The Huygens Probe at Titan

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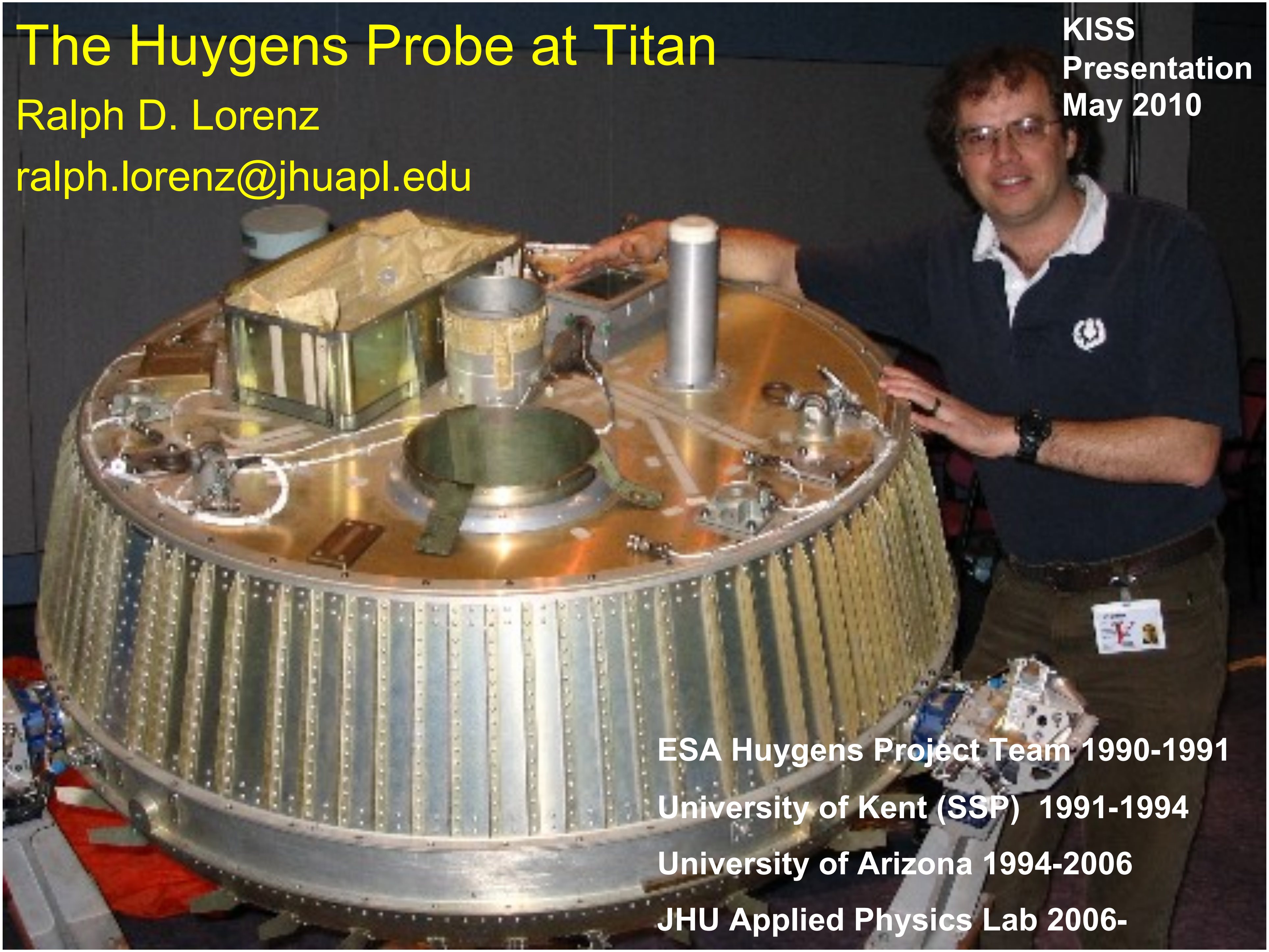
KISS
Presentation
May 2010

