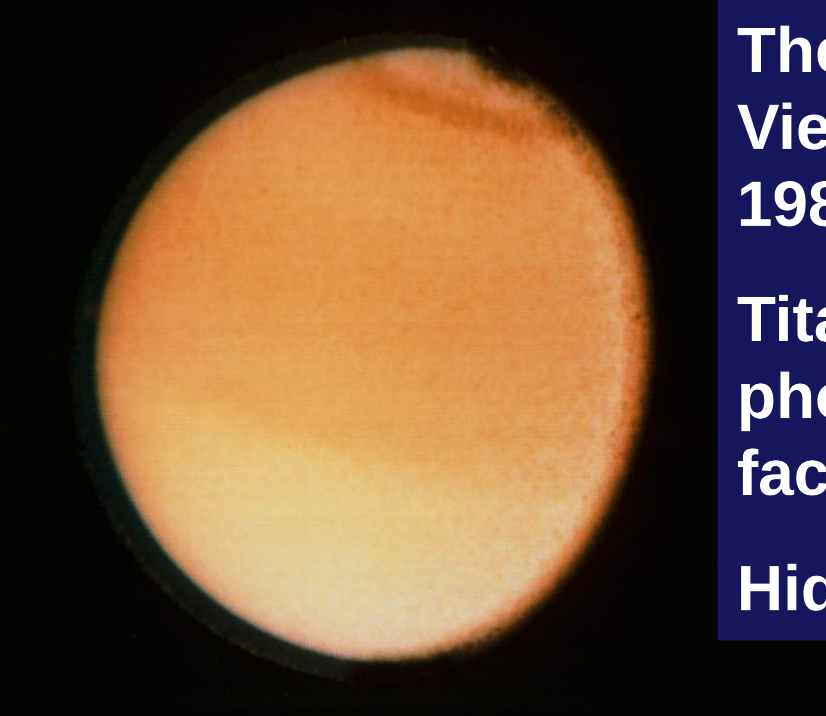
PUP, 2008, 2010



ADS Title Search Refereed Journal Papers
Titan
Europa
Papers per Year
Year
0
20
40
60
80
100
120
140
160
180
1975
1985
1995
2005
2015

Titan's Surface-Atmosphere Interactions give many similarities with the terrestrial planets : Titan is an outstanding laboratory for comparative planetology (even though not formally a planet).

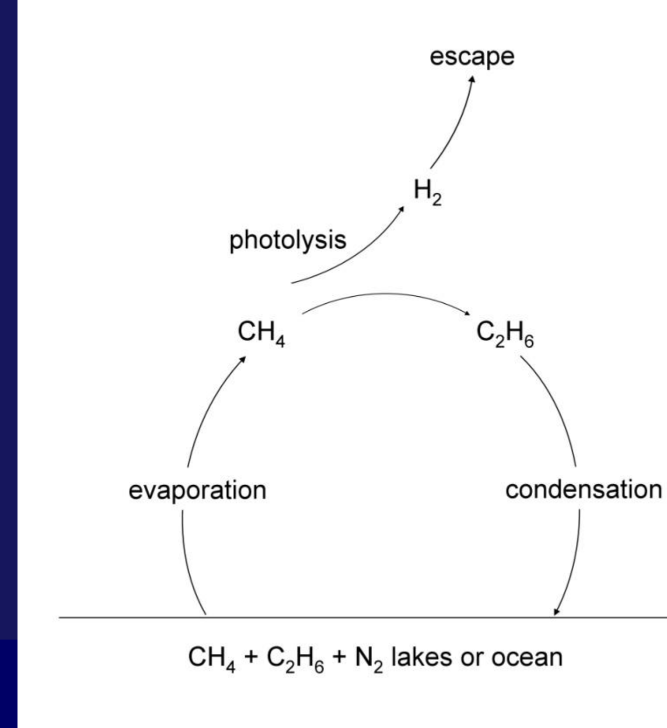
An active hydrology like Earth's, atmospheric dynamics like Venus and Mars, seasons like Earth and Mars, etc.

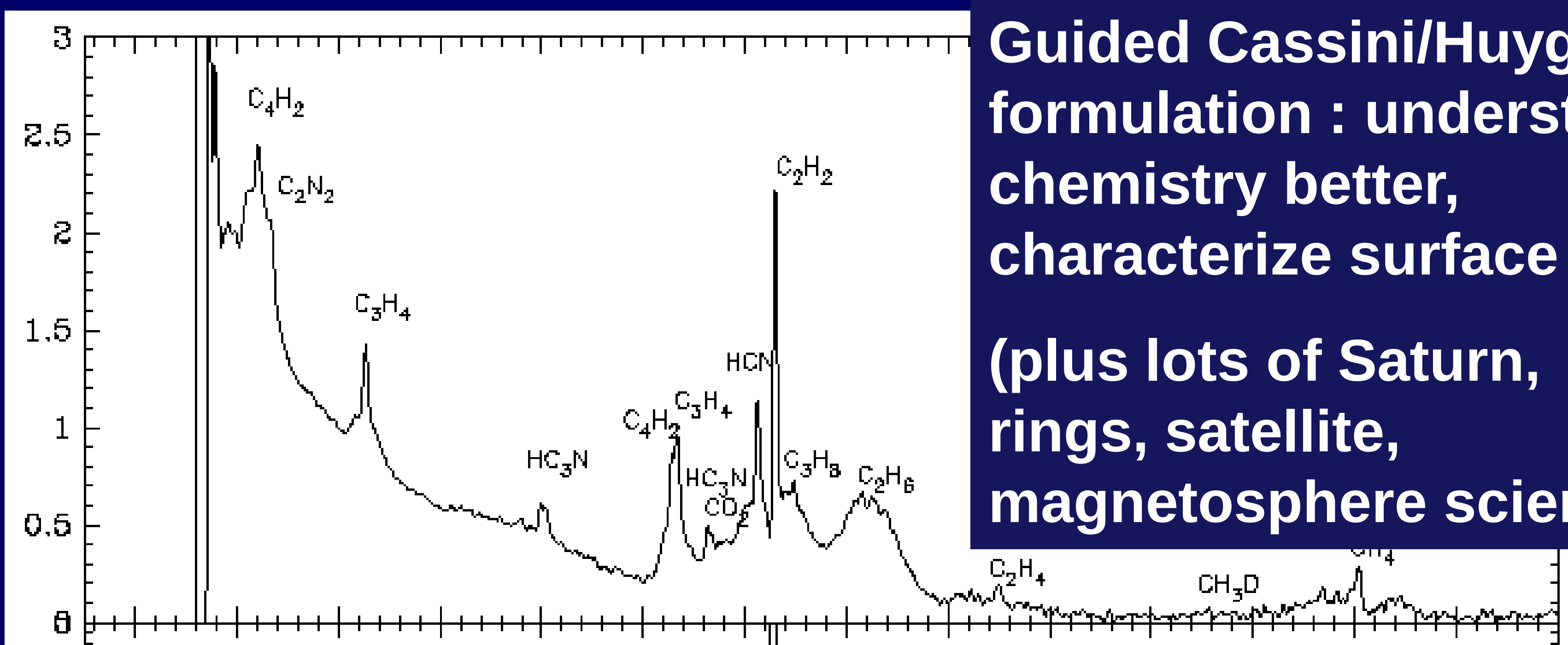


The Voyager View - early 1980s

Titan as a photochemical factory

Hidden surface

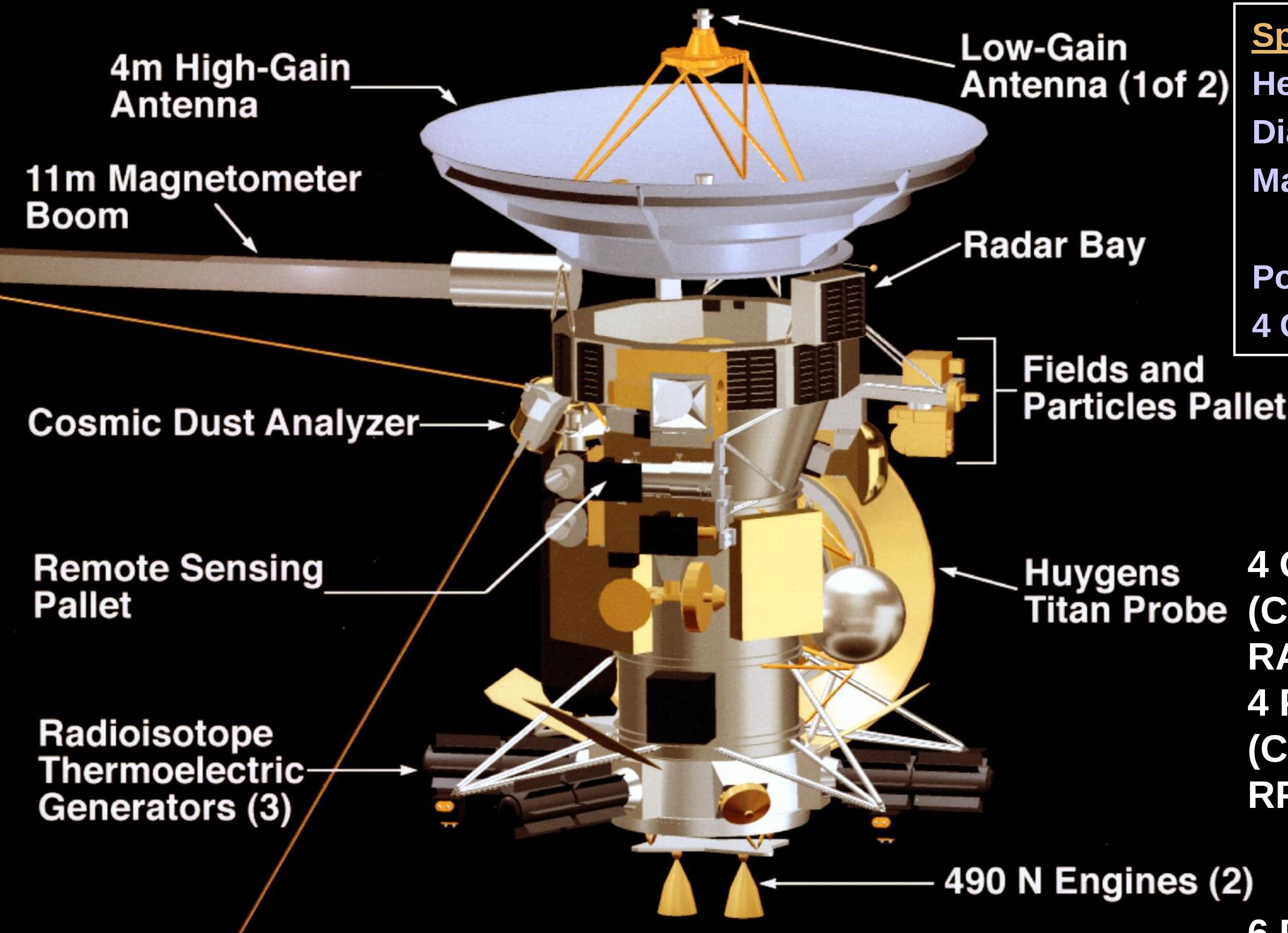




Guided Cassini/Huygens formulation : understand chemistry better, characterize surface

(plus lots of Saturn, rings, satellite, magnetosphere science)

Cassini Spacecraft



Spacecraft Specs

Height: 6.8 m (22 ft)

Diameter: 4 m (13 ft)

Mass: 2500 kg (2.8 tons)

(fueled): 5600 kg (6 tons)

Power: 700 Watts at SOI

4 Gb solid state recorder

4 Optical instruments (CIRS, ISS, VIMS, UVIS)
RADAR + Radio Science
4 Particles & Fields (CDA, MIMI, CAPS, RPWS)

6 Probe instruments (GCMS, DISR, ASI, SSP, ACP, DWE)

France

Aerospatiale
Prime Contractor
Aerothermodynamics
Thermal protection
Dassault/Pyrospace
Pyro devices
Framatomb
Umbilical connectors

Germany

Dasa
System Integration and Test
Thermal control

Finland

Ylinen
Radar Altmeter

United Kingdom

Logica
Flight Software
MBA
Descent Subsystem
IGG
Parts Procurement
Irvin
Parachutes

Belgium

ETCA
Power Subsystem

Sweden

Saab/Ericsson
Probe Transmit Antennae
Receiver Front End
Esrange
Balloon drop test

Ireland

Captec
Independent S/W validation

USA

Systron Donner
Accelerometers
Alliant
Batteries
Inertia Switch
G Switch
UPCO
PDD cartridge

Denmark

Terma
DC/DC converters
Mission timer unit

Norway

NFT
System EGSE
DNV
Reliability Analysis
Cost Analysis
Documentation

Spain

CASA
Internal Structure
Harness
Tecnologica
Parts procurement
CRISA
Mass dummies
Eyser
Project control

Italy

Laben
Data handling subsystem
Alenia Spazio
Communication subsystem
Probe Data Relay Subsystem
(PDRS)

Switzerland

Contraves/Vevey
Front shield structure
Back cover structure
Mechanisms
CIR
P/L Interface simulator

Austria

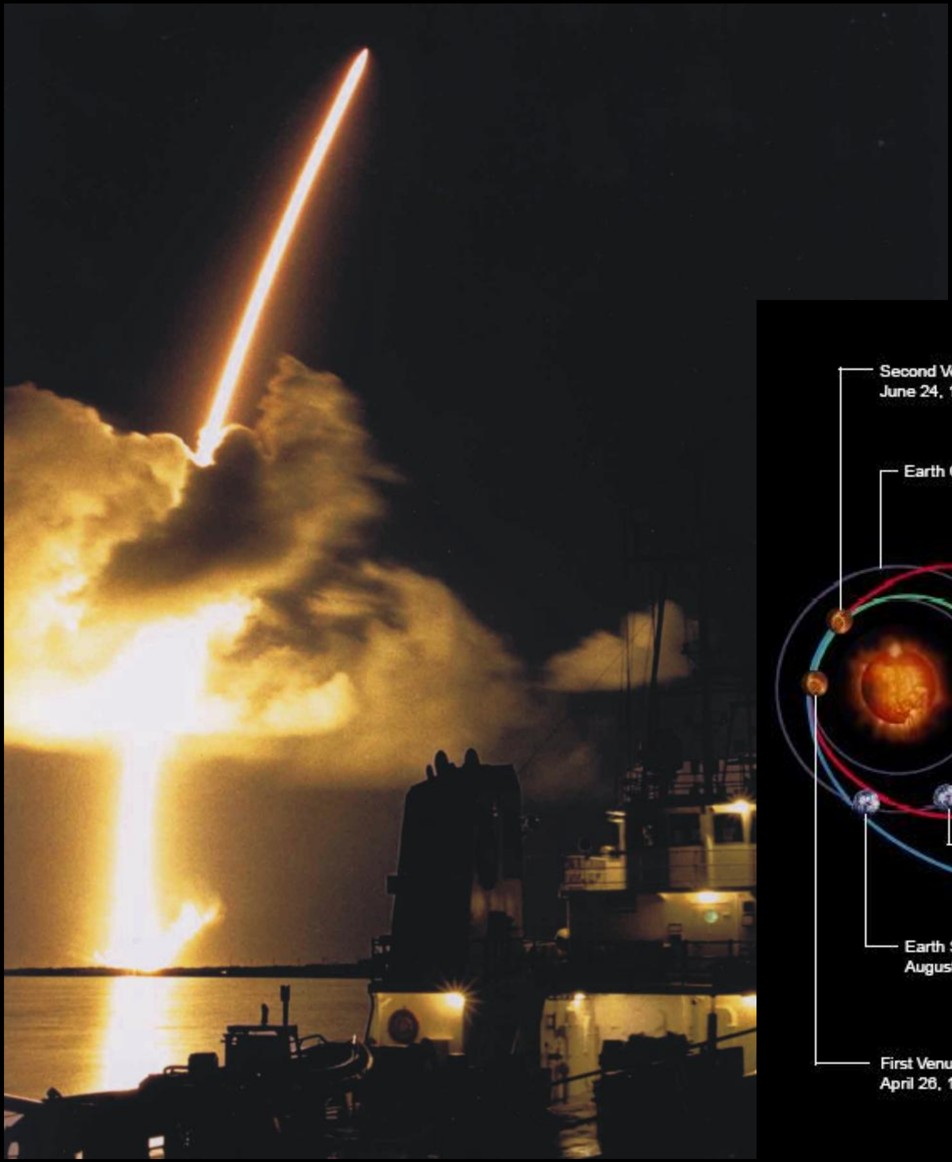
ORS
MGSE
Thermal blanket
Swivel
Schrack
PDRS EGSE