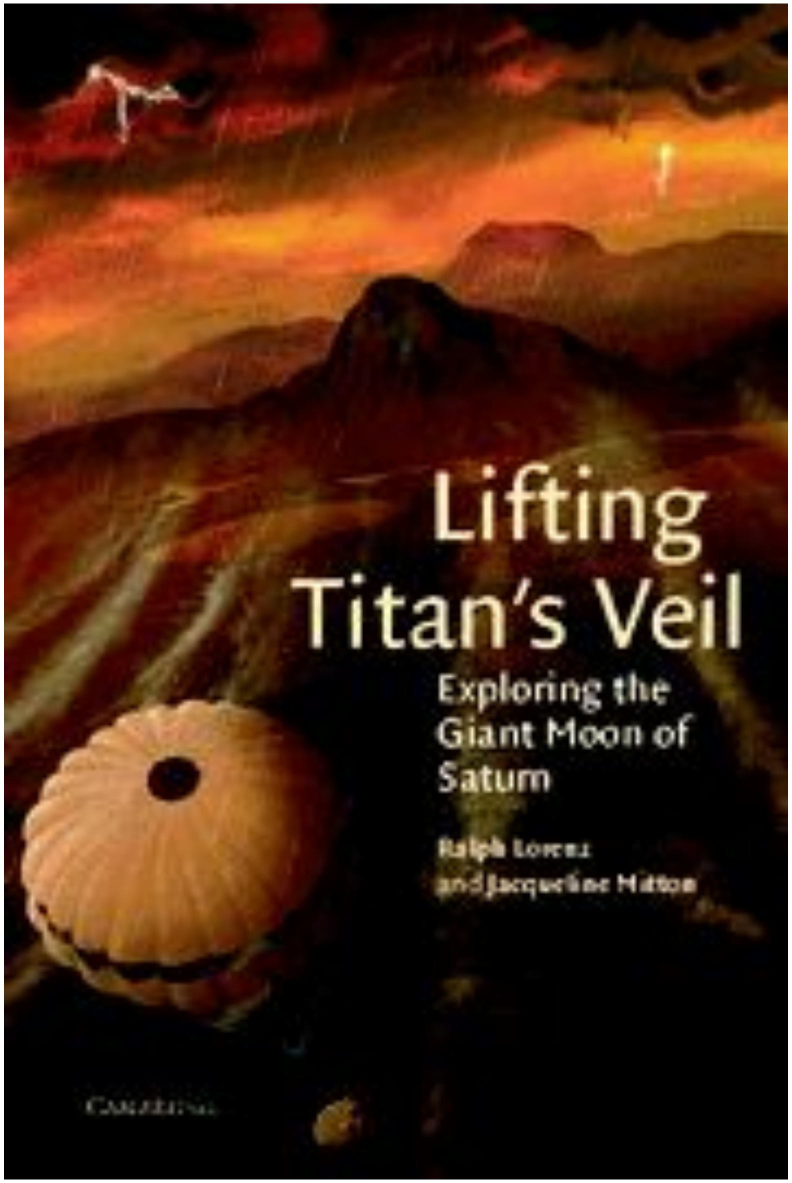


ESA Huygens Project Team 1990-1991

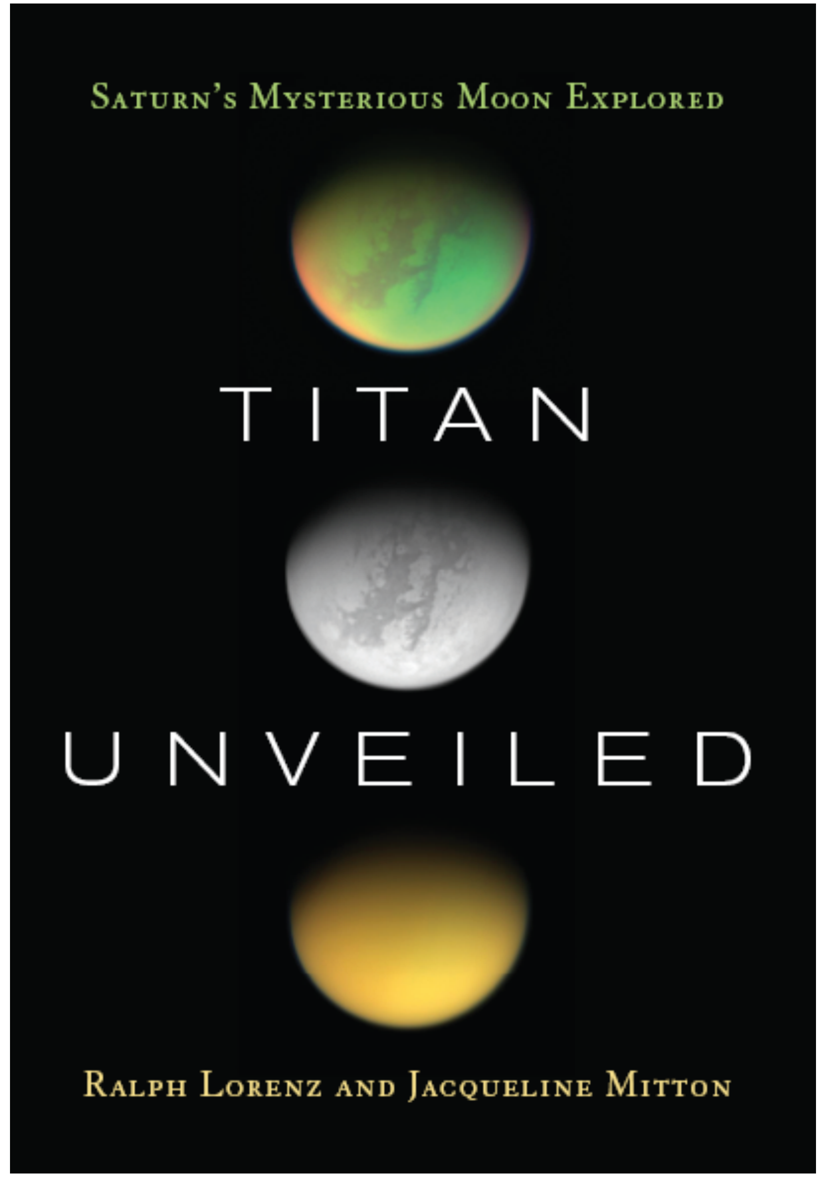
University of Kent (SSP) 1991-1994

University of Arizona 1994-2006

JHU Applied Physics Lab 2006-



CUP, 2002

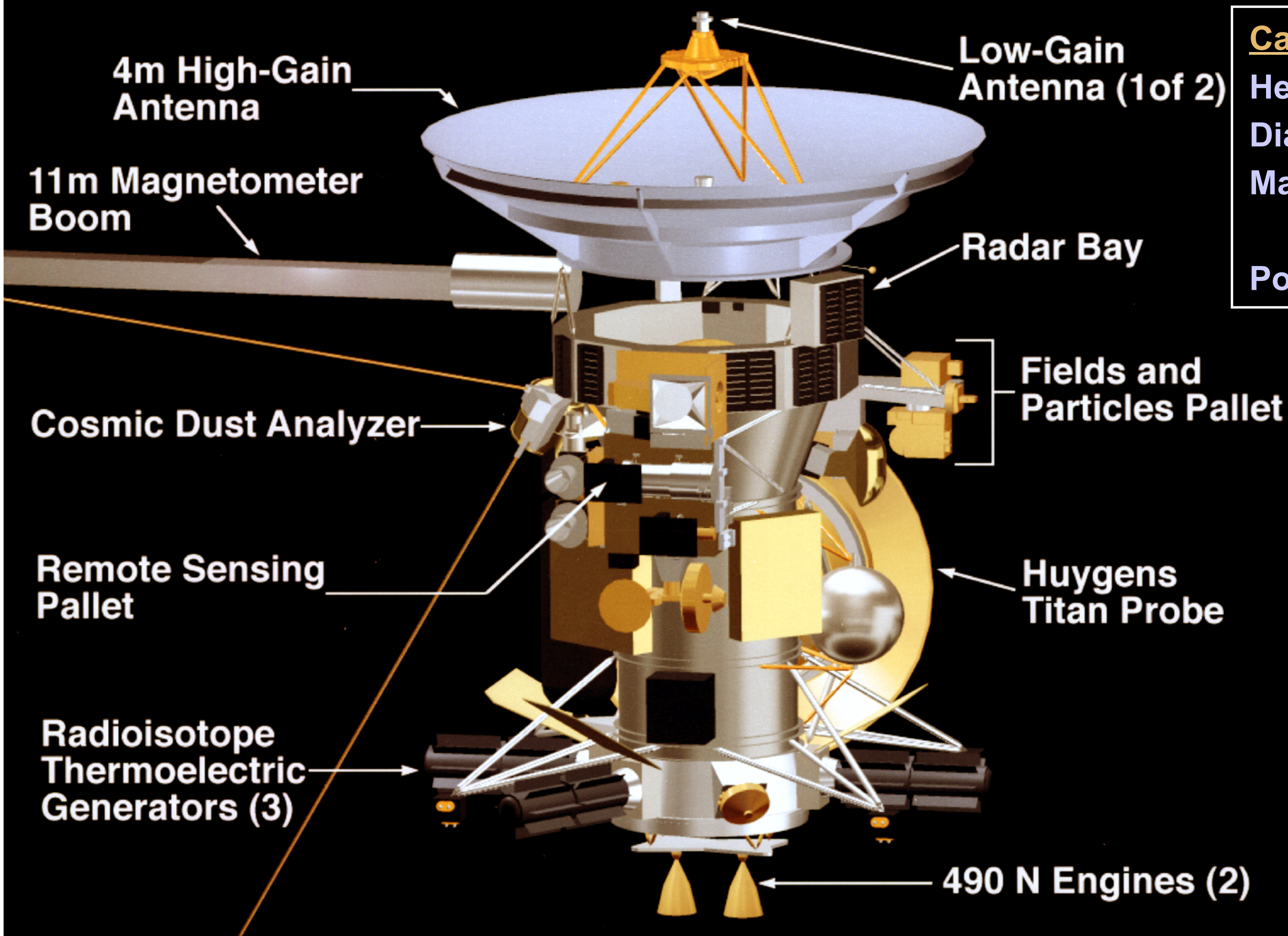


PUP, 2008

Revised paperback 2010


Outline
Huygens Project
Probe Design
Descent Dynamics and Spin
Impact
Thermal Behaviour
(RF multipath ; Receiver Anomaly and Resolution)

Cassini Spacecraft



Cassini 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

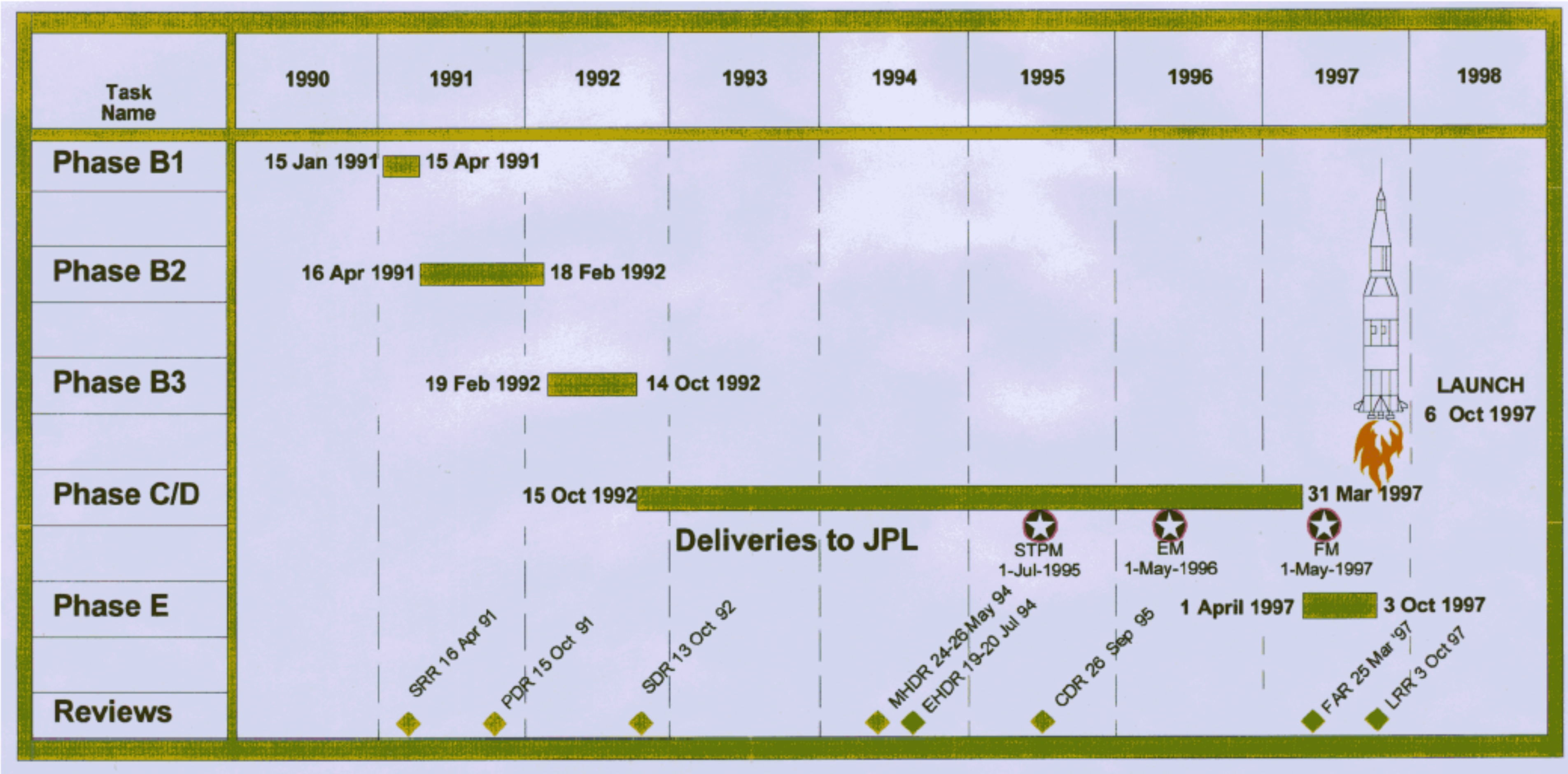
Huygens Probe Specs

Diameter: 2.7 m

Mass: 320kg inc. Heat shield. ~200kg at landing

~1500 W-hr Lithium primary battery

2 S-band telemetry links @ 8kbps



~6.5 year development schedule (NB pacing re: orbiter)

7 year flight time. Implications for knowledge retention, software/hardware maintenance.

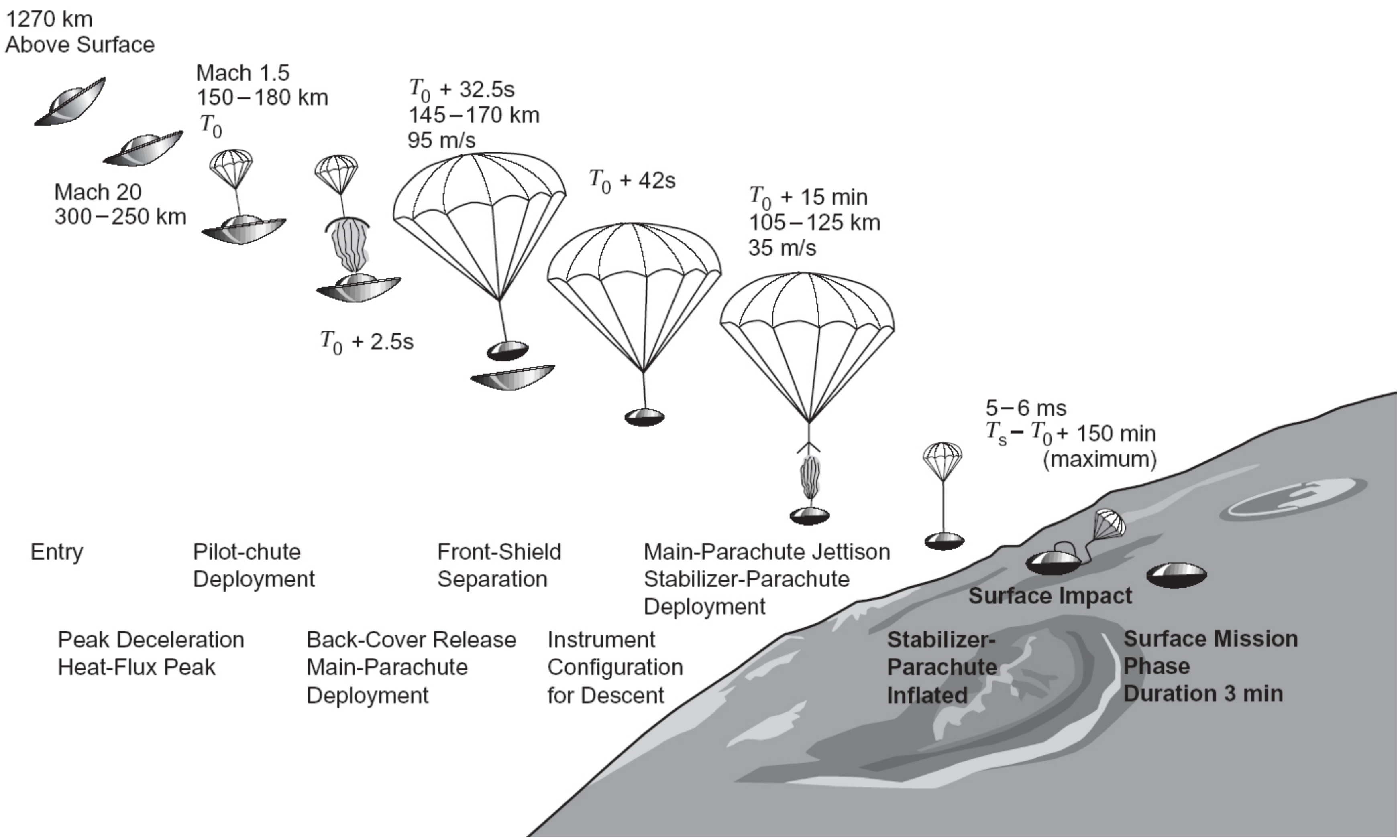
NB change in working methods/tools (electronic documents etc.)

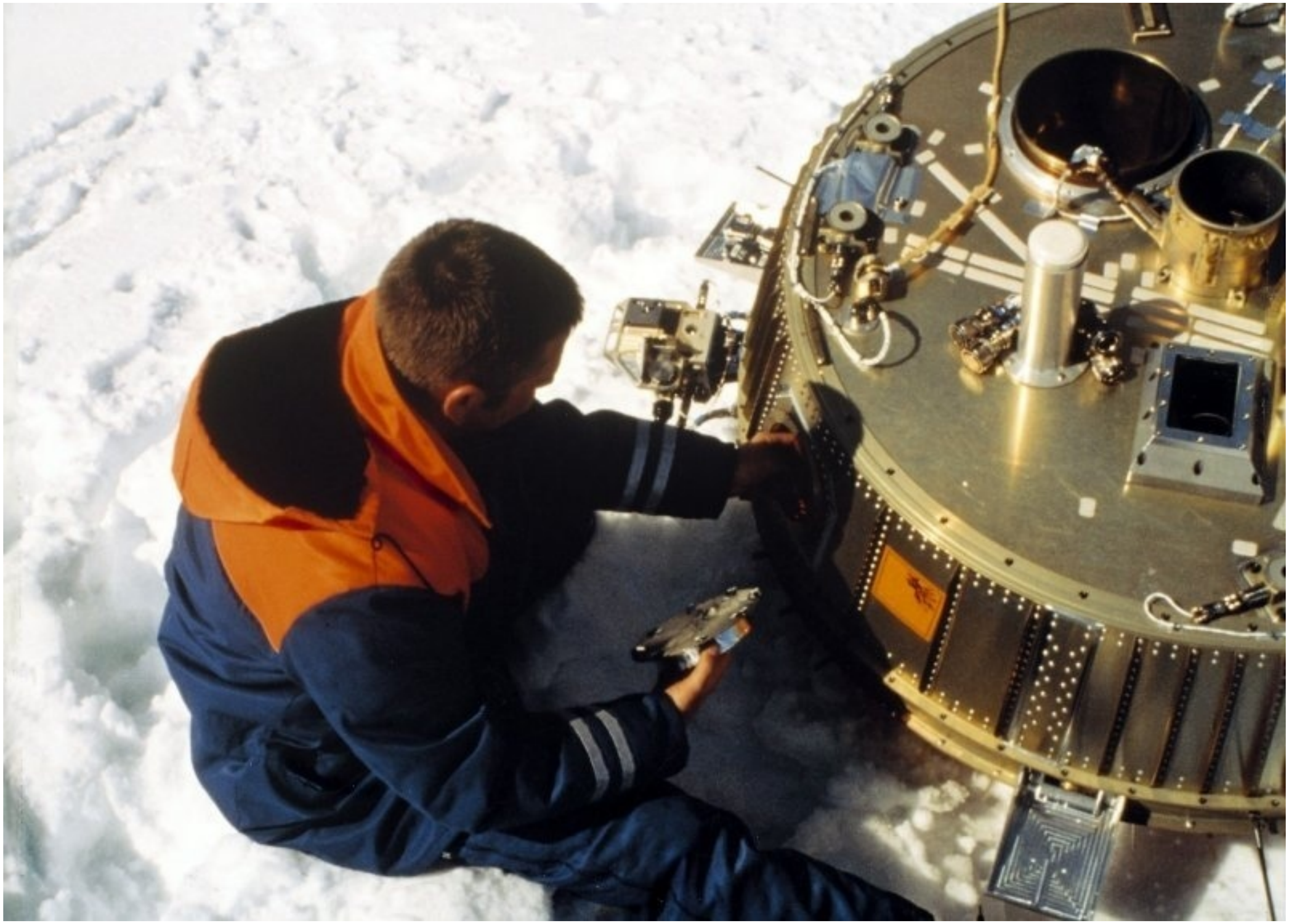
ESA 'juste retour' system for geographical allocation of contracts in proportion to overall budget contribution.

Institutionally essential, perhaps, but programmatically inefficient.

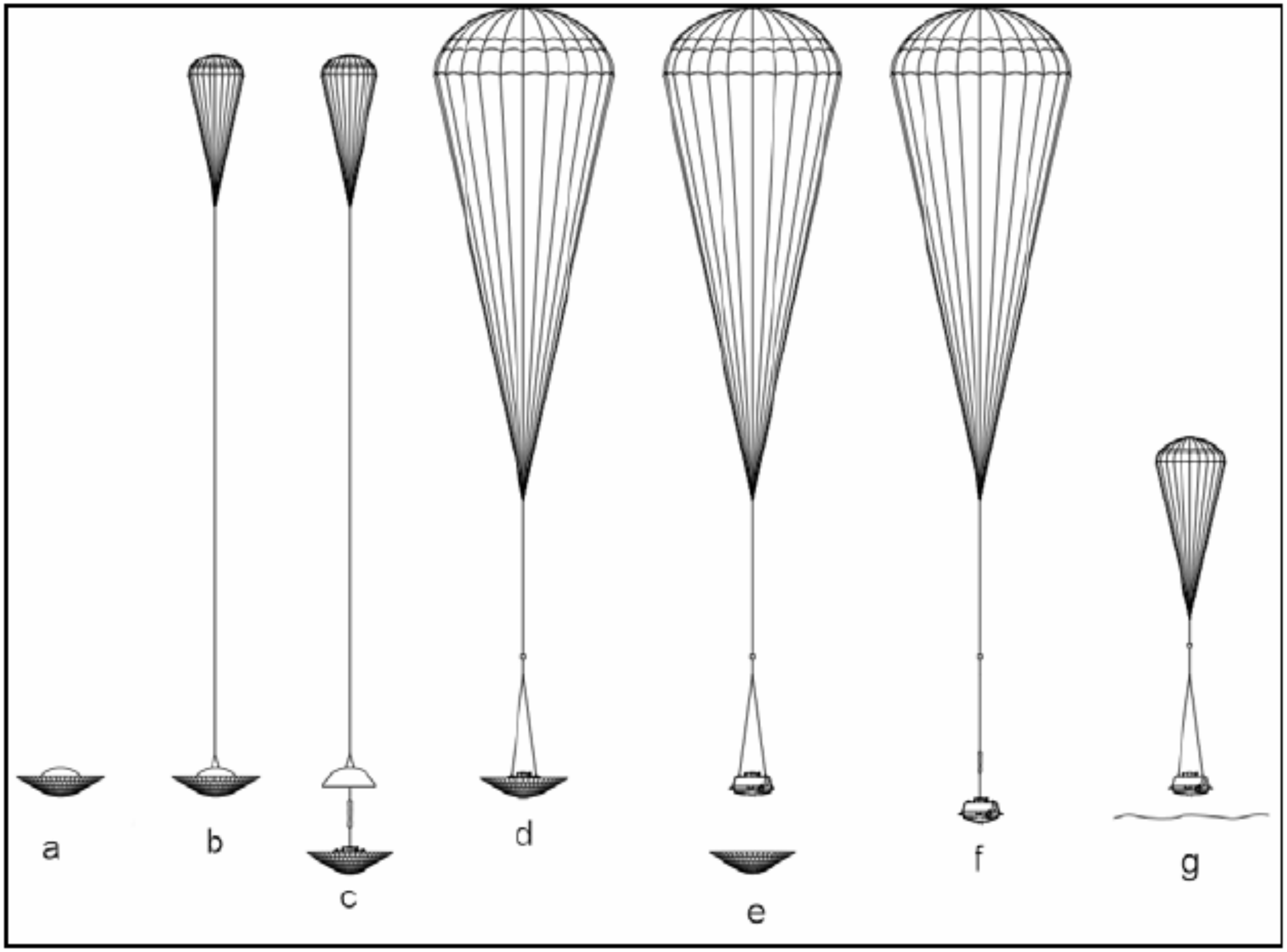
NB Payloads on ESA missions paid for by member states.

Huygens Probe Descent





SM2 - Parachute drop test from 40km balloon over northern Sweden, 1995
Successfully demonstrated heat shield separation/parachute sequence.
Deviant rotational behavior not noticed at the time.