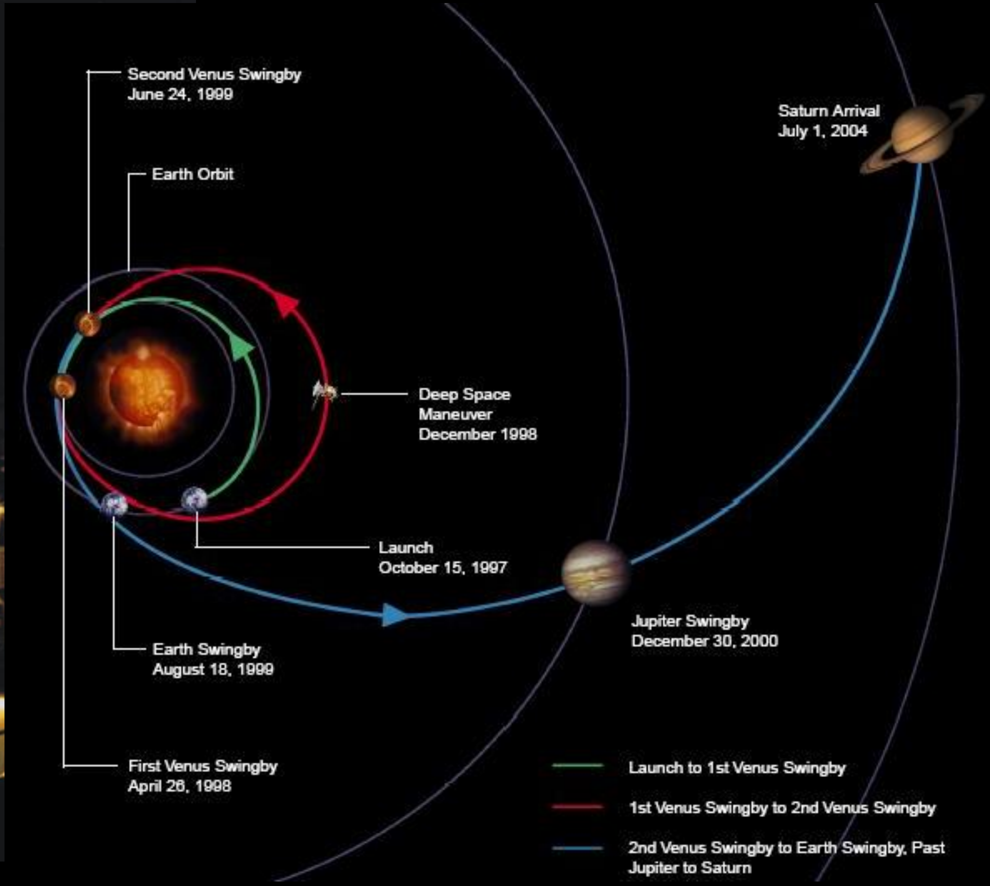
Netherlands

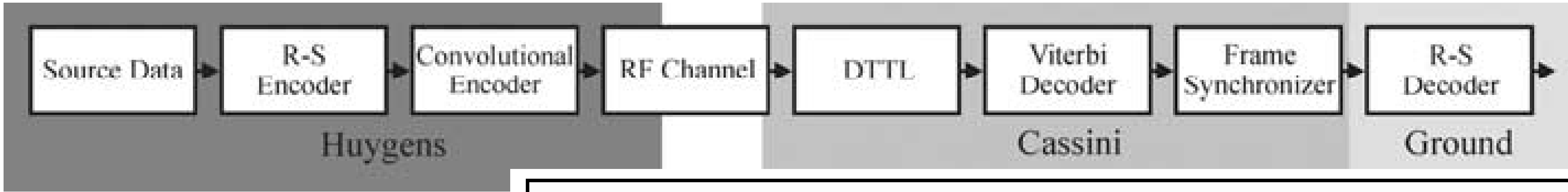
Fokker
Balloon drop test model

Launched on October 15, 1997 from KSC

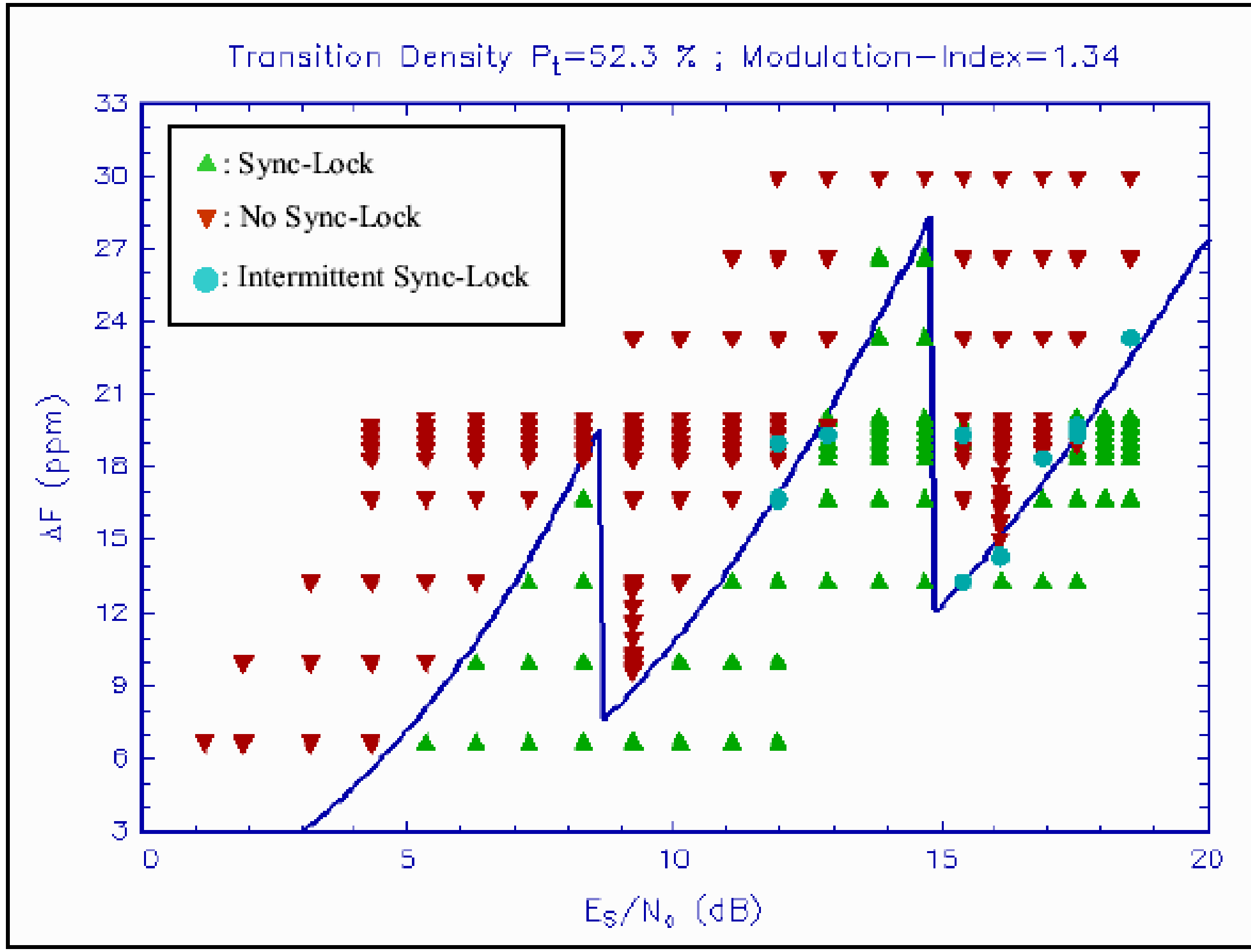
7 Year cruise on VVEJGA trajectory

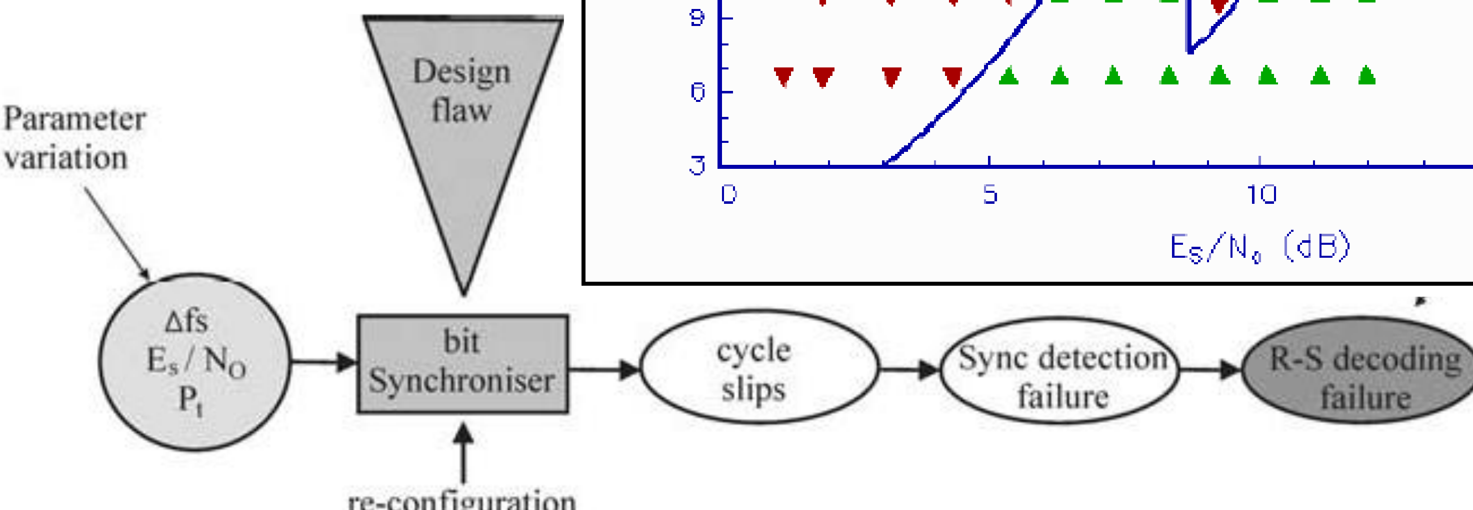


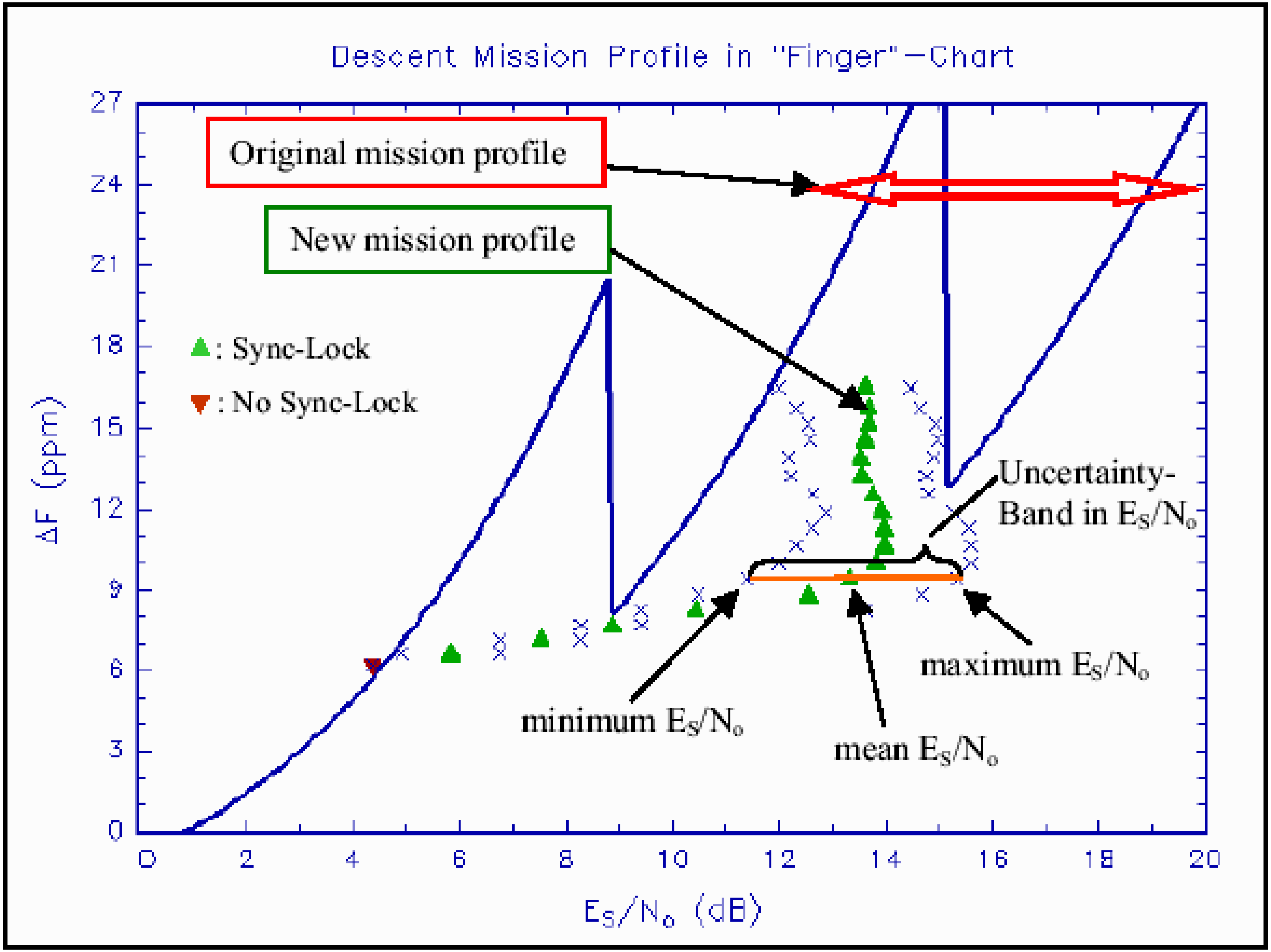




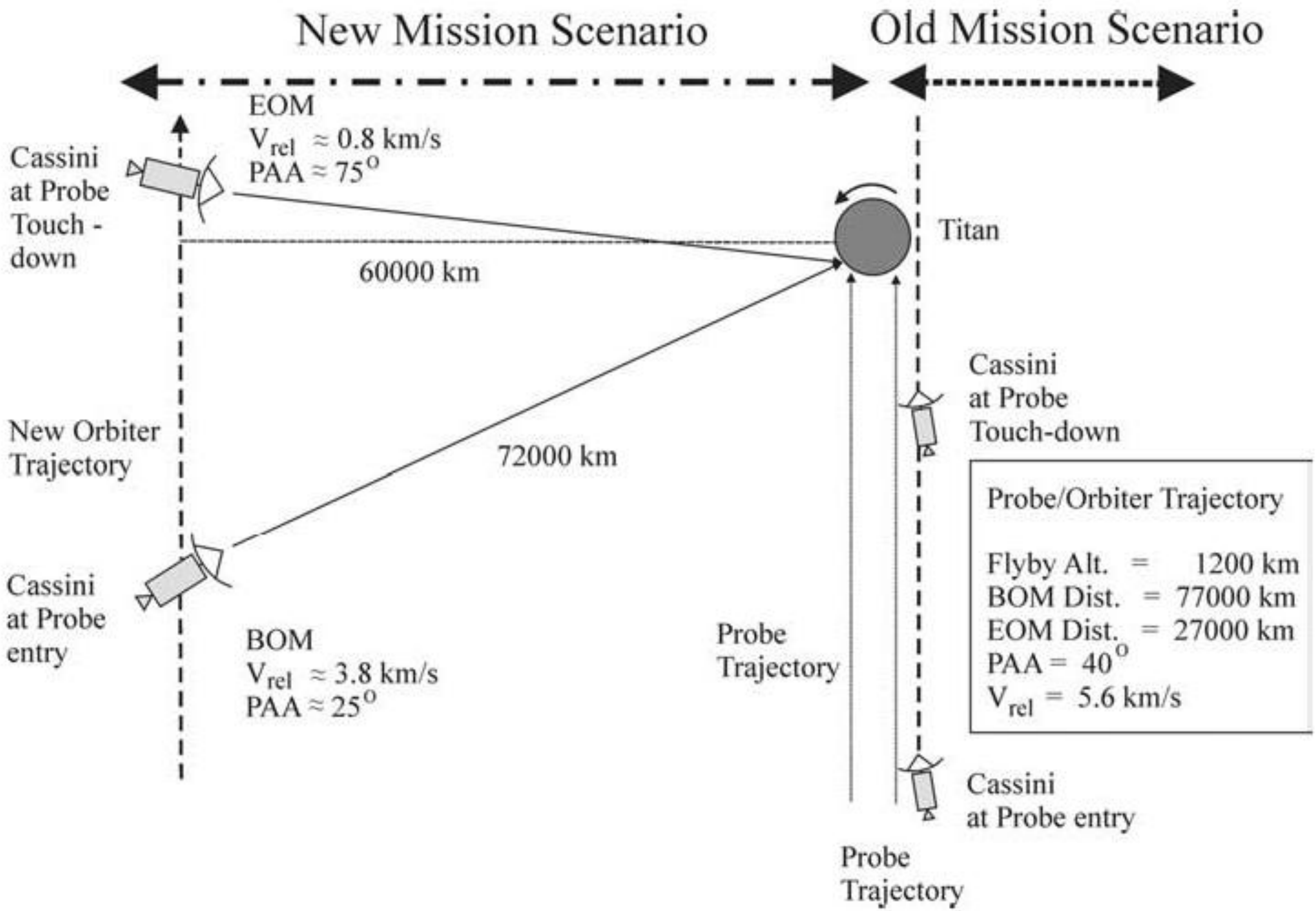
Huygens receiver flaw discovered in relay test during Earth flyby 2 years after launch.
Would result in near-total data loss.