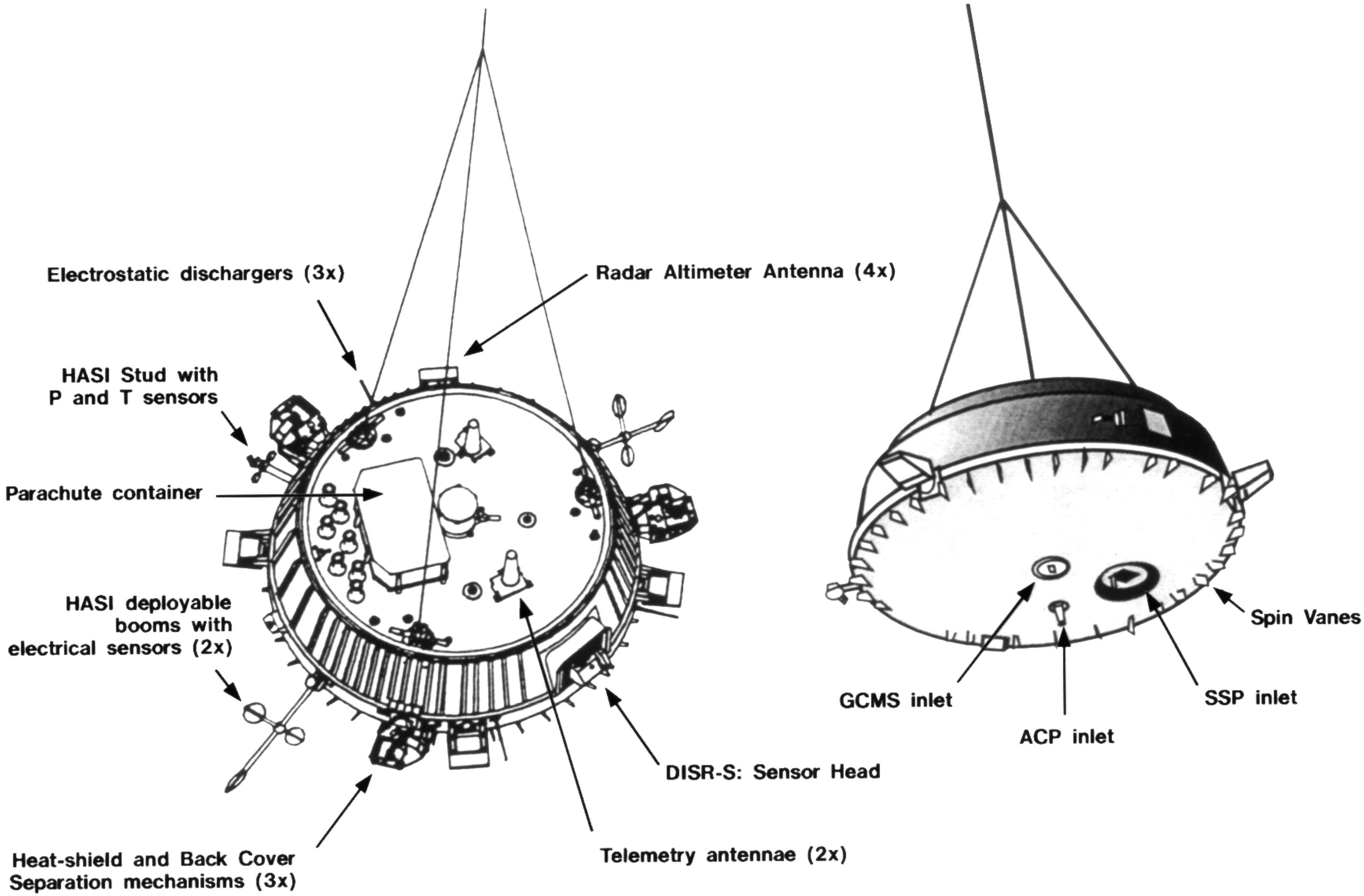


2.59m Pilot chute for transonic stability deployed by mortar through break-out patch.

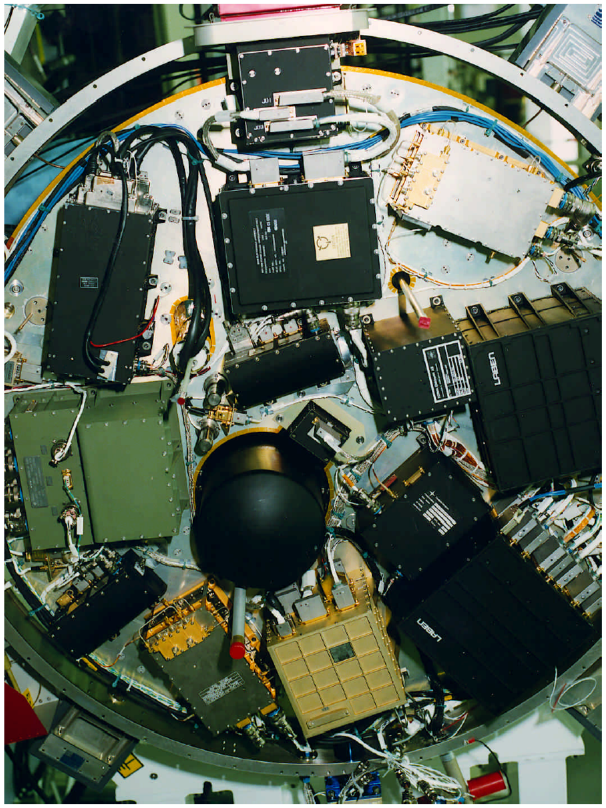
Pulls off back cover and deploys main chute via lanyard. 8.3m main chute needed for safe front shield separation

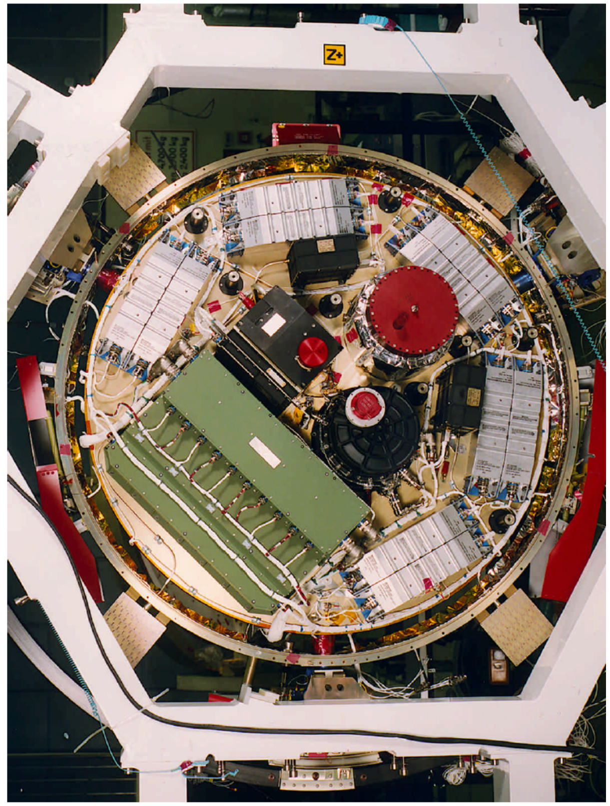
3.3m Stabilising drogue to achieve descent fast enough to reach surface within telecom & energy window

All parachutes nylon DGB with kevlar bridle, riser & lines



Huygens Descent Configuration

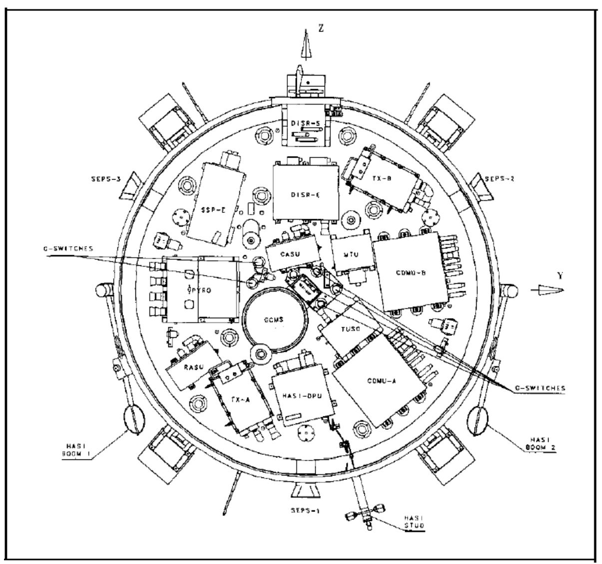


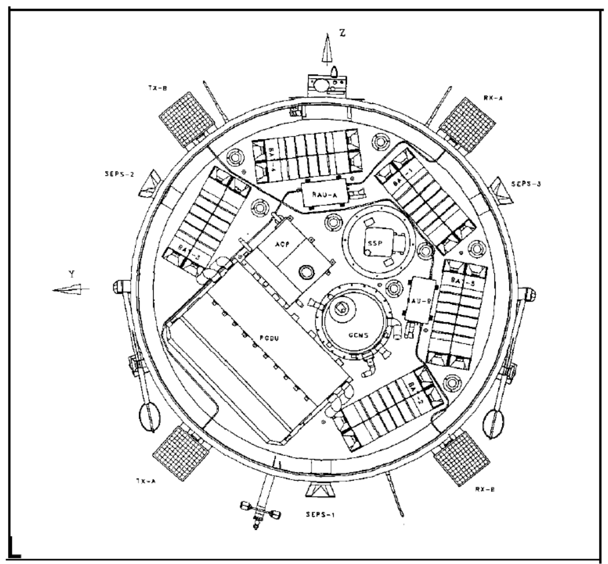


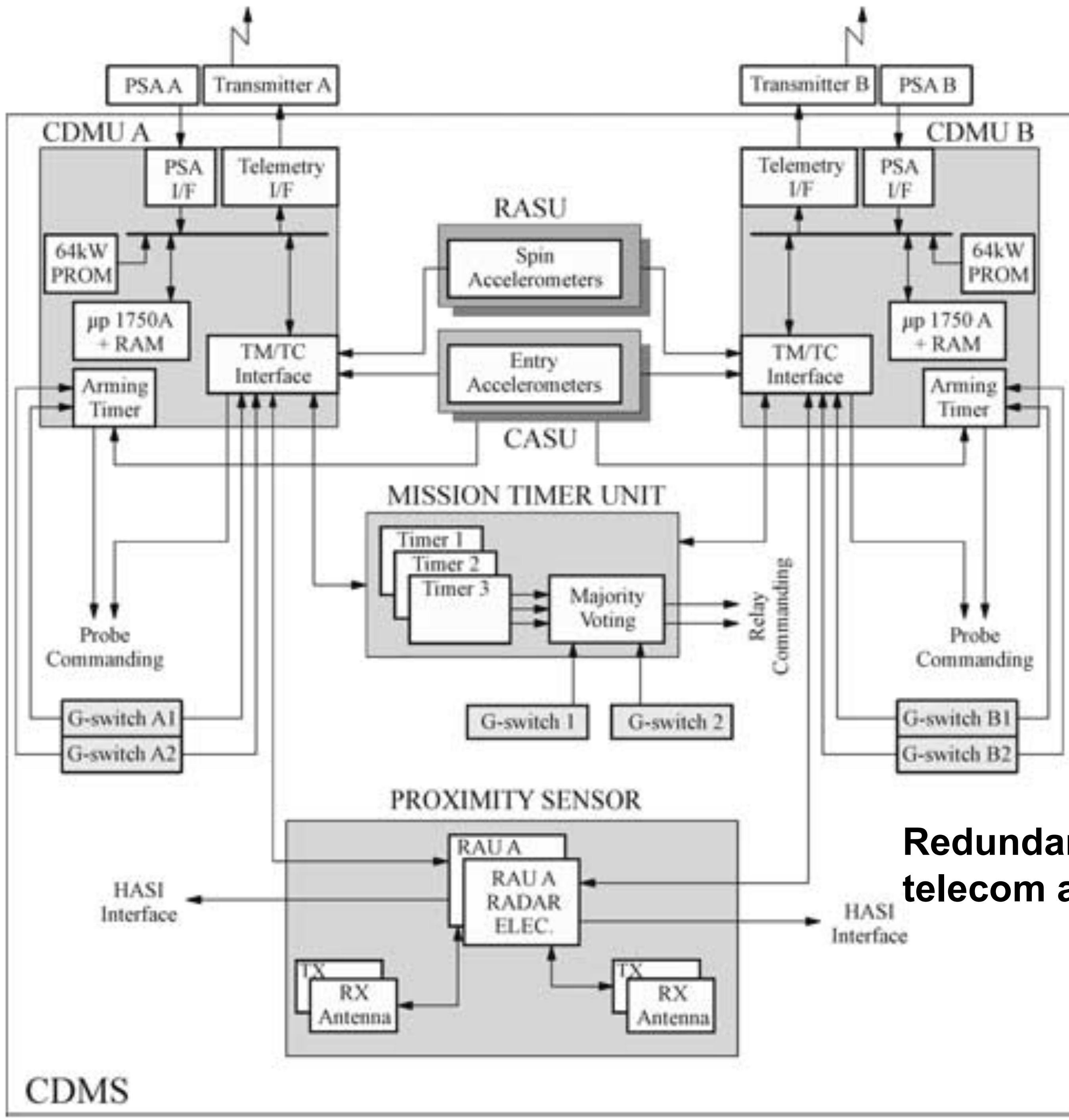
Layout of systems and payload on 1.2m 'experiment platform'

Thin metal shell acts as Faraday cage ; foam insulation.