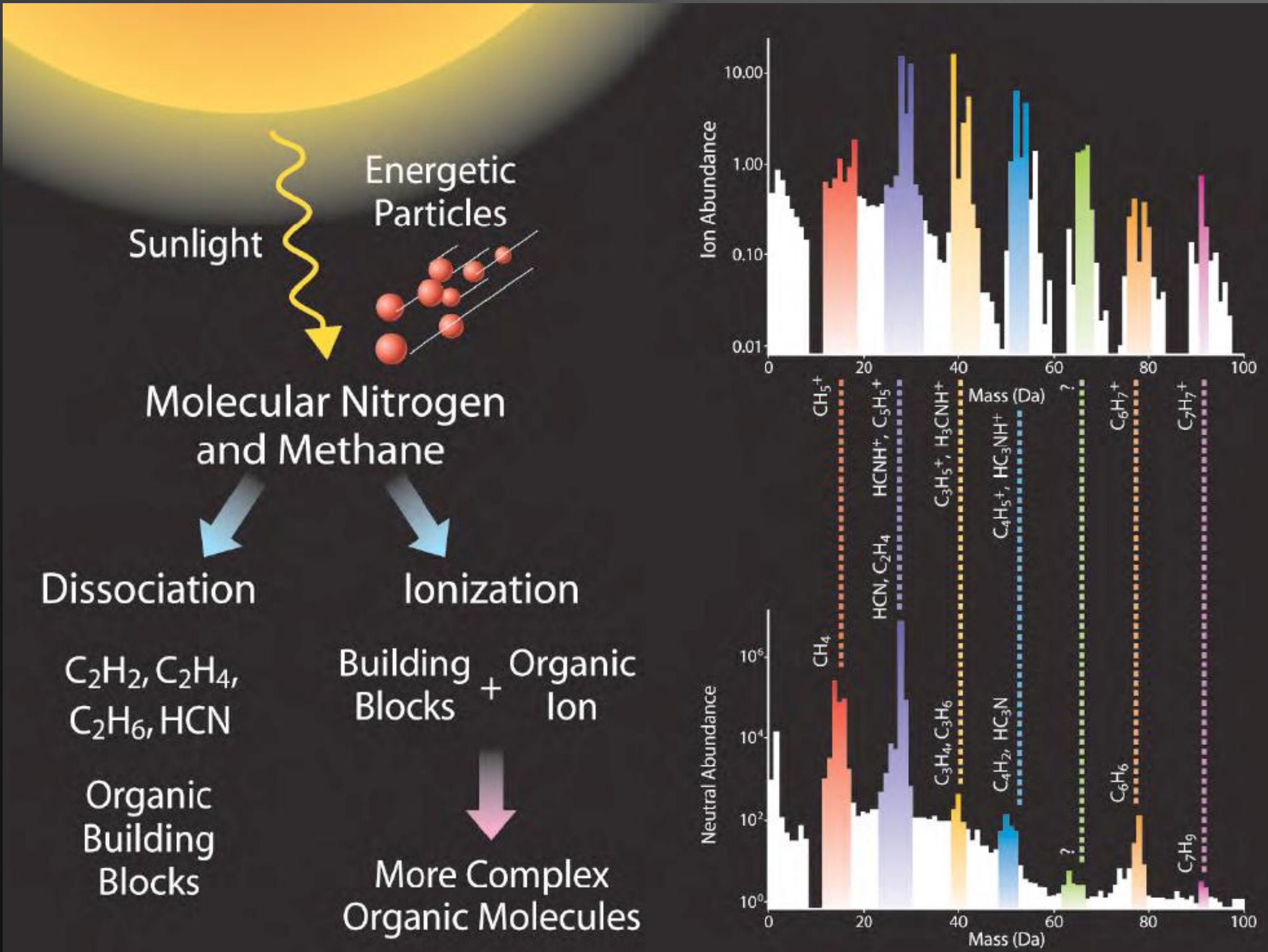


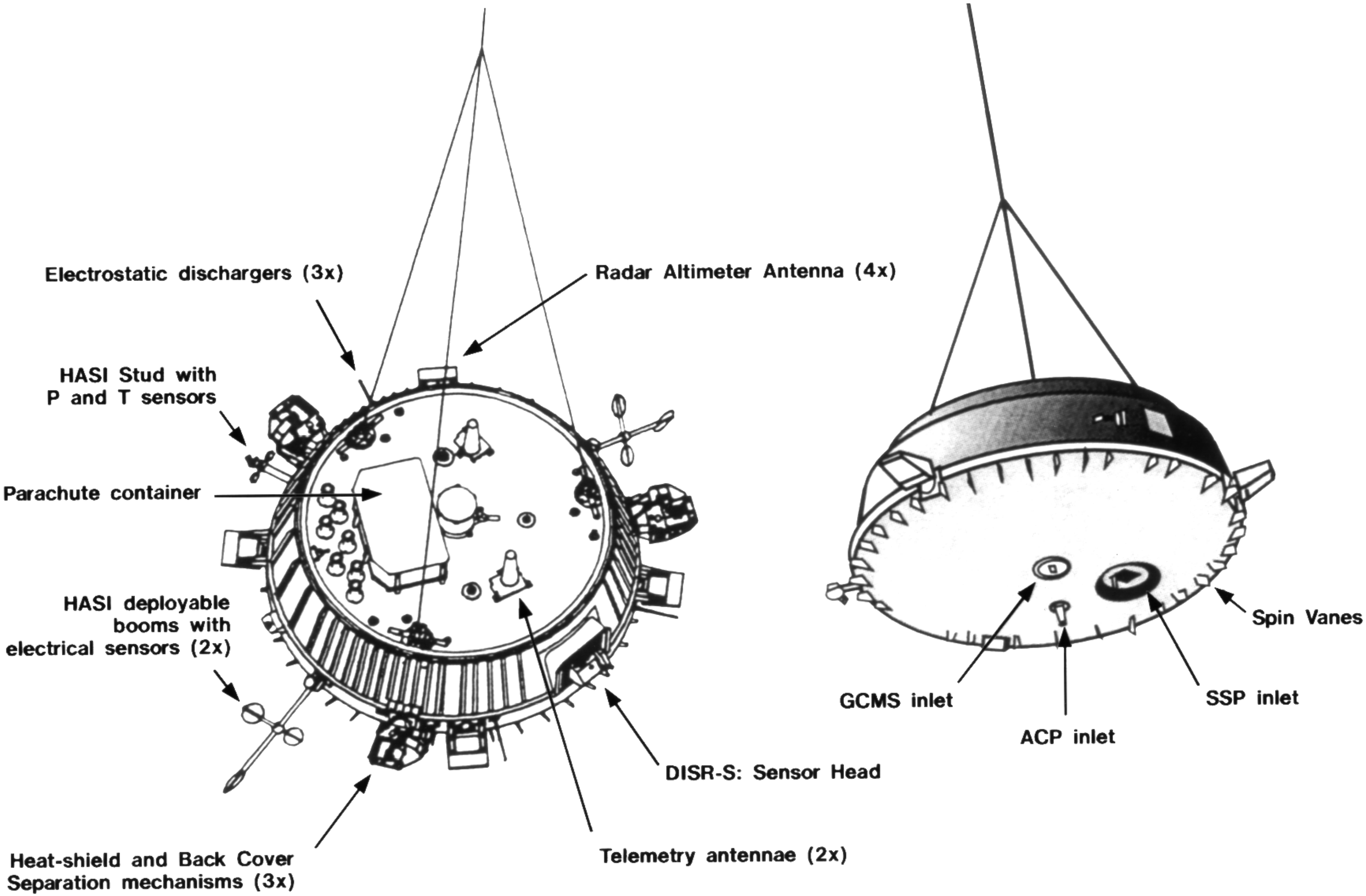


Manipulate ΔF via orbiter trajectory change to reduce range rate, plus pre-heating of probe to exploit temperature dependence in probe transmitter clock.



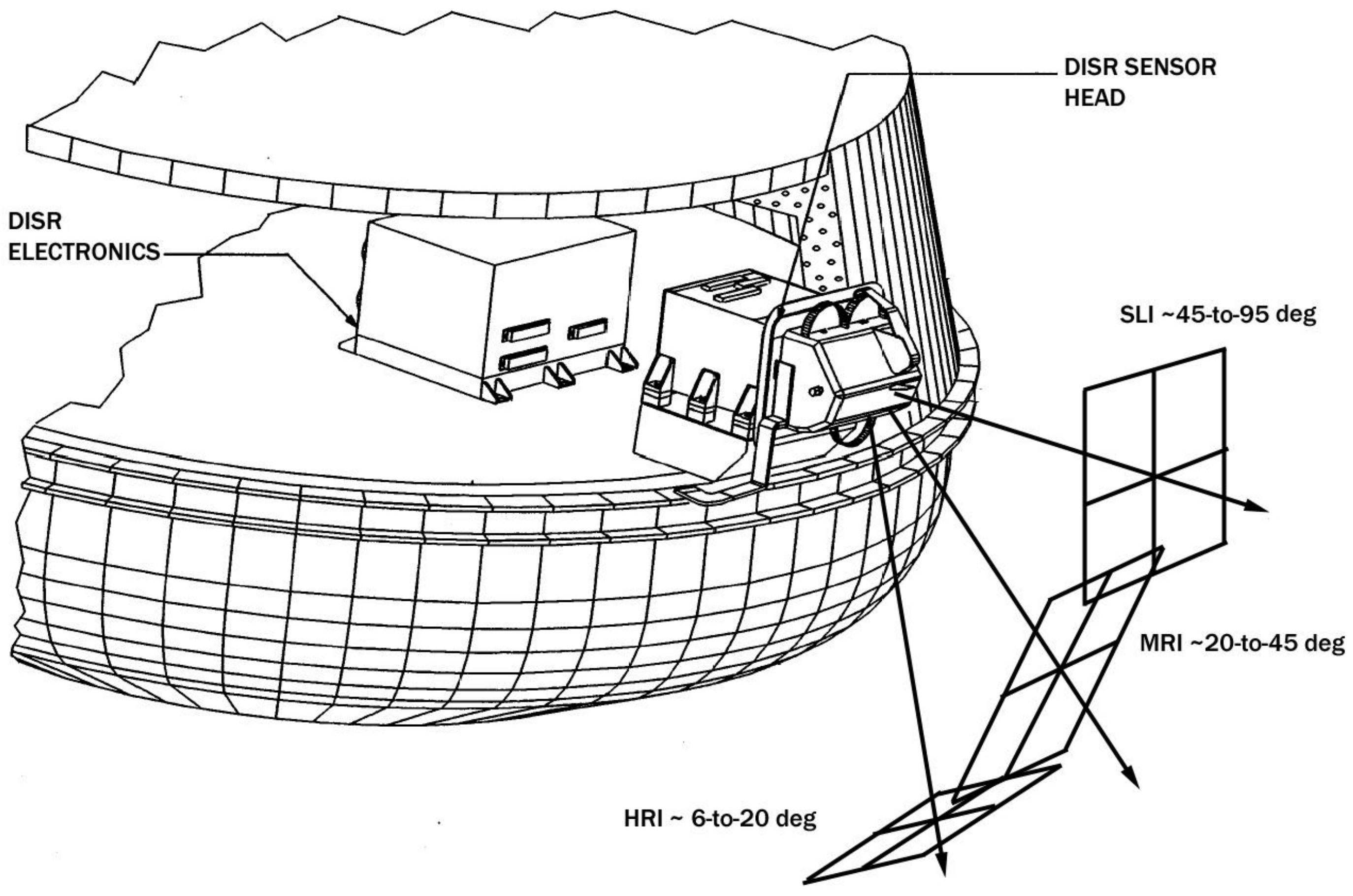
New Mission Scenario
Old Mission Scenario
EOM
$V_{rel} \approx 0.8$ km/s
PAA ≈ 75°
Cassini at Probe Touch - down
60000 km
Titan
Cassini at Probe Touch-down
New Orbiter Trajectory
72000 km
Probe/Orbiter Trajectory
Flyby Alt. = 1200 km
BOM Dist. = 77000 km
EOM Dist. = 27000 km
PAA = 40°
V_{rel} = 5.6 km/s
Cassini at Probe entry
BOM
$V_{rel} \approx 3.8$ km/s
PAA ≈ 25°
Probe Trajectory
Cassini at Probe entry
Probe Trajectory


Sunlight
Energetic Particles
Molecular Nitrogen and Methane
Dissociation
Ionization
C_2H_2, C_2H_4, C_2H_6, HCN
Organic Building Blocks
Building Blocks + Organic Ion
More Complex Organic Molecules
Ion Abundance
10.00
1.00
0.10
0.01
0
20
40
60
80
100
Mass (Da)
CH_5^+
$HCNH^+$, $C_5H_5^+$
$C_3H_5^+$, H_3CNH^+
$C_4H_5^+$, HC_3NH^+
?
$C_6H_7^+$
$C_7H_7^+$
Neutral Abundance
10^6
10^4
10^2
10^0
CH_4
HCN, C_2H_4
C_3H_4, C_3H_6
C_4H_2, HC_3N
?
C_6H_6
C_7H_9
0
20
40
60
80
100
Mass (Da)

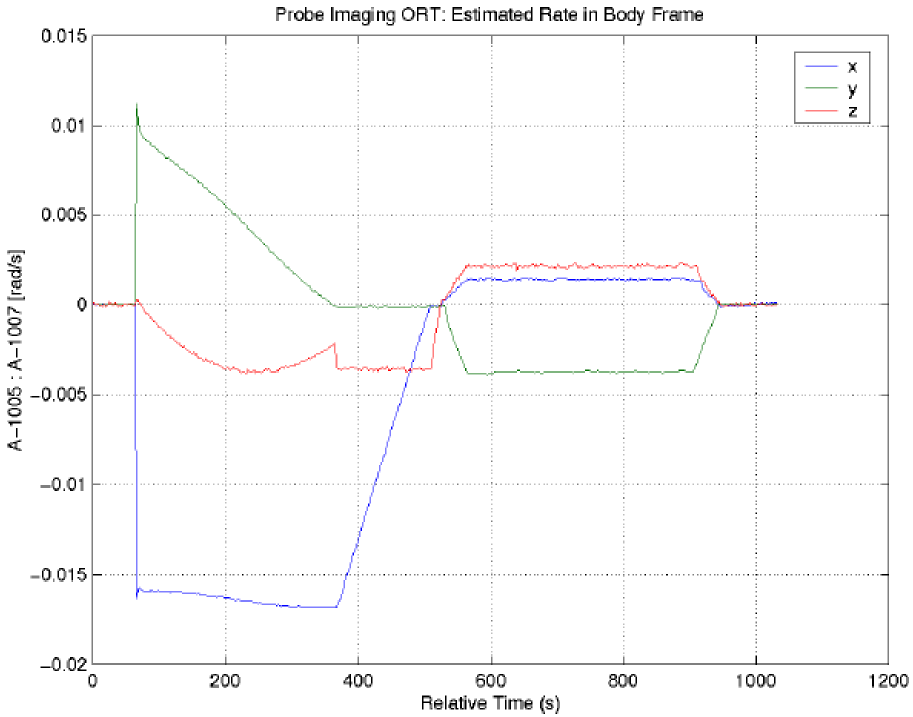


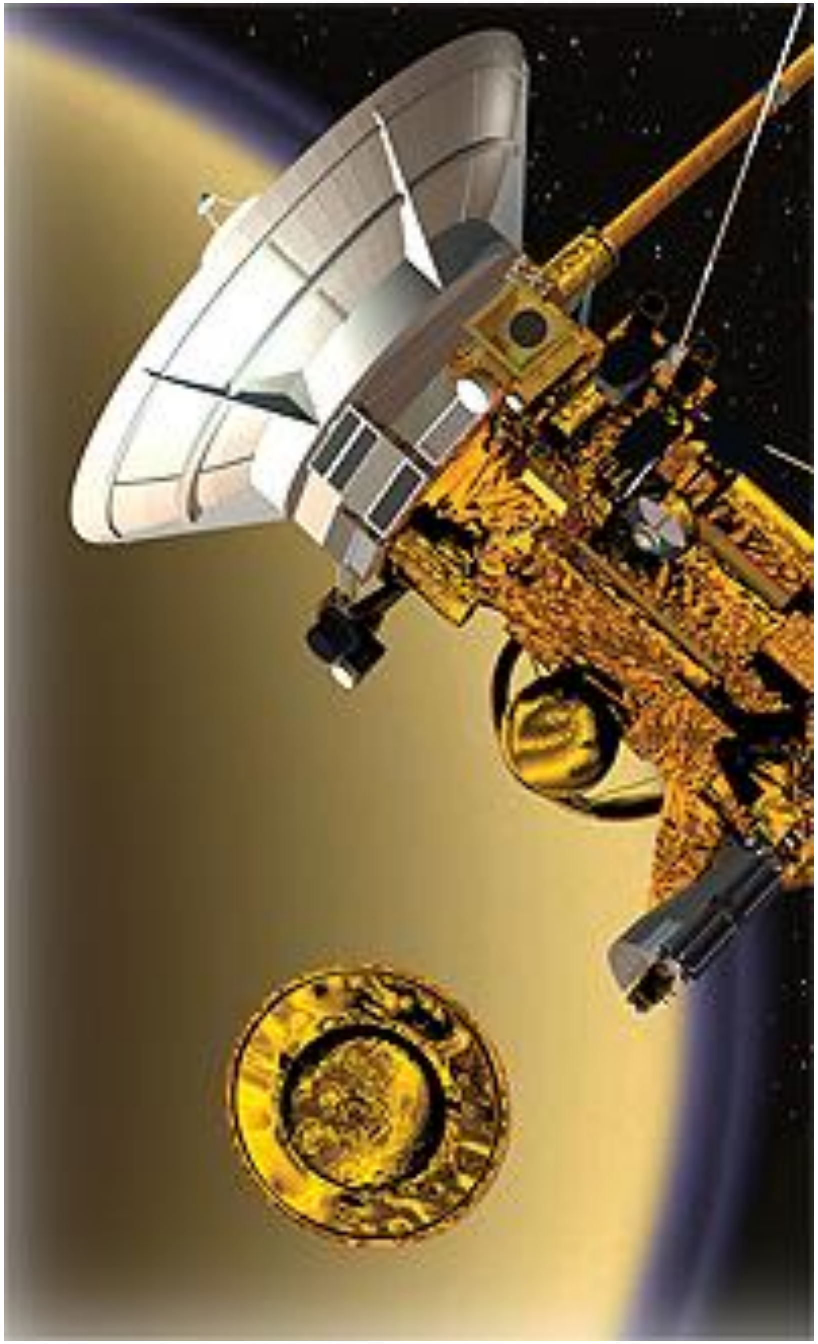
Huygens Descent Configuration

DISR Imagers Approximate Fields-of-View

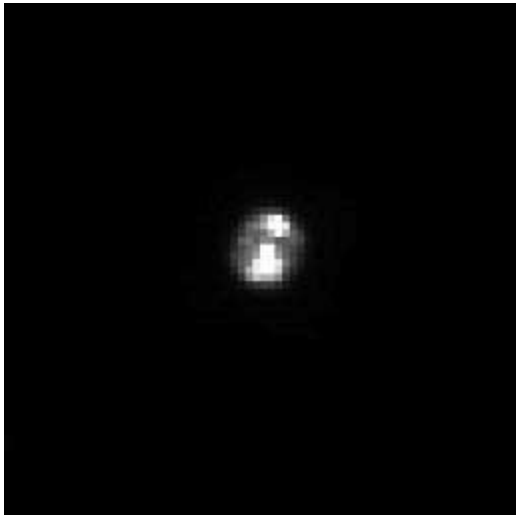


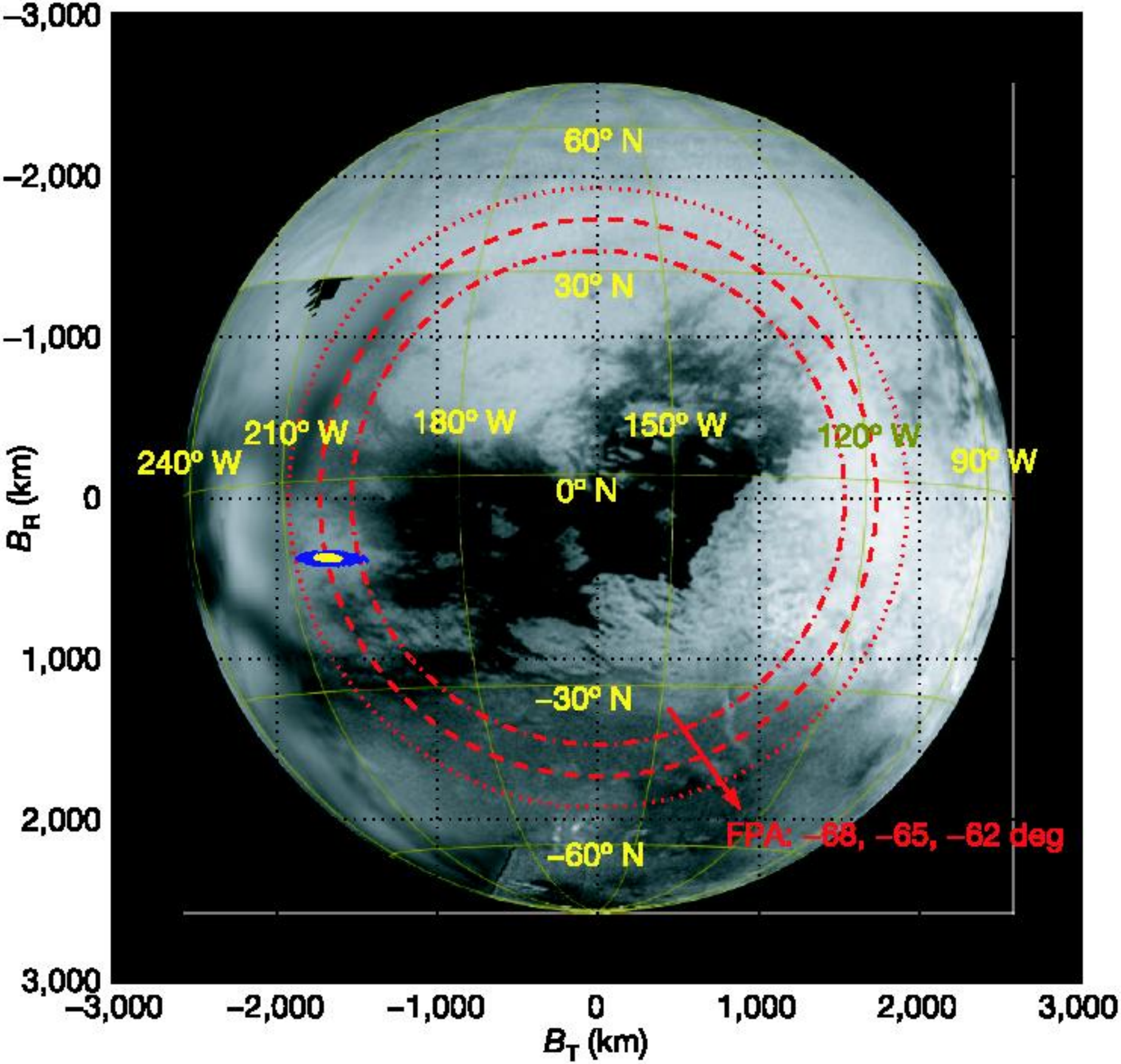
Separation Performed Dec 24, 2004





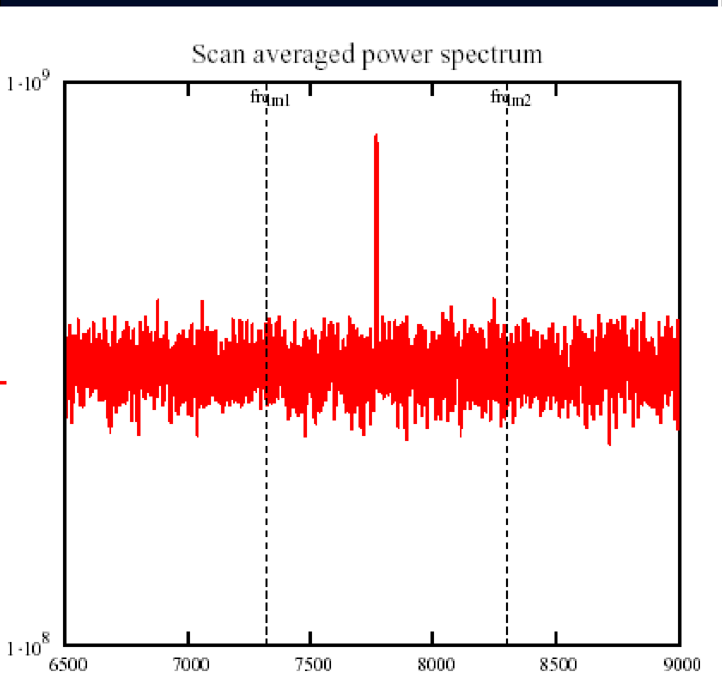
Huygens from
52km away
(Dec 26, 2004)