Impact not a driver for structural design



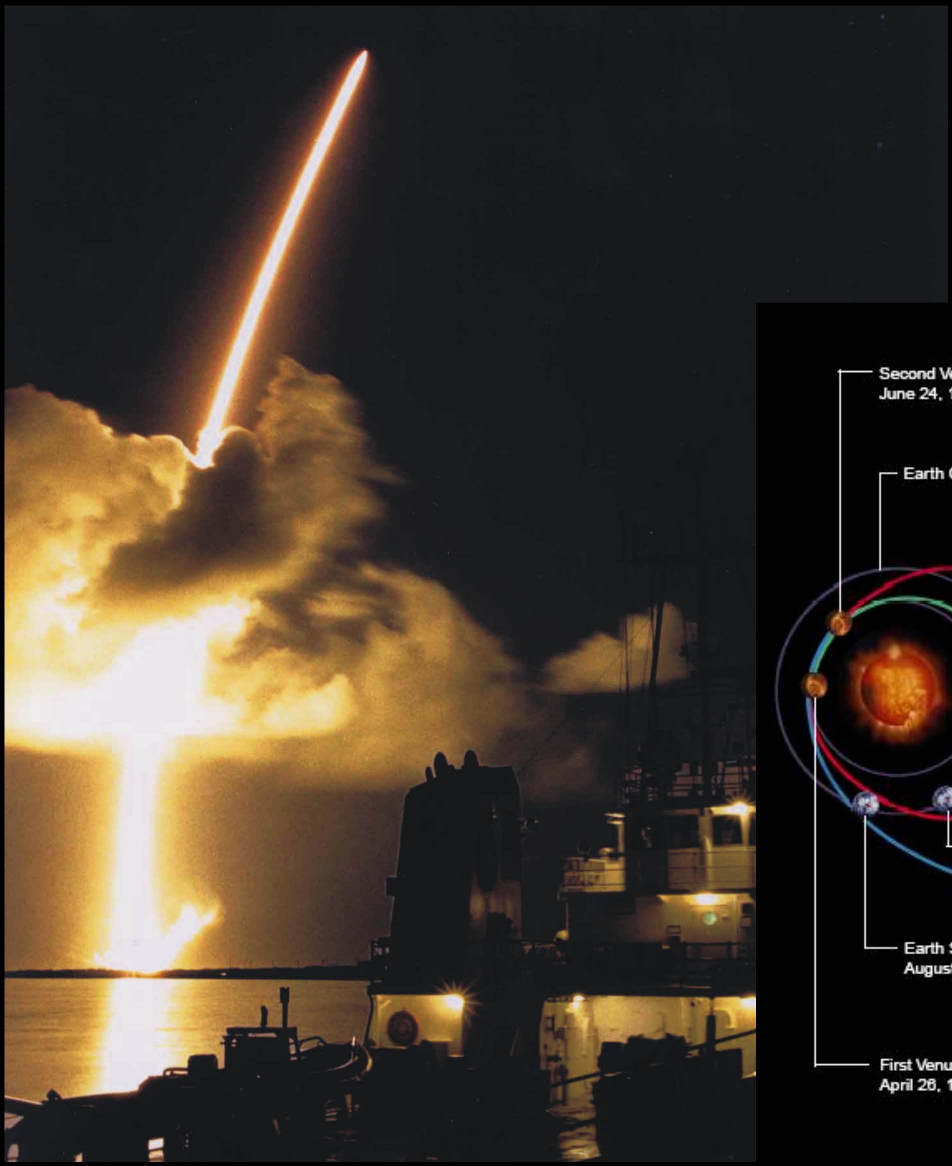


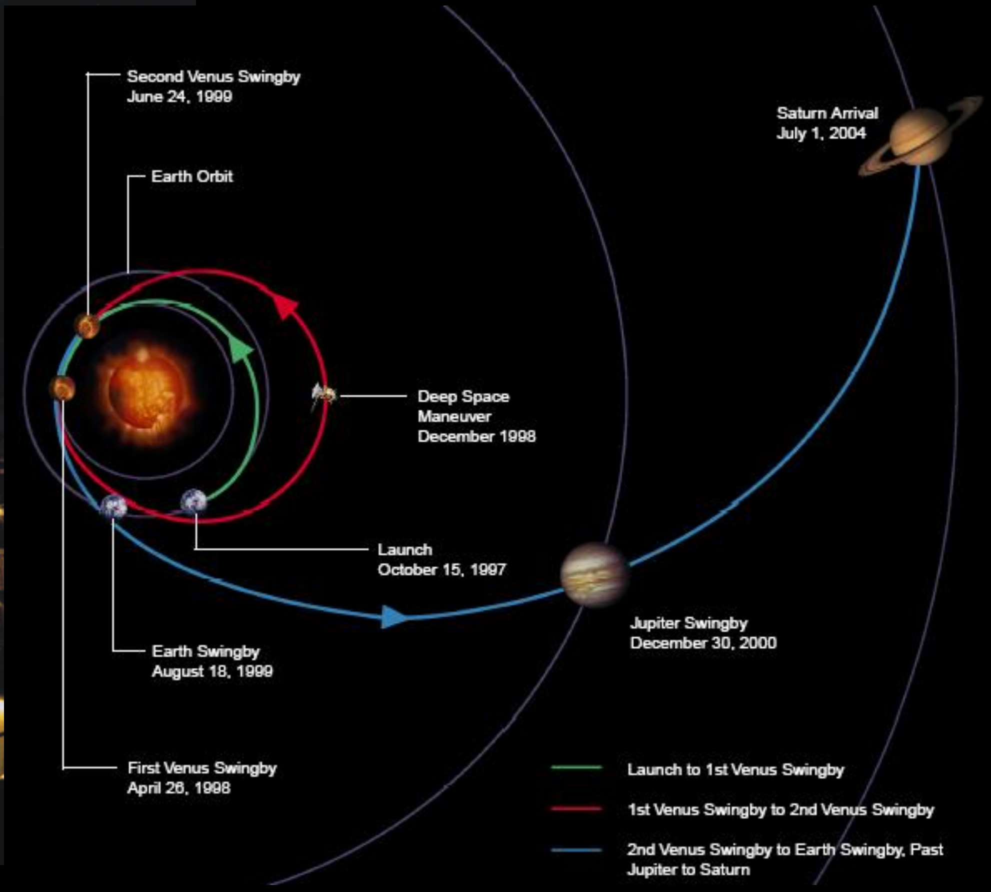


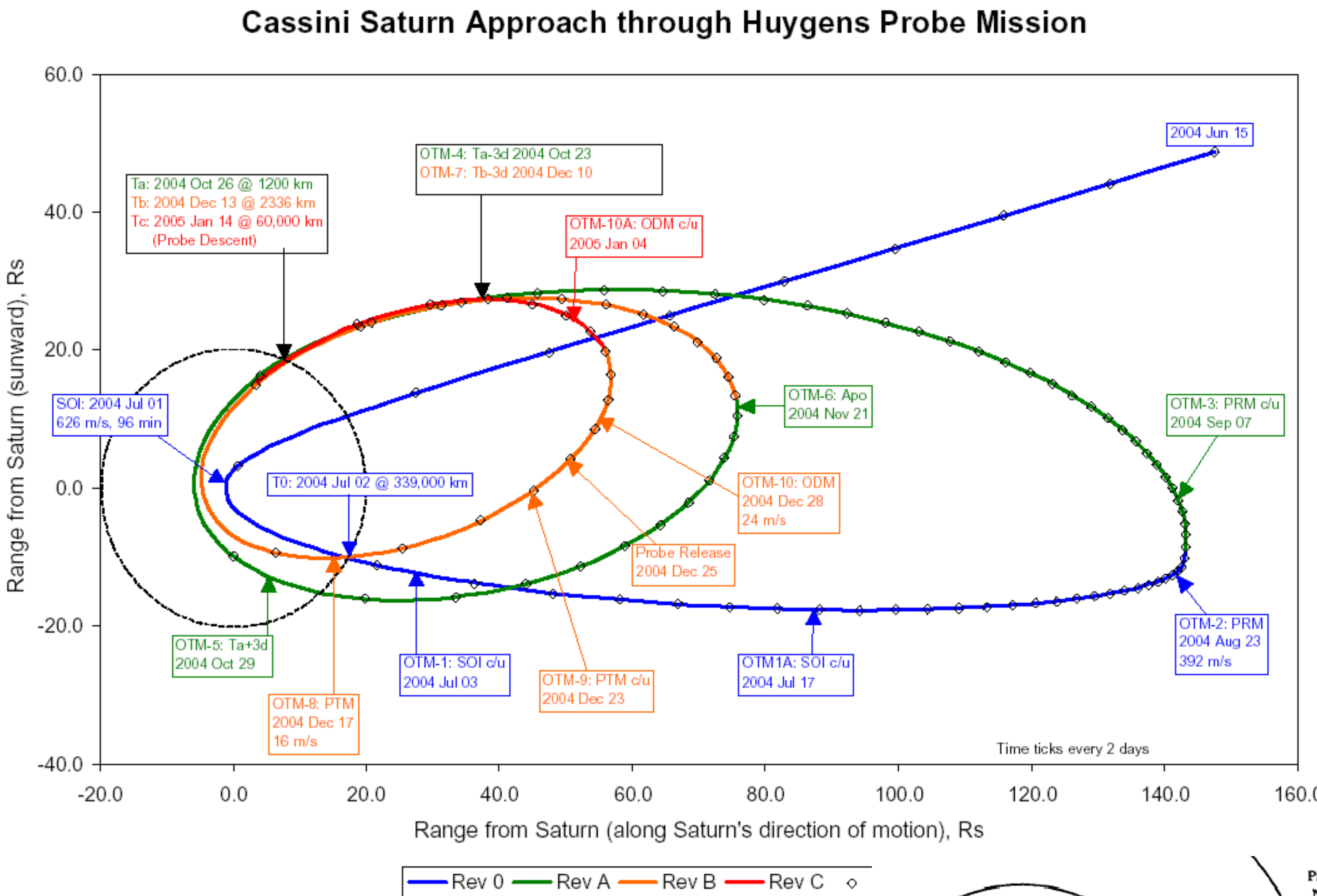
Redundant CDMS and telecom architecture.

Launched on October 15, 1997 from KSC

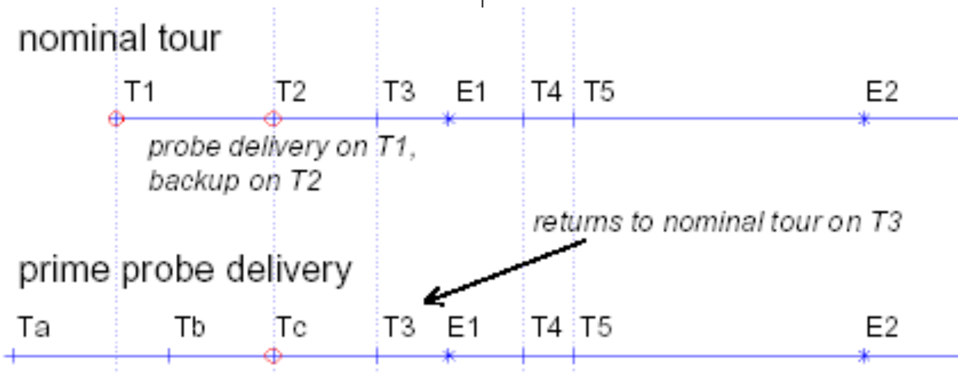
7 Year cruise on VVEJGA trajectory

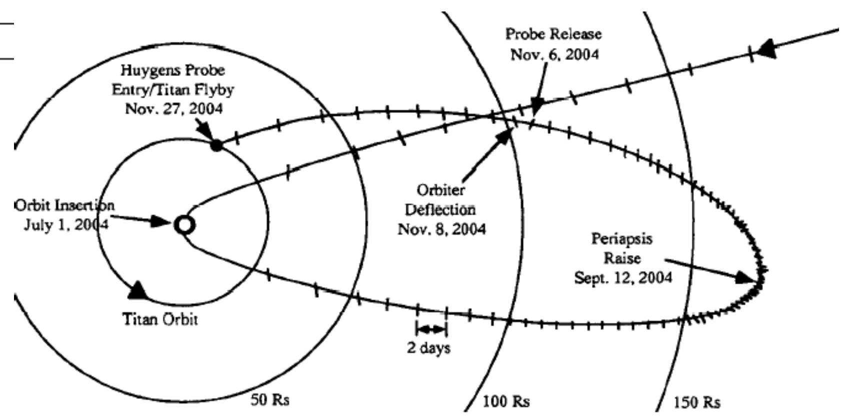




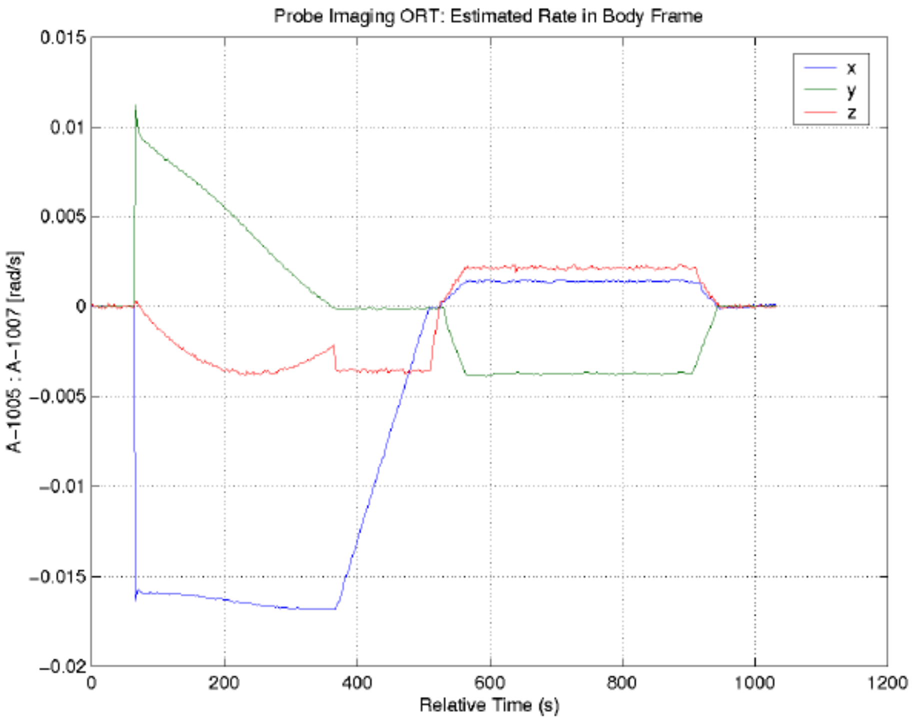


Early orbit sequence and delivery modified after radio flaw discovered in 1999

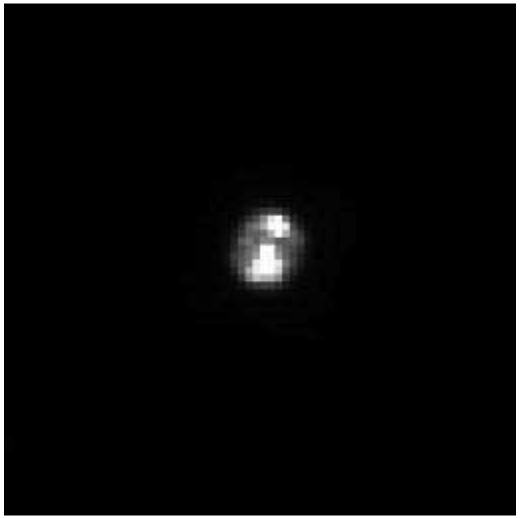


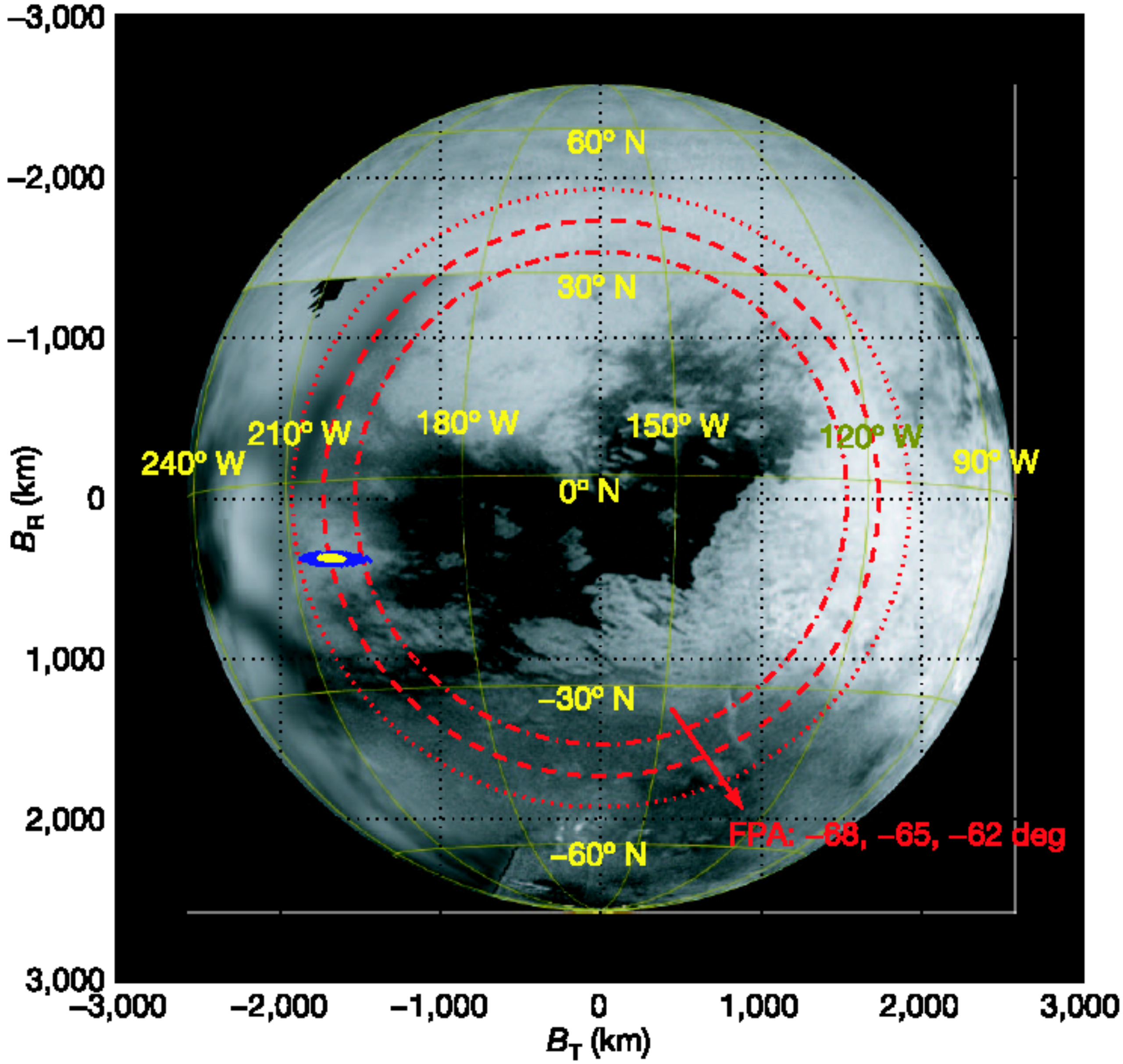


Separation Performed Dec 24, 2004



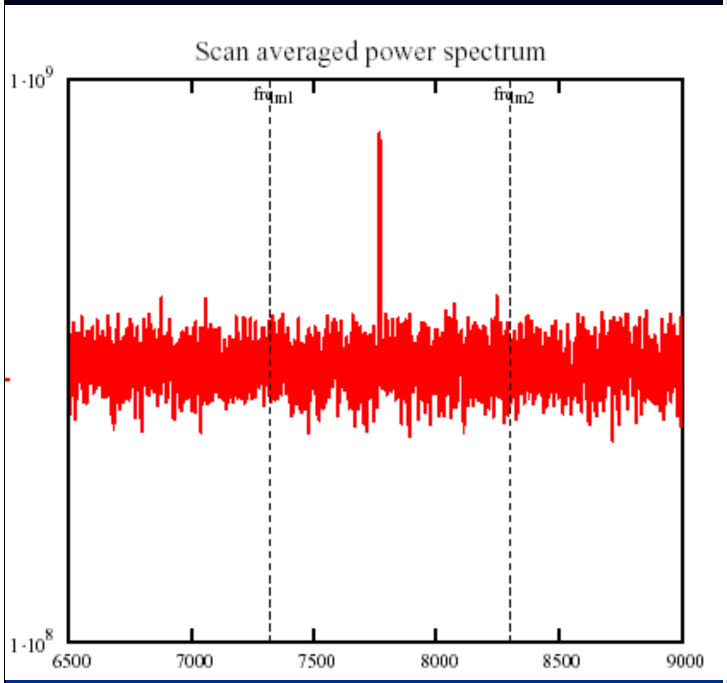
Huygens from 52km away (Dec 26, 2004)

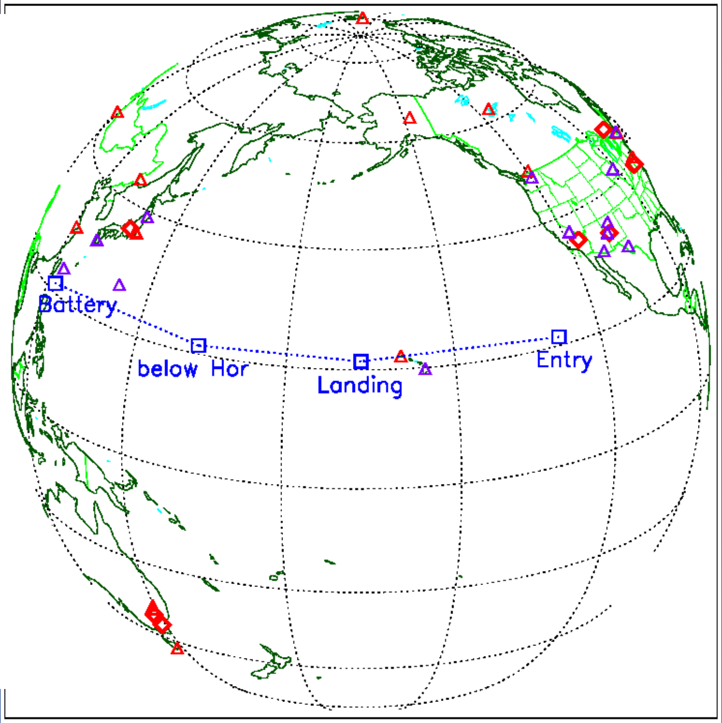




Landing site chosen largely by geometric constraints (entry angle, solar zenith, doppler wind projection)

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



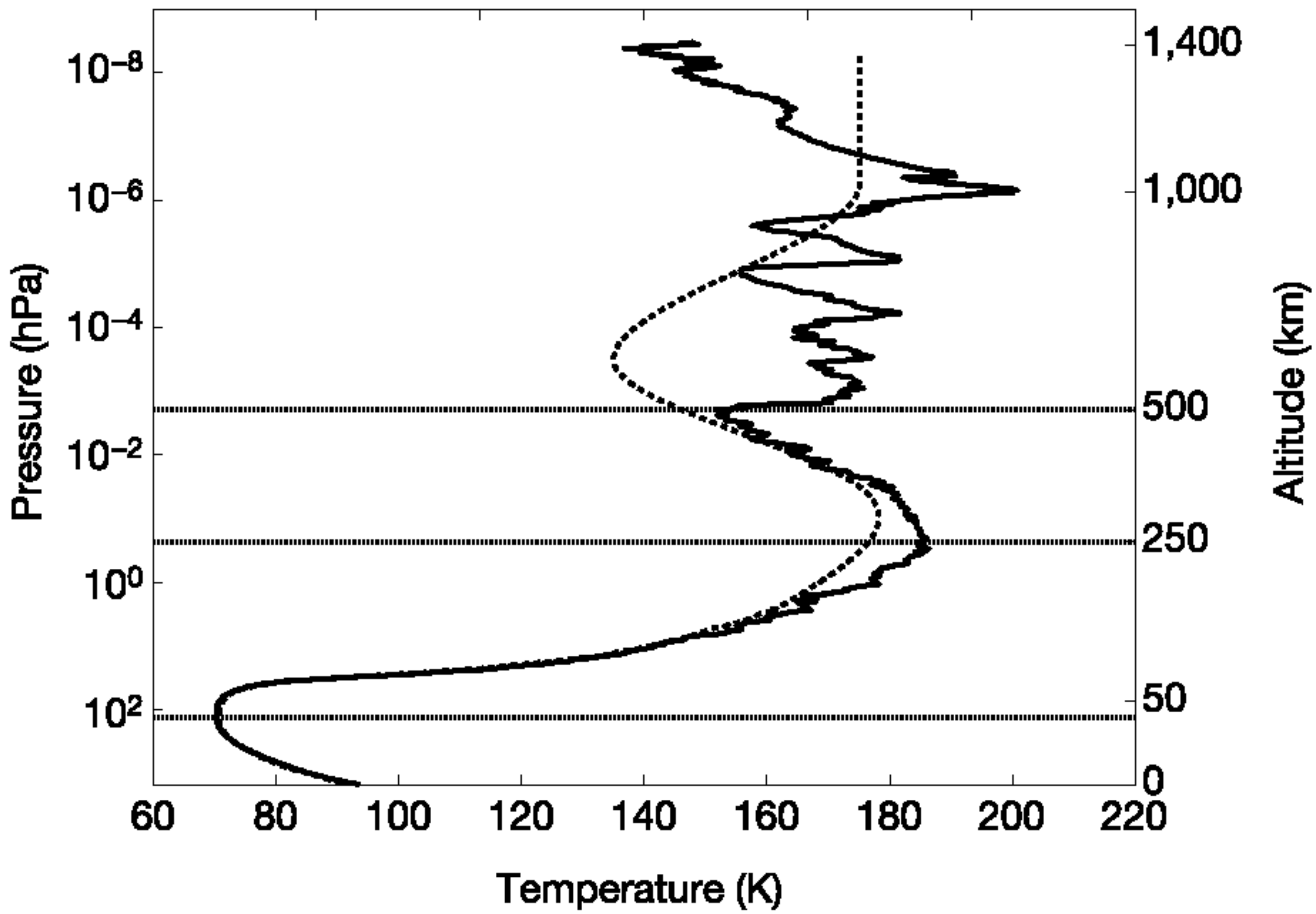


First detection by Green Bank ; Parkes took over. Supplemented by smaller telescopes (e.g. Kitt Peak)   Probe probably transmitted for >15 minutes after last detection.