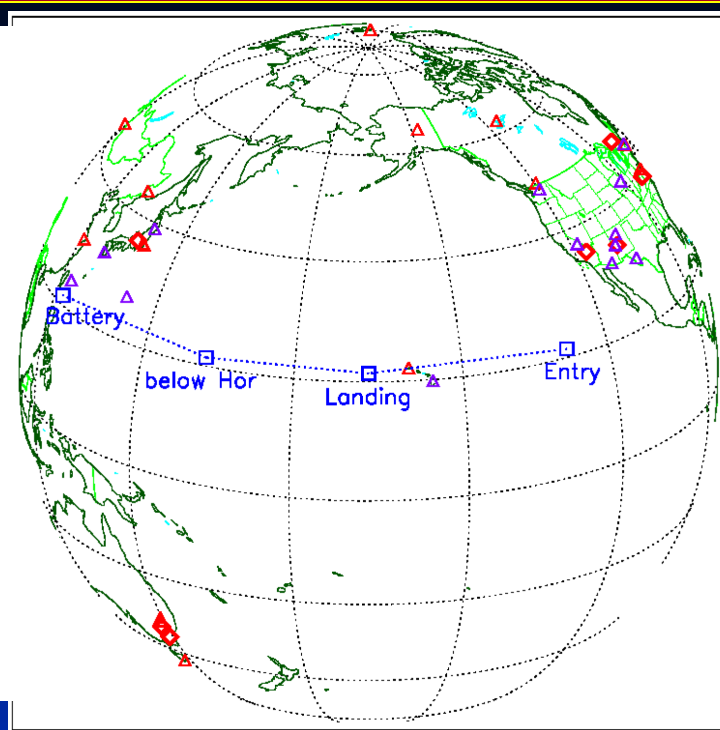




–3,000
–2,000
–1,000
0
1,000
2,000
3,000
–3,000
–2,000
–1,000
0
1,000
2,000
3,000
B_R (km)
B_T (km)
60° N
30° N
0° N
–30° N
–60° N
240° W
210° W
180° W
150° W
120° W
90° W
FPA: –68, –65, –62 deg

Earth as seen by Huygens: 2005.01.14, 10:19 UTC



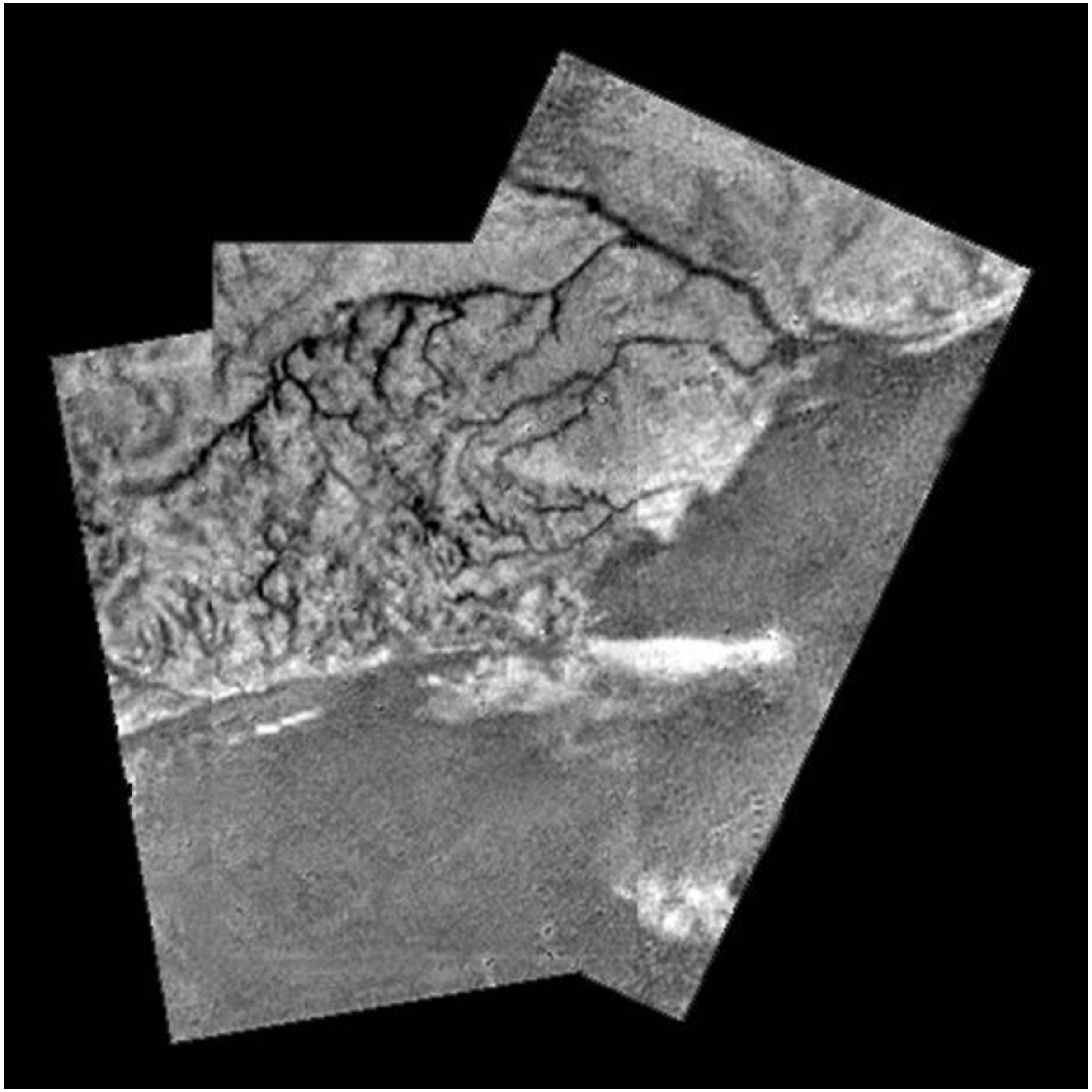


First detection by Green Bank ; Parkes took over. Supplemented by smaller telescopes (e.g. Kitt Peak)   Probe probably transmitted for >15 minutes after last detection.

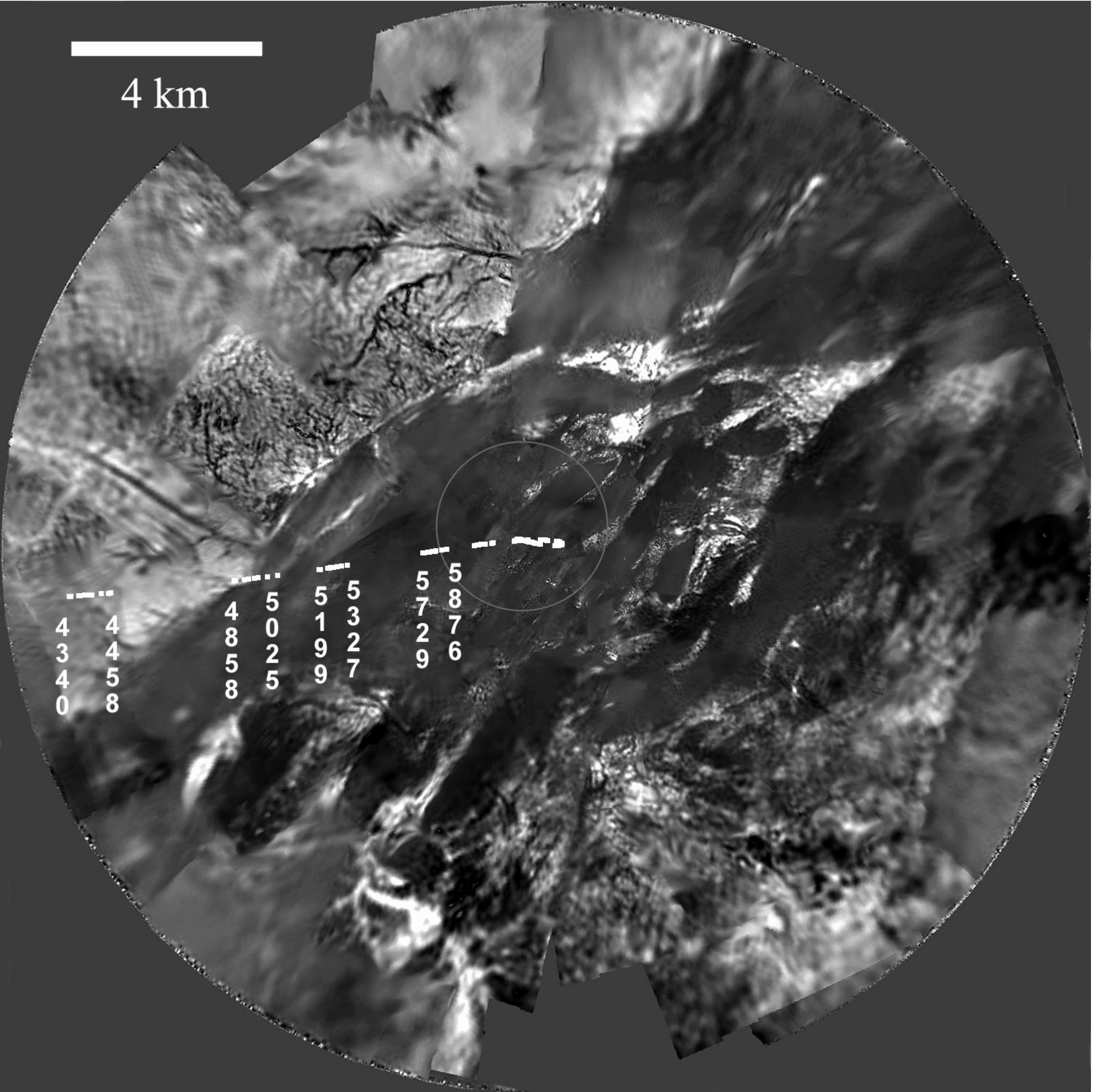
NB two distinct observing campaigns (same dishes, different receivers

1. Real-time doppler (intended as supplement to Cassini on-board doppler recovery)

2. VLBI to monitor position on the sky



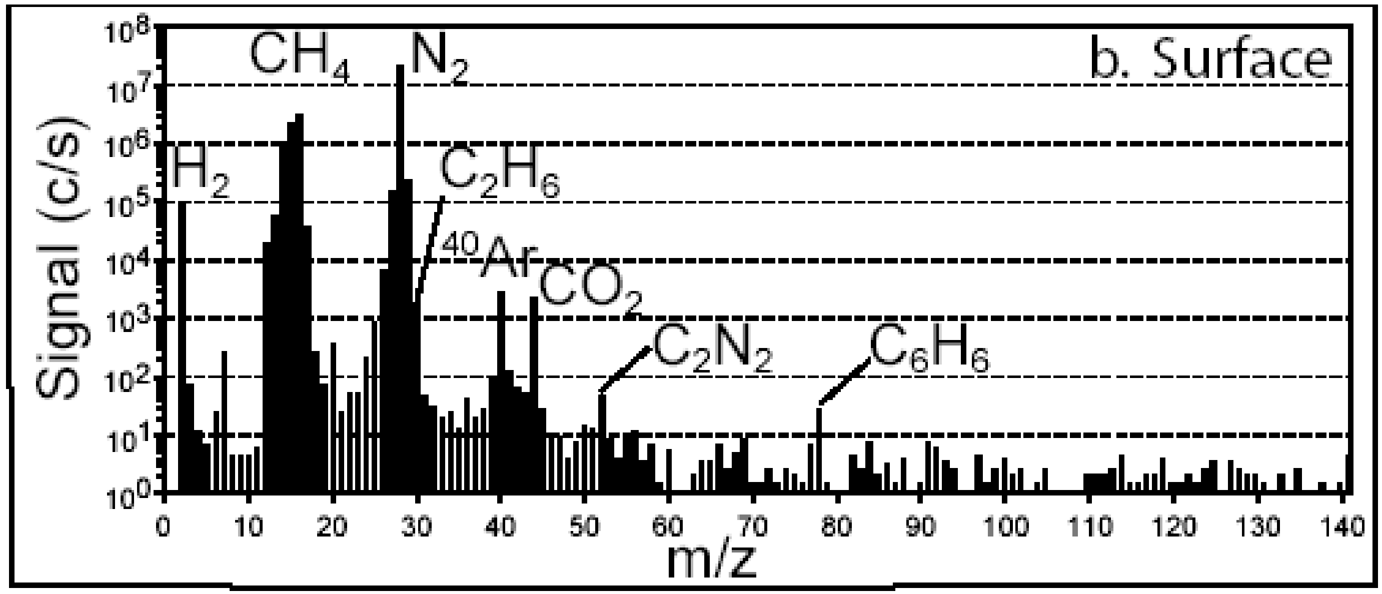
Huygens DISR image UA/ESA/NASA



Descent groundtrack fortuitously crossed bright/dark boundary.

Brighter terrain elevated by ~100m ; pluvial and sapping networks.

Flatter, lower, but not smooth dark terrain.

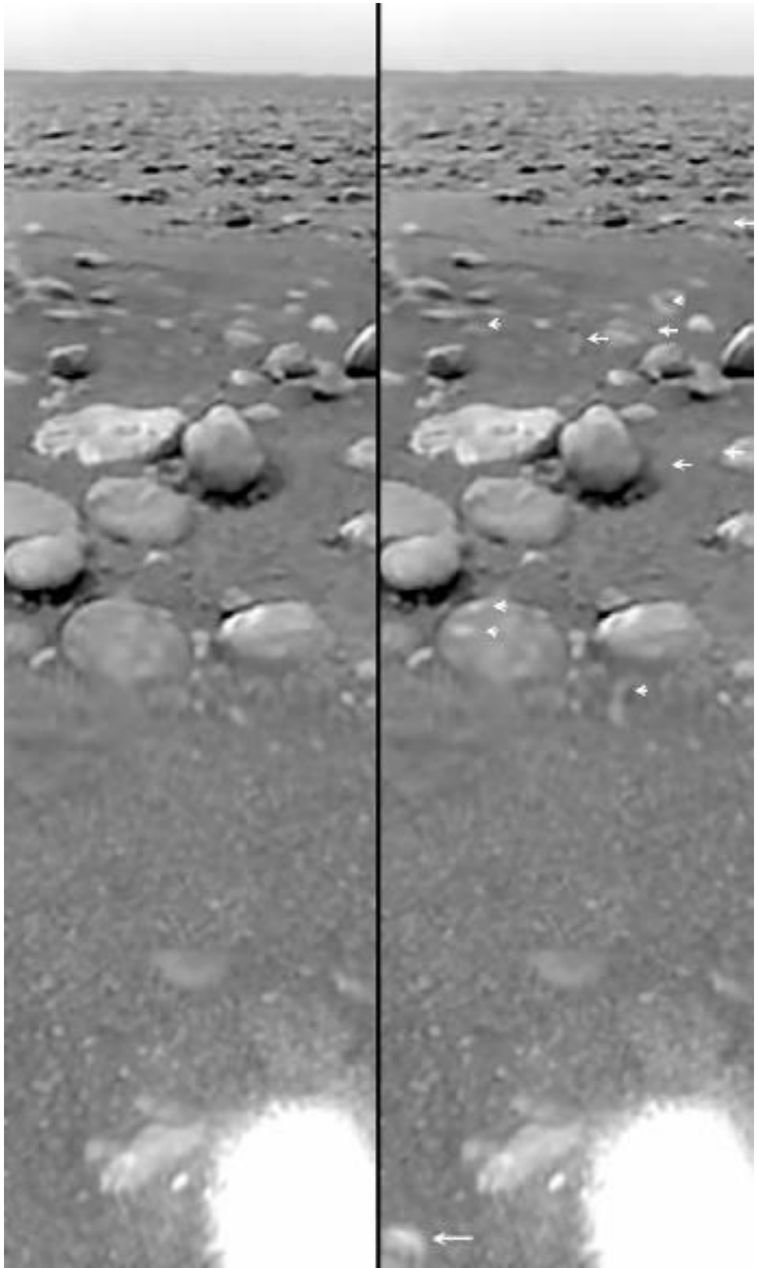


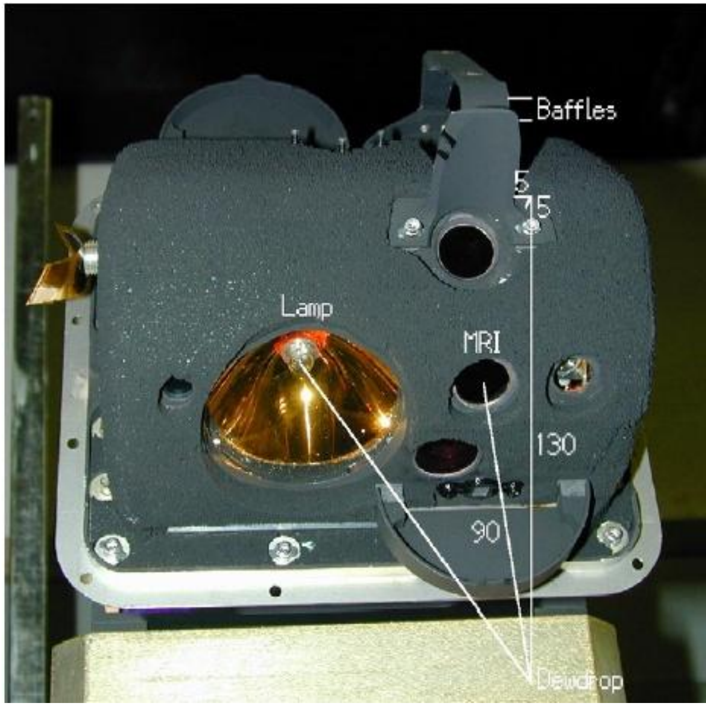
Post-impact operation of Huygens was not guaranteed !

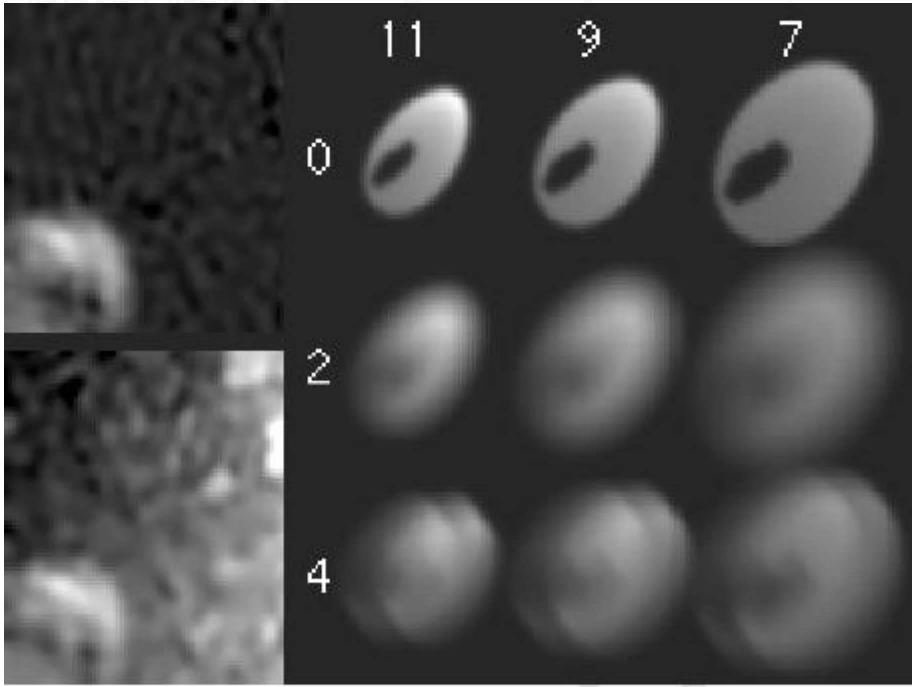
Surface images showed Rounded cobbles. Small pebbles carried away - evidence of fluvial transport

Surface volatiles detected by GCMS – much richer spectrum than atmosphere (volatiles also indicated by DISR and possibly by acoustic absorption)

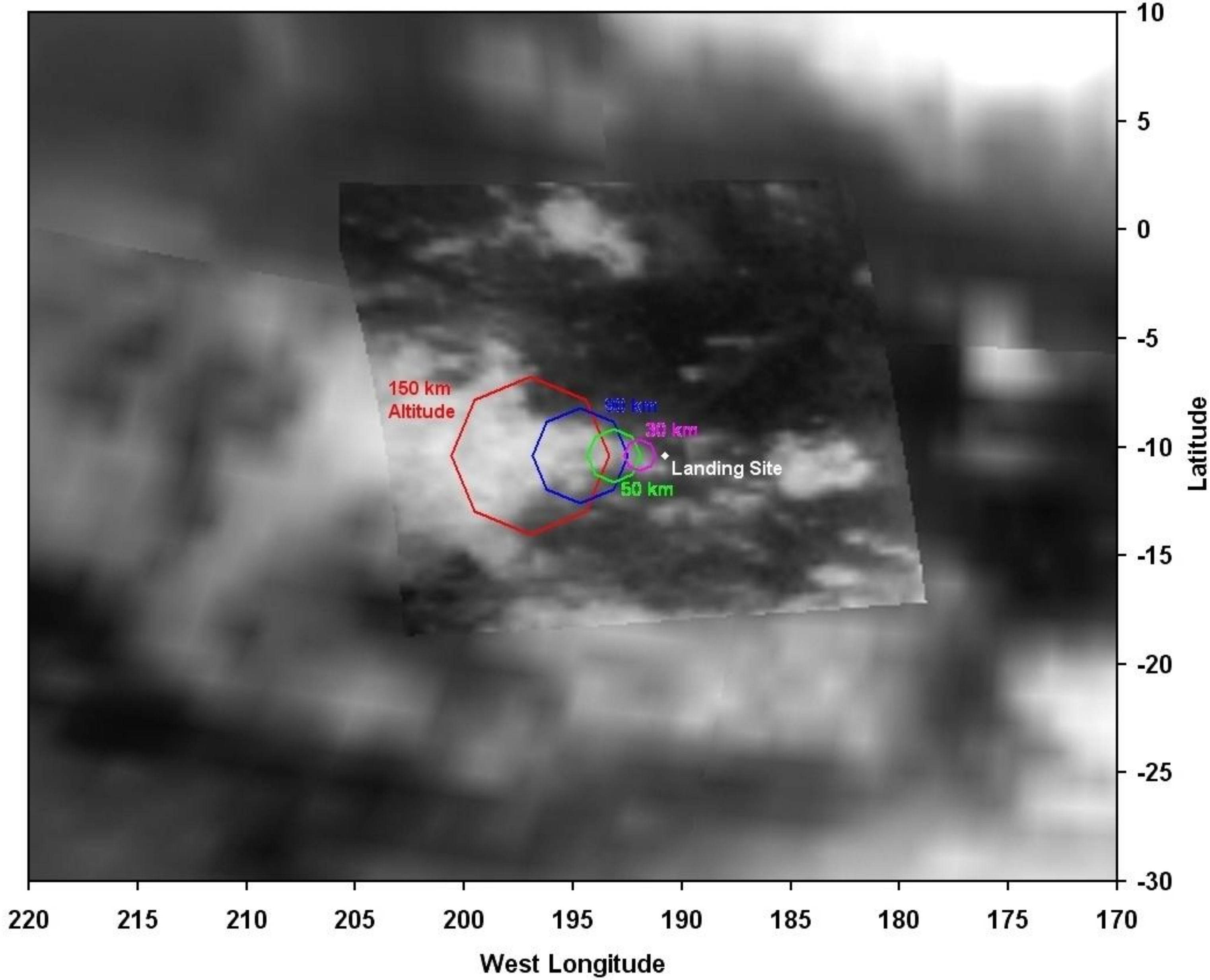
Karkoschka and Tomasko (PSS, 2008)



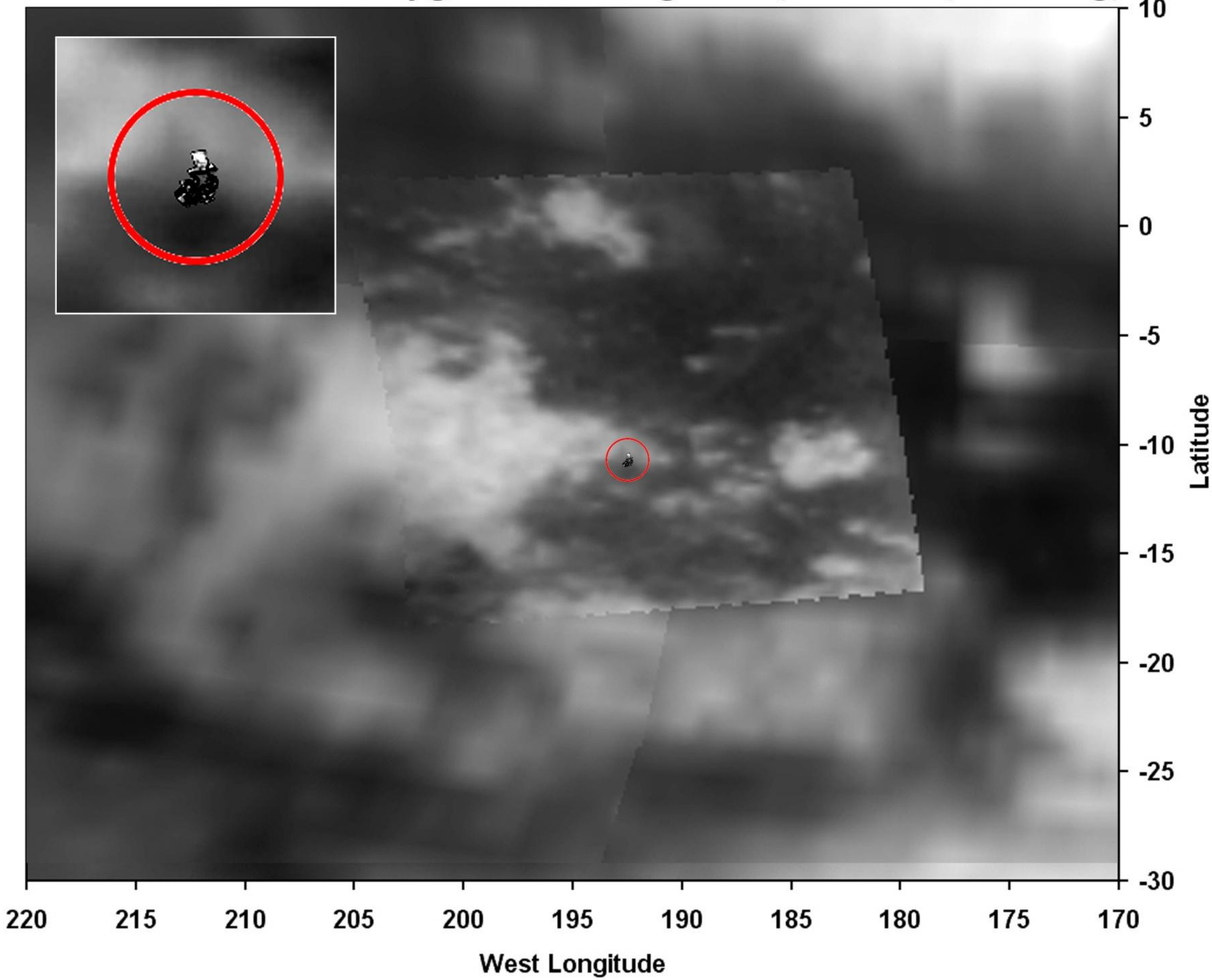


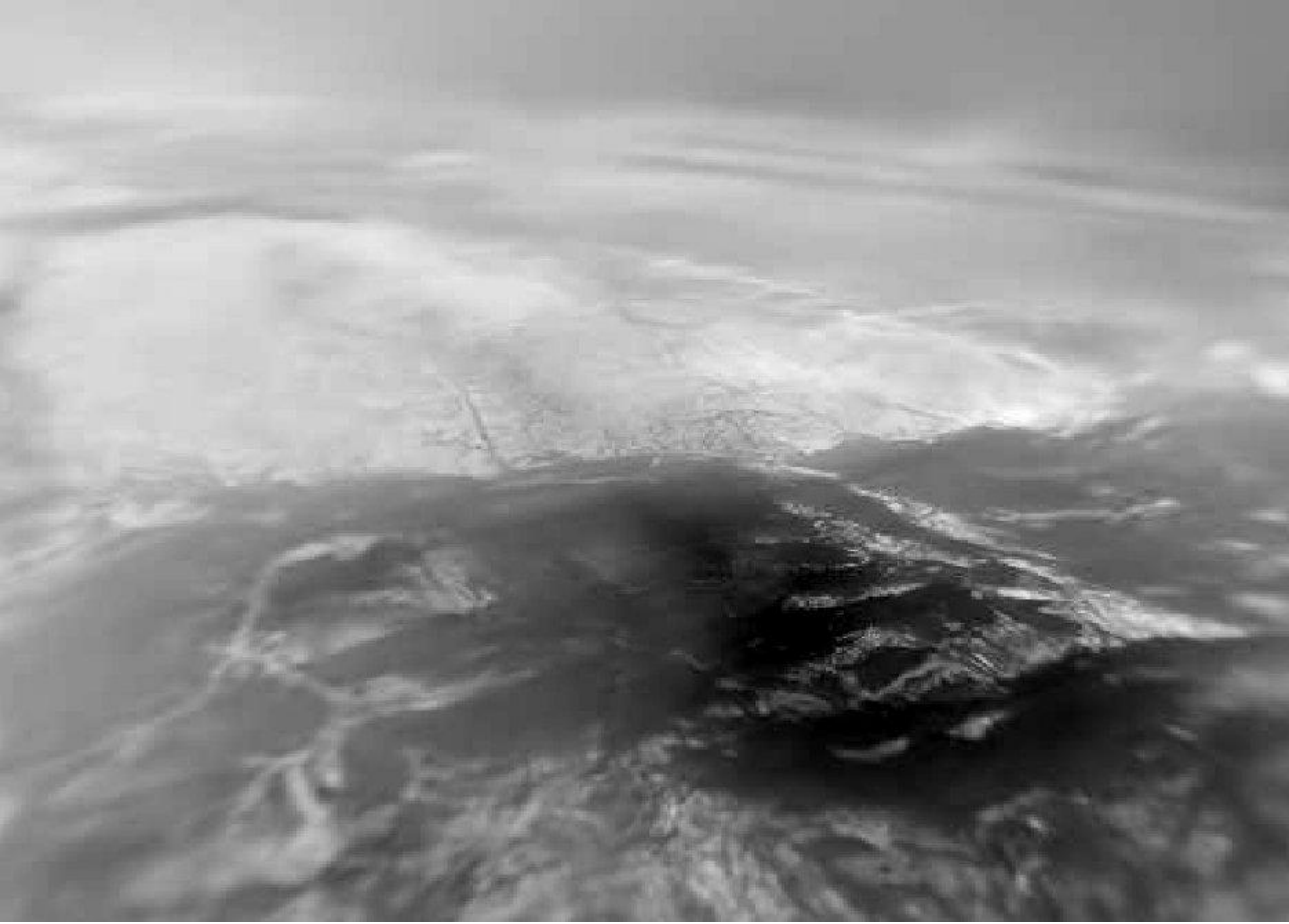


Cassini VIMS Titan Ta Base Map and Predicted Huygens DISR Image Coverage
(Combined HRI and MRI coverage for nominal wind model)



Cassini VIMS Basemap with Guesstimate of Location of DISR Mosaic of Huygens Landing Site (~ error +/- 1 deg)

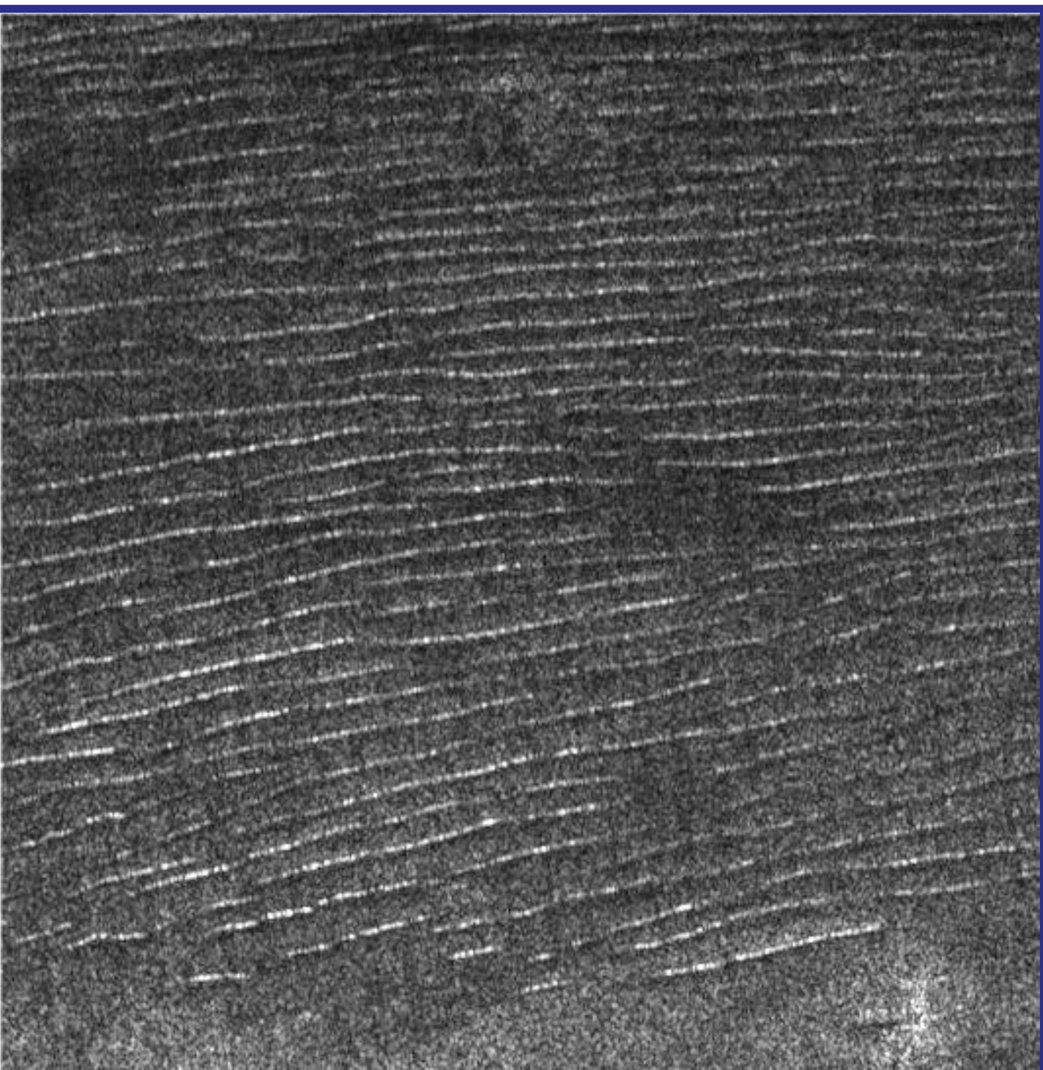


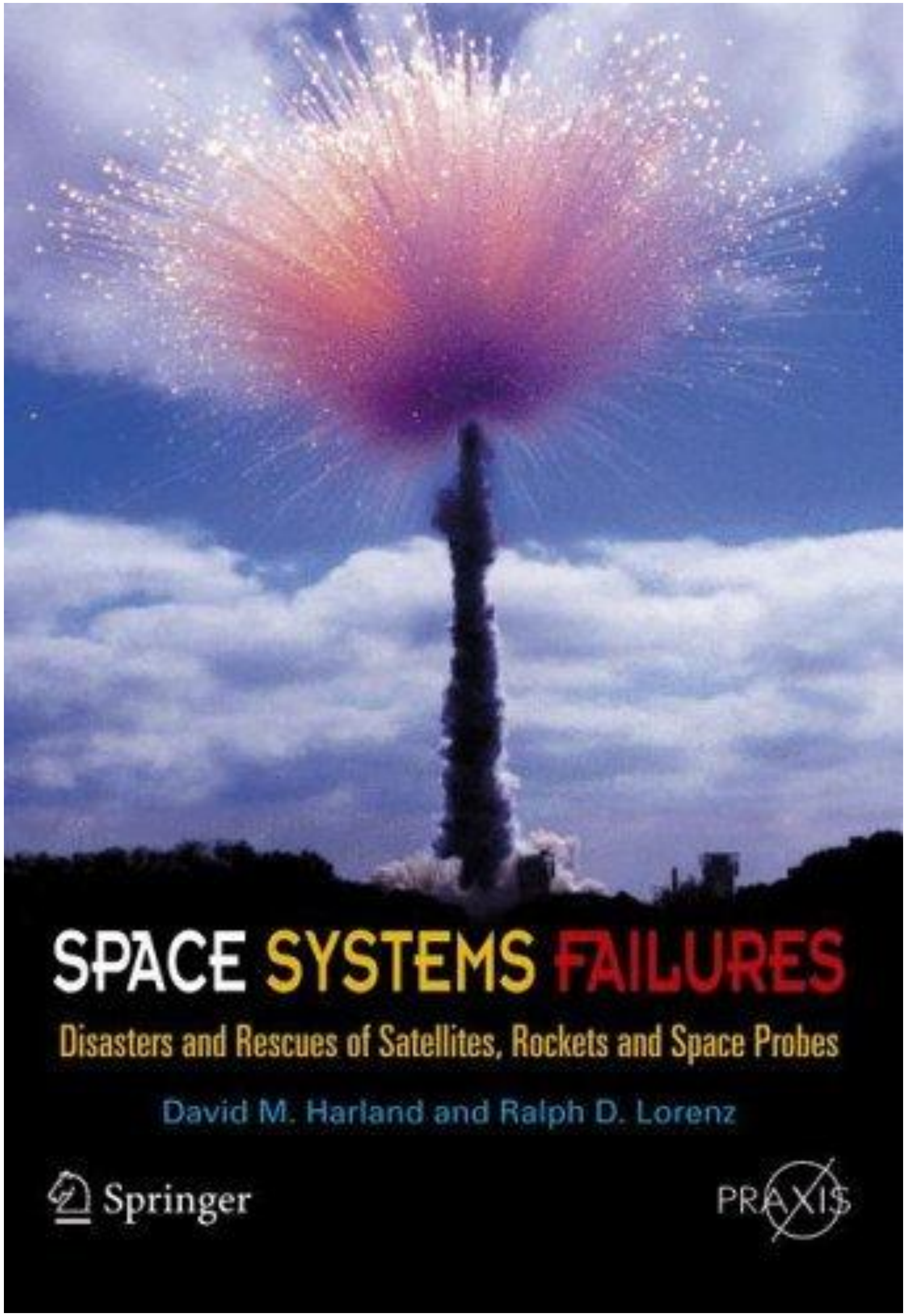


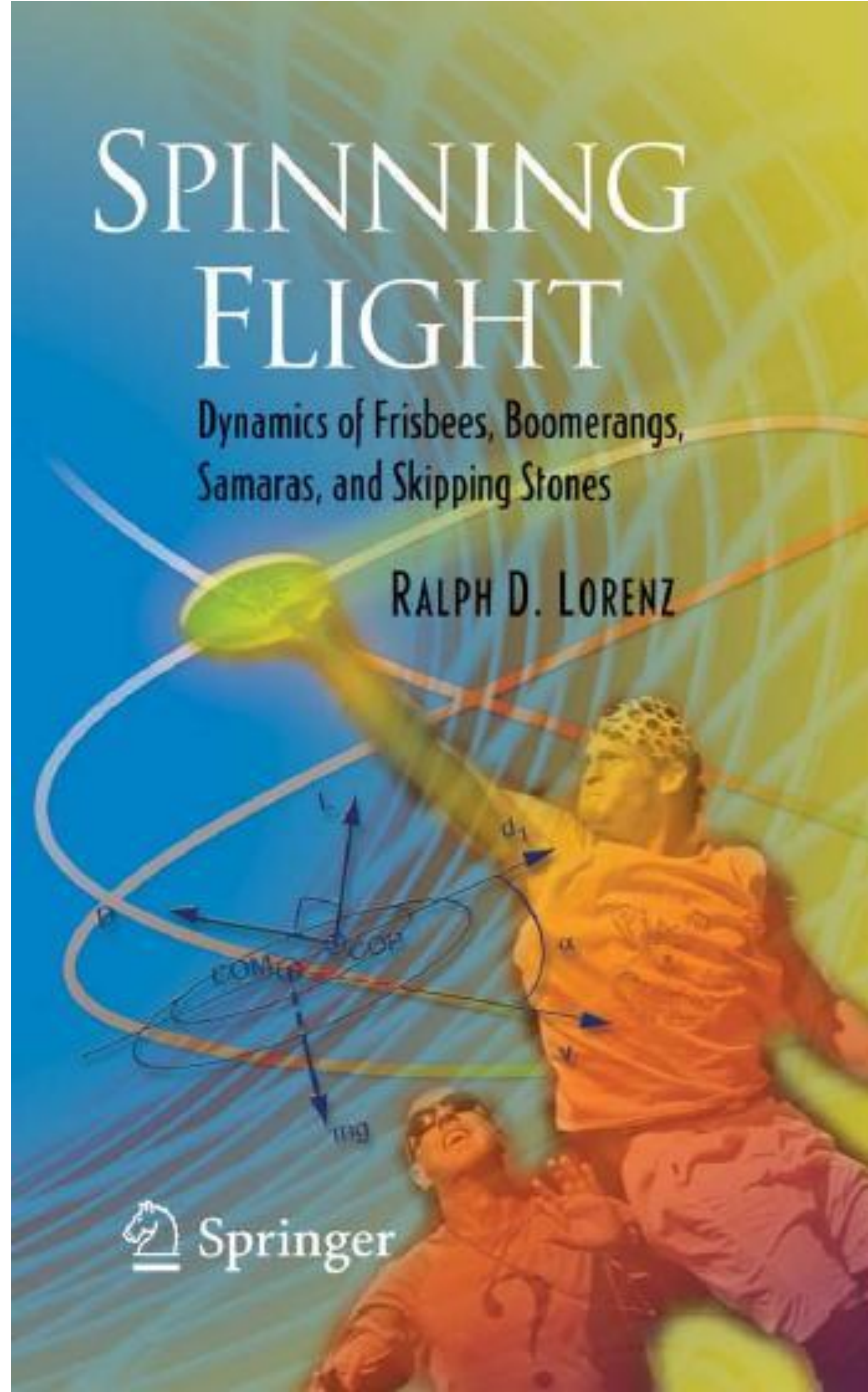
Reprojected DISR mosaic by E. Karkoschka, LPL, UA

A surprise on Titan - (organic) Dunes !

Sometimes seen as positive ridges ~1-2km wide, 150m high. Sometimes only visible as dark streaks against brighter substrate




SPACE SYSTEMS FAILURES
Disasters and Rescues of Satellites, Rockets and Space Probes
David M. Harland and Ralph D. Lorenz
Springer
PRAXIS


SPINNING FLIGHT
Dynamics of Frisbees, Boomerangs, Samaras, and Skipping Stones
RALPH D. LORENZ
Springer

Things to be learned about Titan at all scales.

Mars program is a good template

A Titan orbiter will spend more time close to Titan in its first 5 days than Cassini will have.

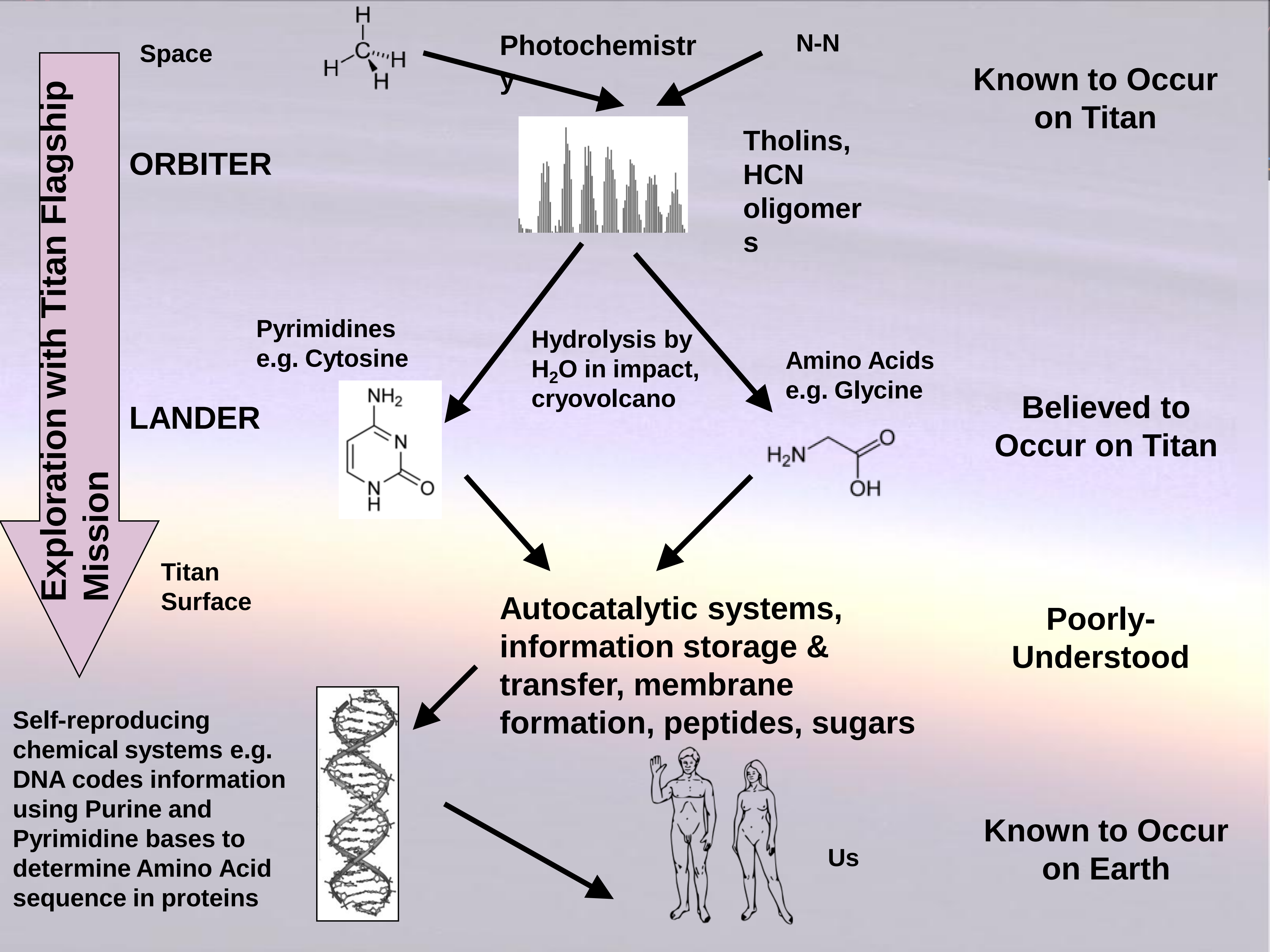
2007 Titan Explorer Flagship study made first comprehensive assessment of post-Cassini science priorities.

Blank slate

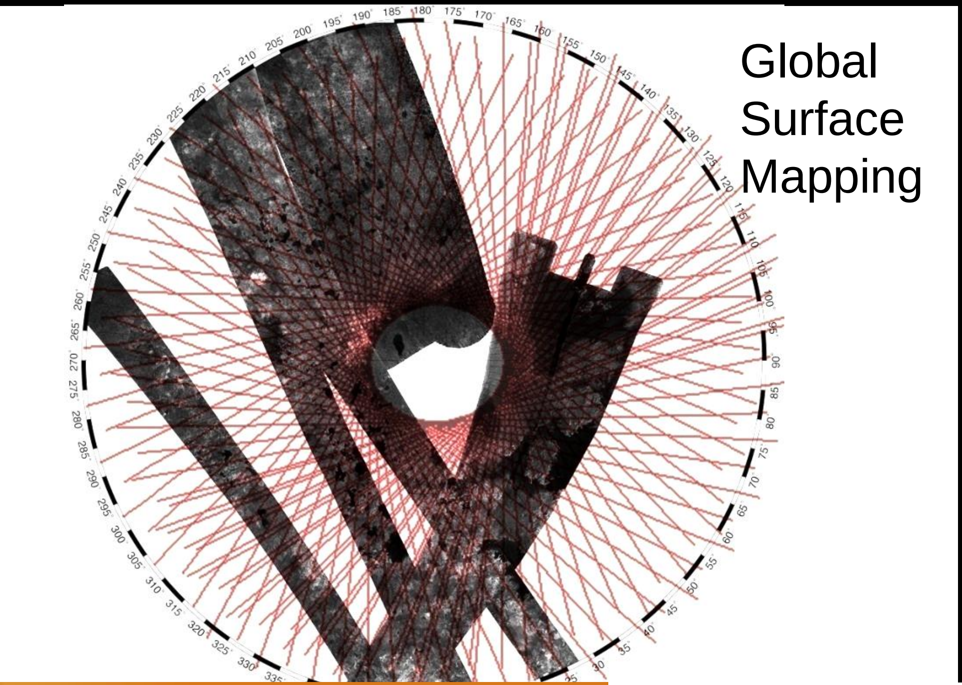
Obvious advantages to aerocapture – allows multiple platforms on single launch

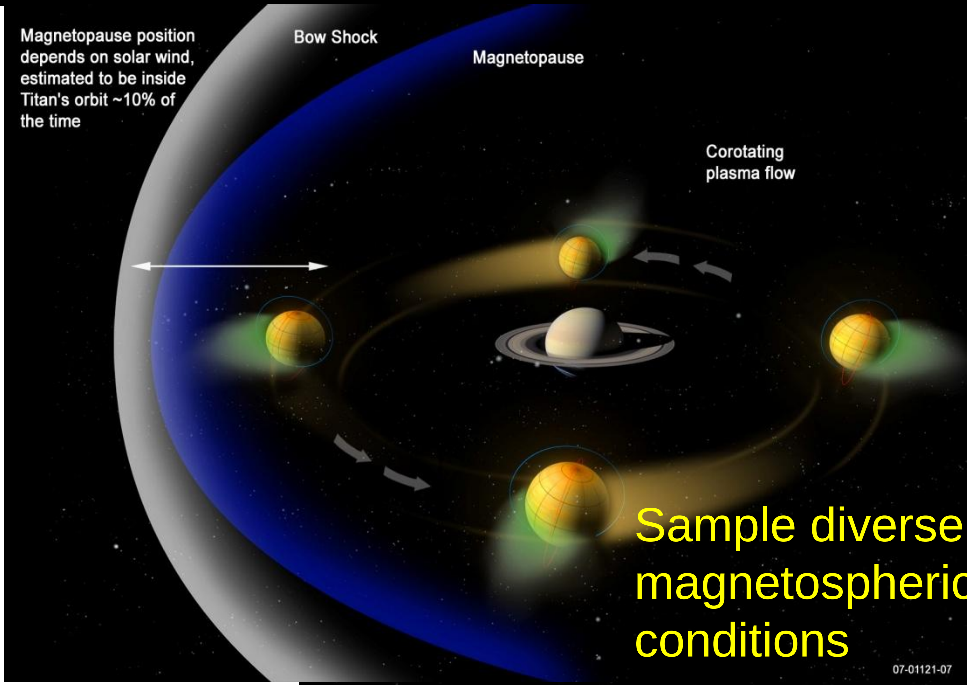
Objectives trace to Decadal Survey and Roadmap Goals

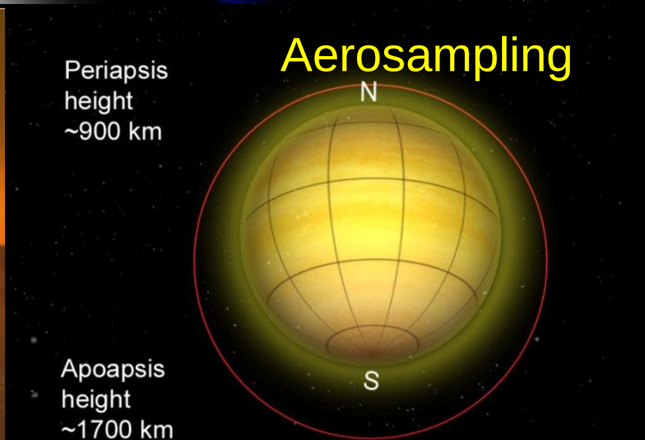
<table>
<tr><th>2003-2013 Solar System Exploration (First "Decadal" Survey)</th><th>2006 SSE Roadmap and 2007 NASA Science Plan</th><th>Titan Flagship Objectives</th></tr>
<tr><td rowspan="2">Learn how the Sun's retinue of planets originated and evolved</td><td>How did the Sun's family of planets and minor bodies originate</td><td>Obj.2 Inv.2 Determine geochemical constraints on bulk composition</td></tr>
<tr><td rowspan="5">How did the solar system evolve to its current diverse state</td><td>Obj.1 Inv.4 Determine differentiation and thermal evolution</td></tr>
<tr><td rowspan="2">Discover how the basic laws of physics and chemistry, acting over eons, can lead to the diverse phenomena observed in complex systems such as planets</td><td>Obj.2 Inv.4 Determine depth, thickness of Subsurface Ocean</td></tr>
<tr><td>Obj.1 Inv.2 Geologic, marine etc. processes</td></tr>
<tr><td rowspan="2">Understand how physical and chemical processes determine the main characteristics of the planets, and their environments, thereby illuminating the workings of the Earth</td><td>Obj.1. Inv.1 Determine composition and transport of volatiles</td></tr>
<tr><td>Obj.1. Inv. 3 Interaction of atmosphere with Saturn magnetosphere</td></tr>
<tr><td rowspan="2">Determine how life developed in the solar system, where it may have existed, whether extant life forms exist beyond Earth, and in what ways life modifies planetary environments</td><td>What are the characteristics of the solar system that led to the origin of life</td><td>Obj.2. Inv.1 Determine chemical pathways of complex organic formation</td></tr>
<tr><td>How did life begin and evolve on Earth and has it evolved elsewhere in the solar system</td><td>Obj.2. Inv. 3 Determine chemical modification of organics to prebiotic molecules</td></tr>
<tr><td>Explore the terrestrial space environment to discover what potential hazards to the Earth's biosphere may exist.</td><td>What are the hazards and resources in the solar system environment that will affect the extension of human presence in space</td><td></td></tr>
</table>


Exploration with Titan Flagship Mission
Space
ORBITER
LANDER
Titan Surface
H
C
H
H
H
Photochemistr y
N-N
Known to Occur on Titan
Tholins, HCN oligomer s
Pyrimidines e.g. Cytosine
NH2
N
N
H
O
Hydrolysis by H_2O in impact, cryovolcano
Amino Acids e.g. Glycine
H2N
O
OH
Believed to Occur on Titan
Autocatalytic systems, information storage & transfer, membrane formation, peptides, sugars
Poorly-Understood
Self-reproducing chemical systems e.g. DNA codes information using Purine and Pyrimidine bases to determine Amino Acid sequence in proteins
Us
Known to Occur on Earth

Orbiter maps surface, atmosphere and space interactions. Lander performs monitoring and surface chemistry. Balloon explores at high resolution.

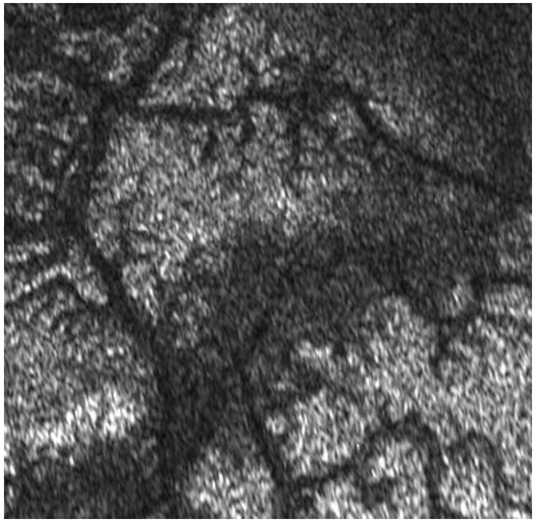




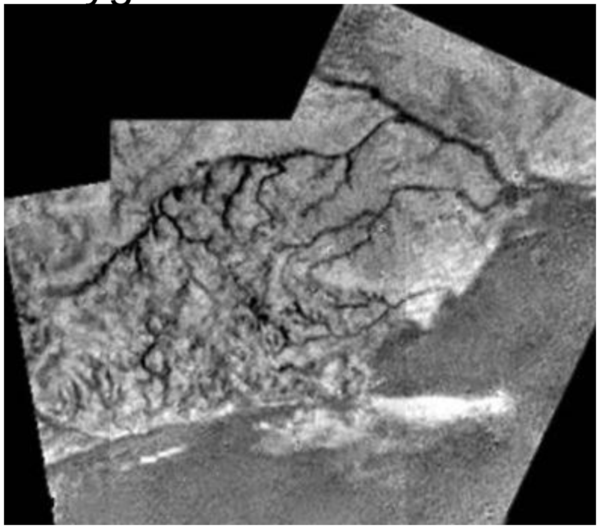


Orbiter – Balloon – Lander : A Multiscale Architecture for Exploring a Diverse Multiscale Surface

T28 SAR ~ 35km



Huygens DISR ~4km



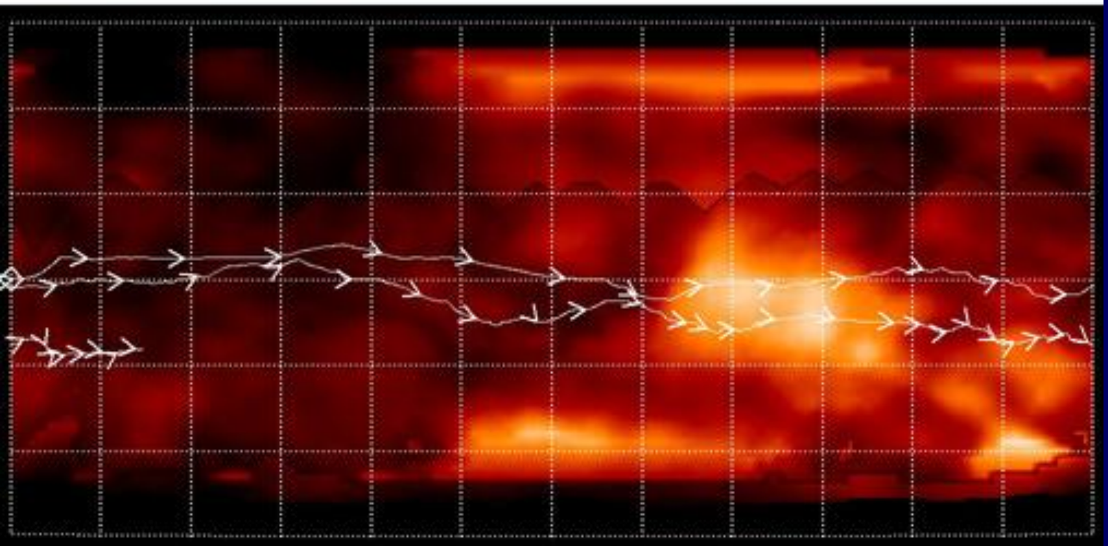
Huygens DISR ~ few m

To understand the processes shaping Titan needs information on all scales – e.g. for fluvial processes need large-scale networks and topography, mid-scale observations to understand e.g. runoff threshold and floor fill, and small scale to characterize sediment itself.

Atmosphere (via optical scattering and enforced high altitude of orbiter) makes mid-scale (~1-10m resolution) difficult to acquire e.g. by HiRISE-type instrument. Lander would not see wide diversity of terrain during descent.

An aerial platform like a balloon bridges the scale gap – wide coverage at high resolution. Reduces risk for future lander missions by characterizing terrain hazards.

Titan is easier to land on than Mars (in many ways). A Titan Lander could conduct seismic, magnetic, meteorological monitoring, and detailed analysis of surface materials.



Balloons on Titan

- Titan's thick, cold atmosphere is easy to fly in (planes, balloons) - hot air balloon is particularly attractive.
- Balloon surveys diverse terrains at very high resolution, obtains spectra through less of atmospheric column, and higher resolution subsurface radar sounding than orbiter.
- Expected zonal tropospheric winds ~1 m/s allow two circumnavigations in one year at ~10km altitude (low enough to image surface)
- Altitude control capability makes mission robust to wind field and may allow tidal wind field to be exploited for latitude change.

Science traceability matrix guides architecture & payload selection (Payloads are representative only – not only set that meets goals)

Investigation Exponent q (score = 100 * (1/RANK)^q)	0.25	Says how important investigation ranking is. q=1 means a lot - Inv2 only half score of Inv1 ; q=0.5 means inv2 is 71% of Inv1, etc
Measurement Exponent r (score = investig score * (Priority/Total Priority)^r	0.5	Says how important measurement priority within investigation is
Completeness Exponent s (score = measurement score * completeness^s	1	Says how much it matters a job is only part done. Suggest leave as s=1 since completeness estimation took that into account. S=0 says that any contribution is great

Objective	Investigation	Measurement	New Objective/Investigation	RANK	Investigation Points	Measurement Points (9=high from old objectives)	Measurement Duplicated before on Investigations	Radar Altimeter	SAR capability	Subsurface Sounding Radar	Orbiter Radio (tracking & Occultations)	Orbiter Magnetometer	Orbiter Microwave Spectrometer	Ion and Neutral Mass Spectrometer	Orbiter Thermal IR	Orbiter UV Spectrometer	Plasma Package	Langmuir Probe	Energetic Neutral Particles	1-Micron Camera	Spectral Mapper	Lander Precision Tracking	Lander Seismometer	Lander Magnetometer	Descent Imager / Radiometer	Lander Meteorology Package	Lander Spectrometer	Lander Camera & Microscope camera	Lander Chemical Analyzer	Balloon TDL Spectrometer & Nephelometer	Balloon Imager	Balloon Subsurface Radar Sounder	Balloon Downlooking Spectrometer	Balloon Met Package	Balloon tracking / Navigation and altimetry	Atmospheric Optics Monitor	Cassini Nav	Cassini End of XM	TOTAL	New Objective/Investigation	Old Objective/Investigation
								Orbiter														Lander								Balloon											
		Platform Total %						63.2														22.5								14.3											
		Instrument Total %						4.67	3.8	3.45	4.73	2.51	7.05	6.26	9.57	4.33	3.12	0.79	0.85	2.82	9.68	1.27	2.53	1.14	1.16	1.04	0.13	1.52	13.7	3.11	1.71	1.15	3.14	0.62	3.17	1.4					
		Platform Total Score						1910.5														879.6								432.1											
		Instrument SCORE (Mirrored from Bottom)						141	109	104	143	75.8	213	189	289	131	94.2	24	19.6	85.1	292	38.5	76.4	34.3	35	31.5	3.82	46	414	93.9	51.7	34.8	94.9	18.7	95.9	42.3	0	0			
OBJECTIVE 1: Titan: an Earthlike System How does Titan function as a system? How do we explain the similarities and differences between Titan and other solar system bodies in the context of the complex interplay of the geology, hydrology, meteorology, and aeronomy present in the Titan system?	Determine the composition and transport of volatiles and condensates in the atmosphere and at the surface, including hydrocarbons and nitriles, on both regional and global scales, in order to understand the hydrocarbon cycle. Determine the climatological and meteorological variations of temperature, clouds and winds.	Determine composition of surface volatile inventory (minerals)	1.1	1	100	35.1	9														0.8								0.8				0.8						22.5	1.1	2.21
		Global distribution of condensates	1.1	1	100	33.1	8								0.6	0.1				0.3	0.7																		13.6	1.1	2.22
		Determine volatile distribution in atmosphere	1.1	1	100	31.0	7						0.4	0.6	0.8	0.4					0.3								0.3	0.7									24.5	1.1	2.23
		Obtain vertical temperature soundings	1.1	1	100	35.1	9				1		0.7		0.9																								23.4	1.1	2.3
		Direct Measurement of zonal winds	1.1	1	100	20.3	3						0.9							0.2	0.2	0.1				0.4									0.8				7.8	1.1	2.31
		Determine mean meridional circulation via tracers	1.1	1	100	33.1	8						0.5	0.6	0.8	0.3				0.3	0.3														0.8				28.8	1.1	2.32
		Measure profiles of organic gas abundance	1.1	1	100	31.0	7						0.4	1	1	0.7																							21.7	1.1	2.33
		Measure time-series meteorology	1.1	1	100	23.4	4																			1								0.8	0.6				9.6	1.1	2.35
		Determine clouds at all altitudes : distribution, morphology etc	1.1	1	100	28.7	6	0.3					0.1		0.8					0.7	0.9																		16.8	1.1	2.36
		Measure surface temperature distribution	1.1	1	100	11.7	1						0.9		0.8																								1.7	1.1	2.37
		Measure deposition of sunlight as fn(altitude)	1.1	1	100	20.3	3									0.7									0.3											0.4			4.2	1.1	2.38
		Measure optical properties of aerosol particles	1.1	1	100	26.2	5								0.5	0.6				0.4	0.8				0.6					0.5						0.8			21	1.1	2.39
		Measure number density and size of aerosol	1.1	1	100	16.6	2							0.5	0.7	0.7				0.4	0.8				0.8					0.5						0.8			10.4	1.1	2.395
		Measure the abundance of radiocarbon in surface materials	1.1	1	100	11.7	1																						1										1	1.1	3.24
	Characterize and assess the relative importance today and throughout time of Titan's geologic, marine and geomorphologic processes e.g. cryovolcanic, aeolian, tectonic, fluvial, hydraulic, impact and erosion.	Detect morphological indicators of exchange (vents etc.)	1.2	2	84.1	24.1	5		0.9											0.8	1										0.6								16.5	1.2	1.24
		Map global topography (1km/10m)	1.2	2	84.1	28.5	7	0.9																															6.3	1.2	2.1
		Measure dynamic lake topography (10km/1m)	1.2	2	84.1	24.1	5	0.8	0.7											0.2	0.7										0.1								12.5	1.2	2.11
		Measure regional topography (100m/1m)	1.2	2	84.1	24.1	5																									0.2			1				6	1.2	2.12
		Regional morphology (1m)	1.2	2	84.1	26.4	6																								1								6	1.2	2.13
		Global morphology and texture (100m)	1.2	2	84.1	32.3	9		1												0.8										0.1								17.1	1.2	2.14
		Global near-IR albedo (100m)	1.2	2	84.1	30.5	8														1										0.1		0.1						9.6	1.2	2.15
		Regional variations of reflectance spectrum (10m)	1.2	2	84.1	26.4	6																										1						6	1.2	2.16
		Local-scale morphology (0.1-0.01m)	1.2	2	84.1	21.5	4																					1			0.1								4.4	1.2	2.17
		Regional subsurface structure (10km/100m)	1.2	2	84.1	18.6	3			0.8																													2.4	1.2	2.18
		Regional subsurface structure (1km/10m)	1.2	2	84.1	10.8	1																									1							1	1.2	2.19
		Measure topography boundary (100km/100m)	1.2	2	84.1	15.2	2	1	0.2	0.8																													4	1.2	2.34
	Determine the interaction of Titan's upper atmosphere with Saturn's magnetosphere and the evolution of Titan's atmosphere, loss of materials, source of free energy and heat. Determine the chemical pathways of tholin formation.	Measure vector magnetic field	1.3	3	78	27.7	6 a					1												0.2															7.2	1.3	2.4
		Measure high-energy magnetospheric electrons	1.3	3	78	25.3	5										0.5																						2.5	1.3	2.41
		Measure thermal electron density and temperature	1.3	3	78	30.0	7			0.7	0.3						0.6	0.8																					16.8	1.3	2.42
		Measure ion velocity distribution in the ionosphere	1.3	3	78	16.0	2							0.3			0.8																						2.2	1.3	2.43
		Measure high-molecular mass ion composition	1.3	3	78	32.0	8							0.7			0.7																						11.2	1.3	2.44
		Measure high-molecular mass neutral composition	1.3	3	78	34.0	9							1																									9	1.3	2.45
		Measure escape flux of superthermal neutrals	1.3	3	78	22.7	4							1																									4	1.3	2.46
		Detect high energy neutrals and ions from interactions	1.3	3	78	19.6	3												1																				3	1.3	2.47
		Measure flux and energy of cosmic rays	1.3	3	78	11.3	1																																0	1.3	2.48
	Determine internal differentiation, thermal evolution of Titan. Determine if Titan has a metal core and an intrinsic magnetic field, extent and origin of geodynamic activity.	Measure rotation parameters (pole position)	1.4	4	70.7	23.6	4		0.9												0.2	1																	8.4	1.4	1.11
		Local subsurface seismic structure	1.4	4	70.7	16.7	2																0.8																1.6	1.4	2.195
		Low-Order Gravity Field (N=8)	1.41	4	70.7	35.4	9				1																												9	1.41	1.12
		Low-Order Topography (polar/equatorial radii)	1.42	4	70.7	33.3	8	1		0.9																													15.2	1.42	1.13
		Vector magnetic field around Titan	1.43	4	70.7	31.2	7 a					1												0.2															8.4	1.43	1.14
		Detect presence of seismic activity (tidal and tectonic)	1.44	4	70.7	28.9	6																0.8																4.8	1.44	1.15
OBJECTIVE 2: 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?	Determine the chemical pathways leading to formation of complex organics at all altitudes in the Titan atmosphere and their modification and deposition on the surface with particular emphasis on ascertaining the extent of organic chemical evolution on Titan.	Determine CHONPS elemental composition of surface	2.1	1	100	34.6	6																						1										6	2.1	3.11
		Determine surface composition of complex organics	2.1	1	100	42.4	9																						1										9	2.1	3.12
		Characterize physical state of organics	2.1	1	100	24.5	3																					1											3	2.1	3.13
		Measure isotope ratios of C,N,O of surface organics	2.1	1	100	40.0	8																						1										8	2.1	3.14
		Measure chirality of organic compounds	2.1	1	100	20.0	2																						1										2	2.1	3.15
		Measure chemical abundance of gases in atmosphere	2.1	1	100	34.6	6						0.3	0.6	0.7	0.4													0.8	0.3									18.6	2.1	3.2
		Measure chemical composition of particulates	2.1	1	100	37.4	7								0.2														0.4	0.1									4.9	2.1	3.21
		Measure sources of free energy	2.1	1	100	28.3	4									1	1																						8	2.1	3.22
		Measure atmospheric thermal structure with latitude	2.1	1	100	31.6	5				1		1		1																								15	2.1	3.23
	Determine geochemical constraints on bulk composition, the delivery of nitrogen and methane and exchange of surface materials with the interior	Measure noble gases and isotopes (esp Kr, Xe)	2.2	2	84.1	43.3	9																						1										9	2.2	1.21
		Detect Ammonia in surface material	2.2	2	84.1	40.8	8														0.5								0.7				0.5						13.6	2.2	1.22
		carbon, nitrogen isotopes in surface/atmosphere reservoirs	2.2	2	84.1	35.3	6						1		1														0.7	0.5									10.2	2.2	1.23
		Measure D/H in surface material	2.2	2	84.1	28.8	4																						0.8										3.2	2.2	1.25
		Composition of gases released from vents etc	2.2	2	84.1	38.2	7						1														0.1		0.2	0.5			0.1						13.3	2.2	1.26
	Determine chemical modification of organics on surface e.g. hydrolysis via impact melt.	Determine CHONPS composition of modified deposits	2.3	3	78	41.0	7																						0.7										4.9	2.3	3.31
		Determine composition of complex organics in special sites	2.3	3	78	46.5	9																						0.7										6.3	2.3	3.32
		Identify potential chemical modification sites from mapping	2.3	3	78	43.9	8		0.1												0.8												0.3						9.6	2.3	3.33
		Measure induced magnetic field	2.4	4	70.7	28.2	7					0.8												0.8															9.8	2.4	1.31
		Detect seismic reflections within crust	2.4	4	70.7	23.8	5																0.8																4	2.4	1.32
		Measure normal seismic modes	2.4	4	70.7	26.1	6 b																0.8																4.8	2.4	1.33
		Detect subsurface radar reflections	2.4	4	70.7	21.3	4			0.8																						0.9							6.8	2.4	1.34
		Measure libration and variations in rotation period	2.4	4	70.7	18.5	3		0.5													0.7																	3.6	2.4	1.35
		Regional scale topography (~20km) (flexure)	2.4	4	70.7	15.1	2	1		0.6																									1				5.2	2.4	1.36
		Measure changes in gravity field (k2)	2.4	4	70.7	32.0	9				1																												9	2.4	1.37
		Measure orbital changes in topography (h2)	2.4	4	70.7	30.2	8	0.8																															6.4	2.4	1.38

Europa vs. Titan

Planetary scientists are in the final stretch of a first-time competition designed to get the most science for the buck from the next big planetary mission while avoiding the fiscal debacles of the past

TEMPE, ARIZONA—Frances Bagenal wants to get back to the outer solar system, but that will take some doing. It will be at least

"I think that's healthy," says Bagenal. "Each team has had to hone its arguments [even though] it means not everyone gets

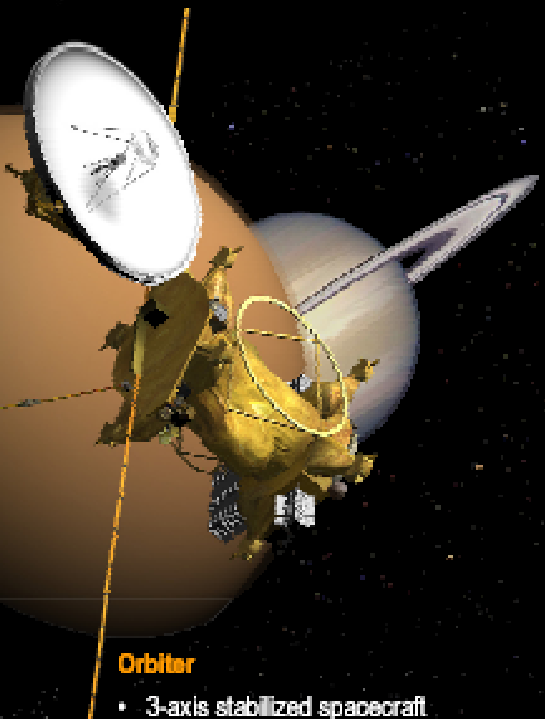
nature Vol 457|22 January 2009

SPECIAL REPORT

Which moon to shoot for?

Planetary scientists have a rare chance to pick the destination for their next big mission. But will it be Titan or Europa? **Eric Hand** reports.

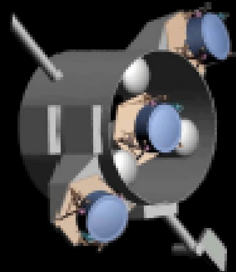
2[nd] phase in Flagship shoot-out. Aerocapture ruled out. In-situ elements from Europe (lake lander and balloon). Must do Enceladus science as well as Titan.



Mission & Spacecraft Overview

NASA Orbiter with ESA *In situ* elements
- Orbiter + Solar Electric Propulsion (SEP)
- Lake Lander and Montgolfière Balloon
- NASA provided launch vehicle and Radioisotope Power System

Mission Design
- 2020 gravity assist SEP trajectory
- 9 years to Saturn arrival
- SEP stage released ~5 yr after launch
- Montgolfière released on 1st Titan flyby, Lander on 2nd Titan flyby
- ~4 year prime mission: 2 yr Saturn tour, 2 mo Titan aerosampling, 20 mo Titan orbit

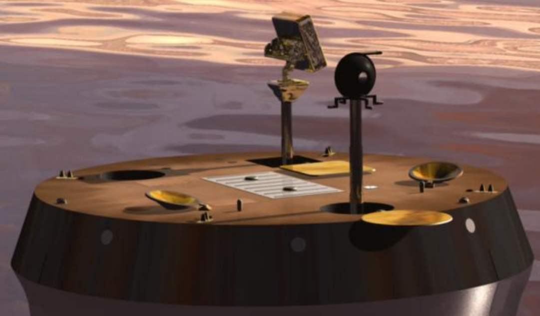


Orbiter
- 3-axis stabilized spacecraft
- 4 m High Gain Antenna with 35 W Ka-band amplifier gives high data downlink
- 5 Advanced Stirling Radioisotope Generators (4 baselined, 1 spare) provide 540 W at end of mission (Design also compatible with MMRTG RPS)
- 165 kg instrument payload allocation
- Orbiter dry mass 1613 kg (includes 35% system margin)
- Provides accommodation for two *in situ* elements (833 kg total allocation)
- SEP stage included for inner solar system thrusting
  - 3 NEXT ion thrusters
  - Two 7.5 kW Orion CEV-derived Ultraflex solar arrays
- Total launch mass 6203 kg on Atlas V 551

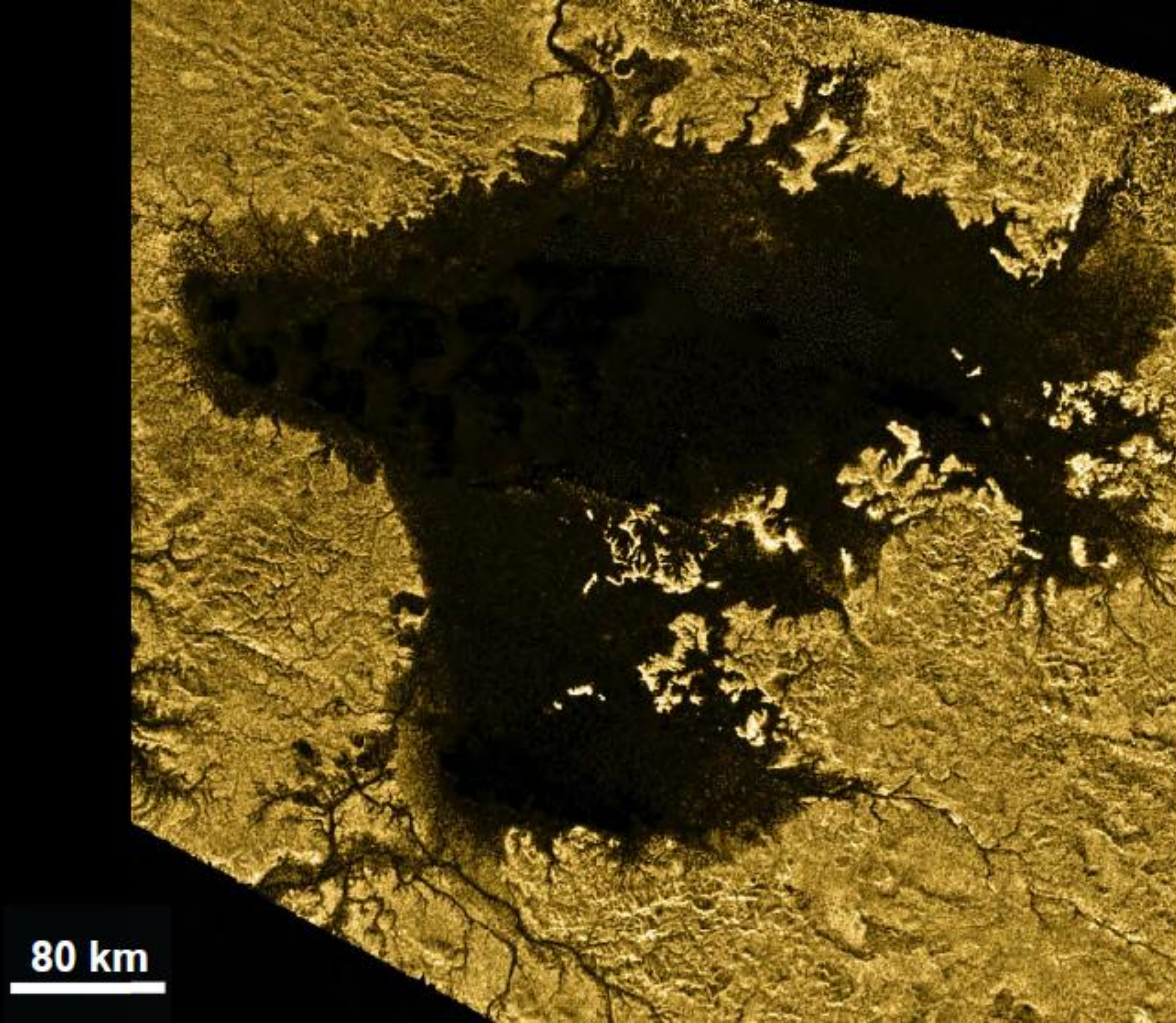
Montgolfière
- Buoyancy provided by US-supplied Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) (~1700 W thermal)
- 10.5 m diameter envelope
- 10 km nominal cruise altitude
- 6 mo nominal mission length
- Up to 600 kg launch mass including aeroshell
- Telecom relay through orbiter via 0.5 m HGA

Lander
- Lander targeted for northern mare
- Battery operated
- 9 hour nominal mission duration
- 190 kg launch mass including aeroshell
- Telecom relay through orbiter via X-band omni antenna

A Brief History of TiME



- Titan’s lakes discovered summer 2006; seas in 2007
- TiME Proposed in 2007 to DSMCE study call for PI-led (i.e. small) missions enabled by ASRG Stirling Generator
- Concept refined during DSMCE study; proposed to Discovery 12 opportunity in 2010
- Selected May 2011 for Phase A study. Generated much intere
- InSight selected August 2012
- ASRG development delayed, then suspended.
- No RPS allowed for Discovery 2014.


80 km

TiME Science Objectives

- **Constrain sea composition**
  - Determine the chemistry of seas to constrain Titan's methane cycle, look for patterns in the abundance of constituents in the liquids and analyze noble gases. ***Instruments:*** Mass Spectrometer (MS), Meteorology and Physical Properties Package (MP3).
- **Constrain sea depth**
  - Determine the depth of the Titan sea to determine sea volumes, and thus, organic inventory. ***Instrument:*** MP3 (Sonar).
- **Measure sea surface properties**
  - Characterize physical properties of sea liquids and how they vary with depth. ***Instrument:*** MP3.
  - Determine how the local meteorology over the seas ties to the global cycling of methane on seasonal and longer timescales. ***Instrument:*** MP3
  - Analyze the nature of the sea surface (waves, foam) and the state of the atmosphere above the sea. ***Instrument:*** Descent and Surface Imagers (DI, SI).

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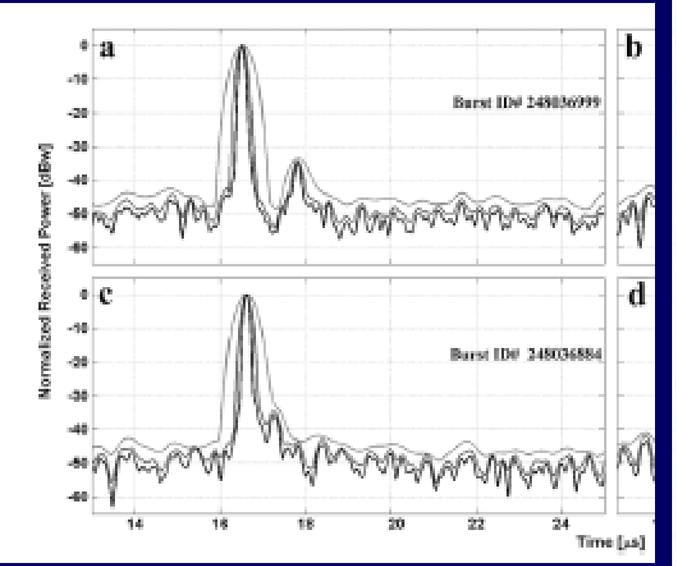
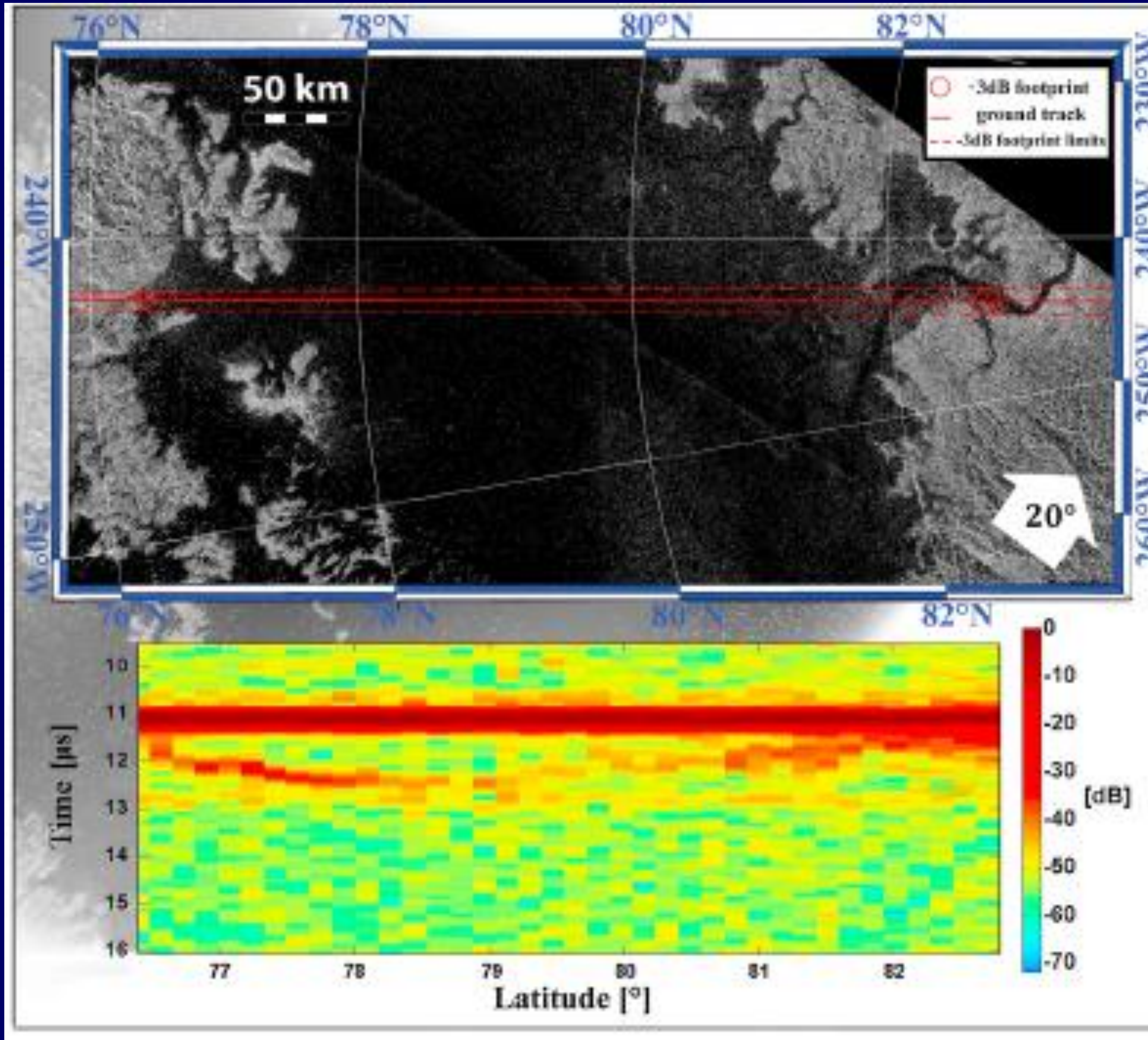
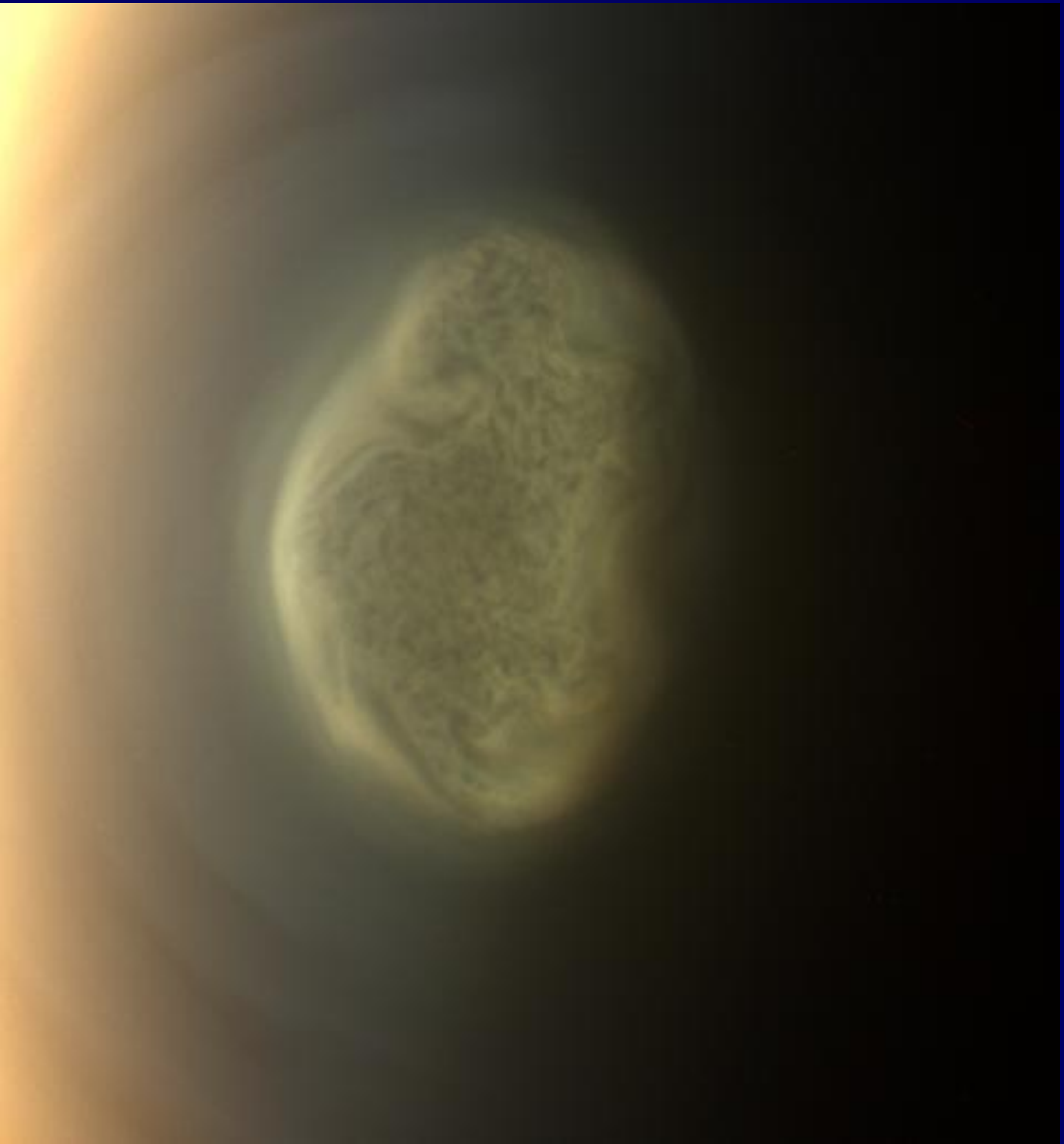
Recently, Mastrogiuseppe et al (GRL, 2014) reported a distinct second echo from altimetry over Ligeia Mare on T91 (May 2013). Such an echo (from a depth of up to ~160m) requires the sea to be exceptionally radar-transparent (consistent with lab measurements of methane/ethane)

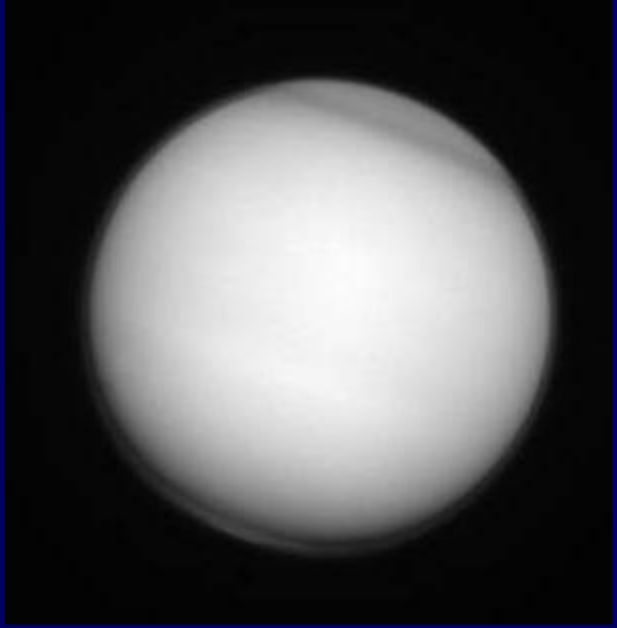




Which means viscosity should be low, not too hard to form waves…

June 2012 : South Polar Vortex cloud





June 29, 2012 Blue

AVIATR – Aerial Vehicle for In-Situ and Airborne Titan Reconnaissance

A Titan Airplane Mission Concept

Jason W. Barnes · Lawrence Lemke · Rick Foch · Christopher P. McKay · Ross A. Beyer · Jani Radebaugh · David H. Atkinson · Ralph D. Lorenz · Stéphane LeMouélic · Sebastien Rodriguez · Jay

Cassini Mission Overview

Four-Year Prime Tour, Equinox Mission, and Solstice Mission (Proposed), July 2004 - July 2017

Titan remains a compelling target of future exploration, with more scientific disciplines represented, and more vehicle types possible (with consequent public appeal), than anywhere else but Earth.

Lots of low-hanging scientific fruit.

But long duration missions require radioisotope power.

Exclusion of Titan from New Frontiers mission list is questioned by many.

Lots of exciting findings still coming from Cassini.