NB two distinct observing campaigns (same dishes, different receivers

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

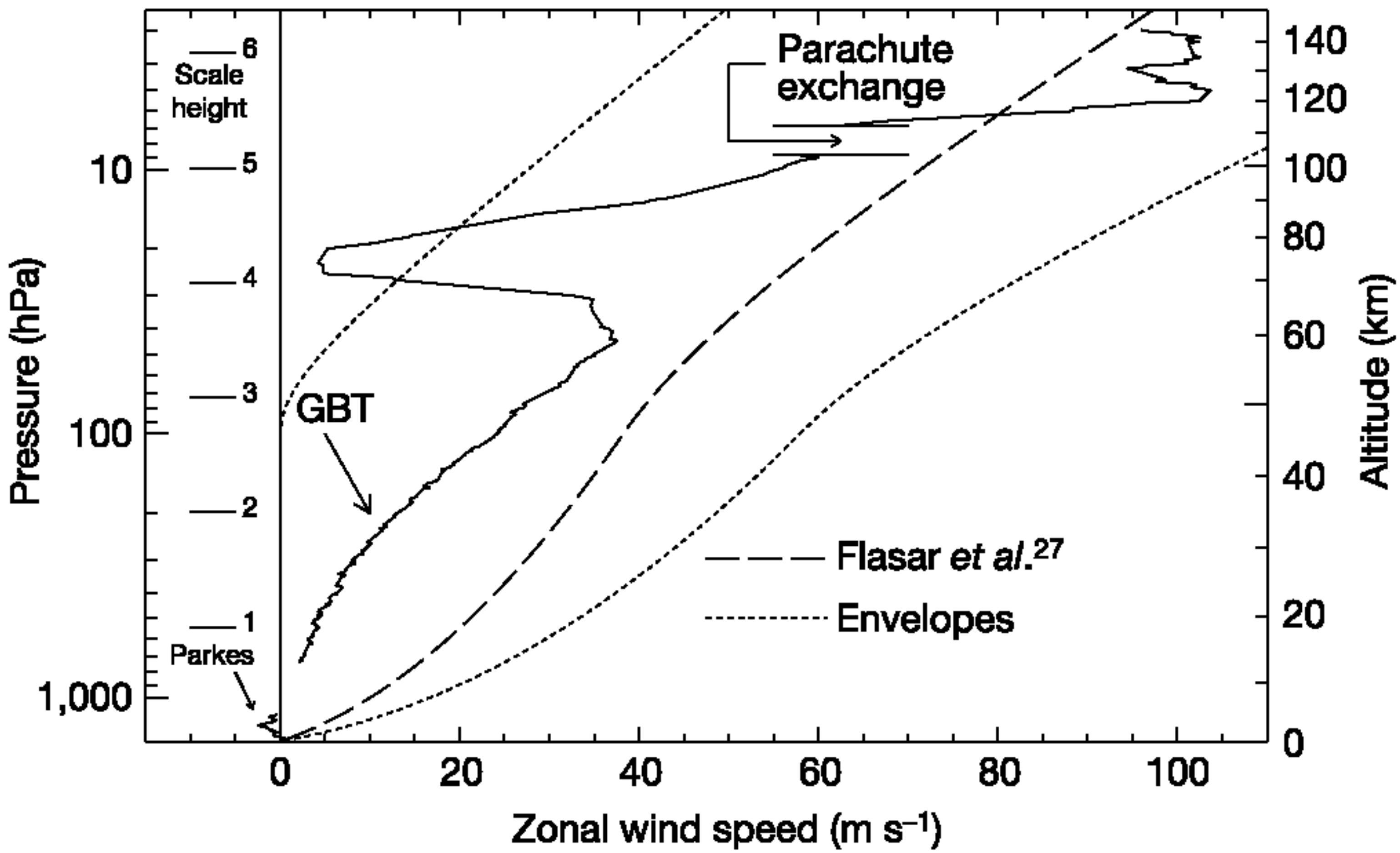
2. VLBI to monitor position on the sky



Huygens Atmospheric Structure Instrument

High-altitude temperature profile derived from aerodynamic deceleration (in fact, the accelerometer was the most sensitive used on a planetary mission - a few micro-g, picked up the atmosphere at 1500km!)

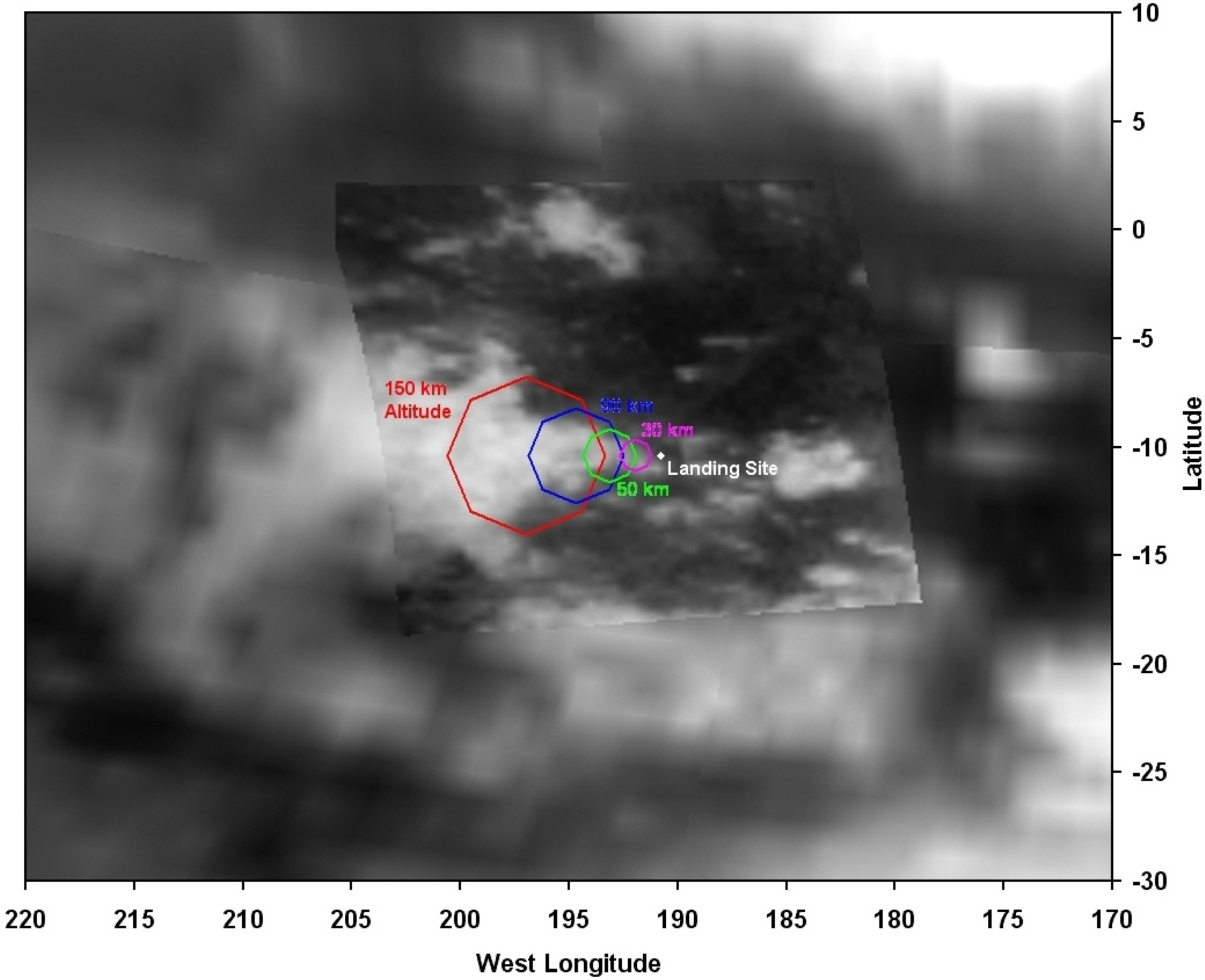
Mesosphere (minimum in dotted line) was basically absent! Lots of small-scale structure due to gravity waves and possibly tides.



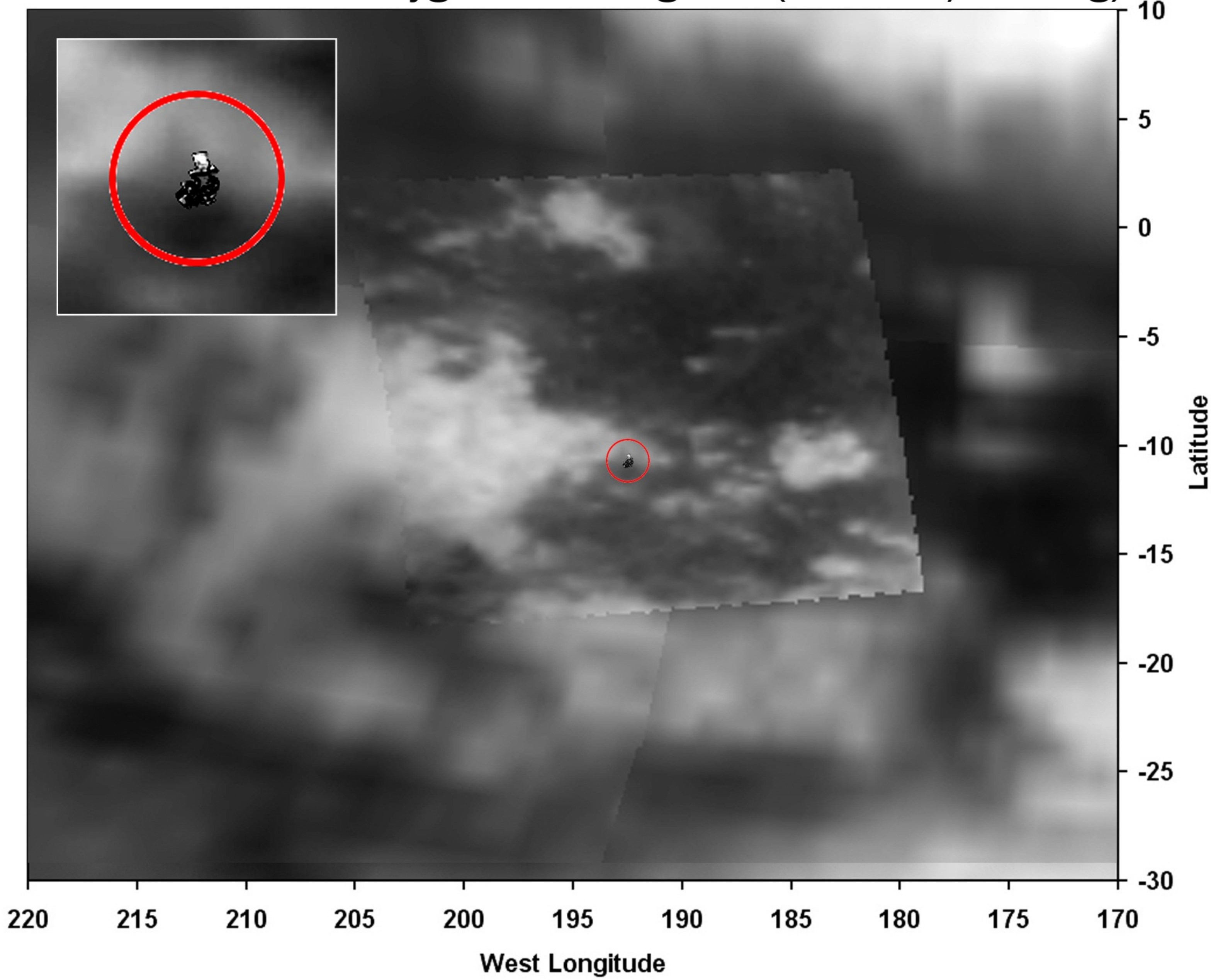
Doppler Wind Experiment (using groundbased rather than Cassini data !)

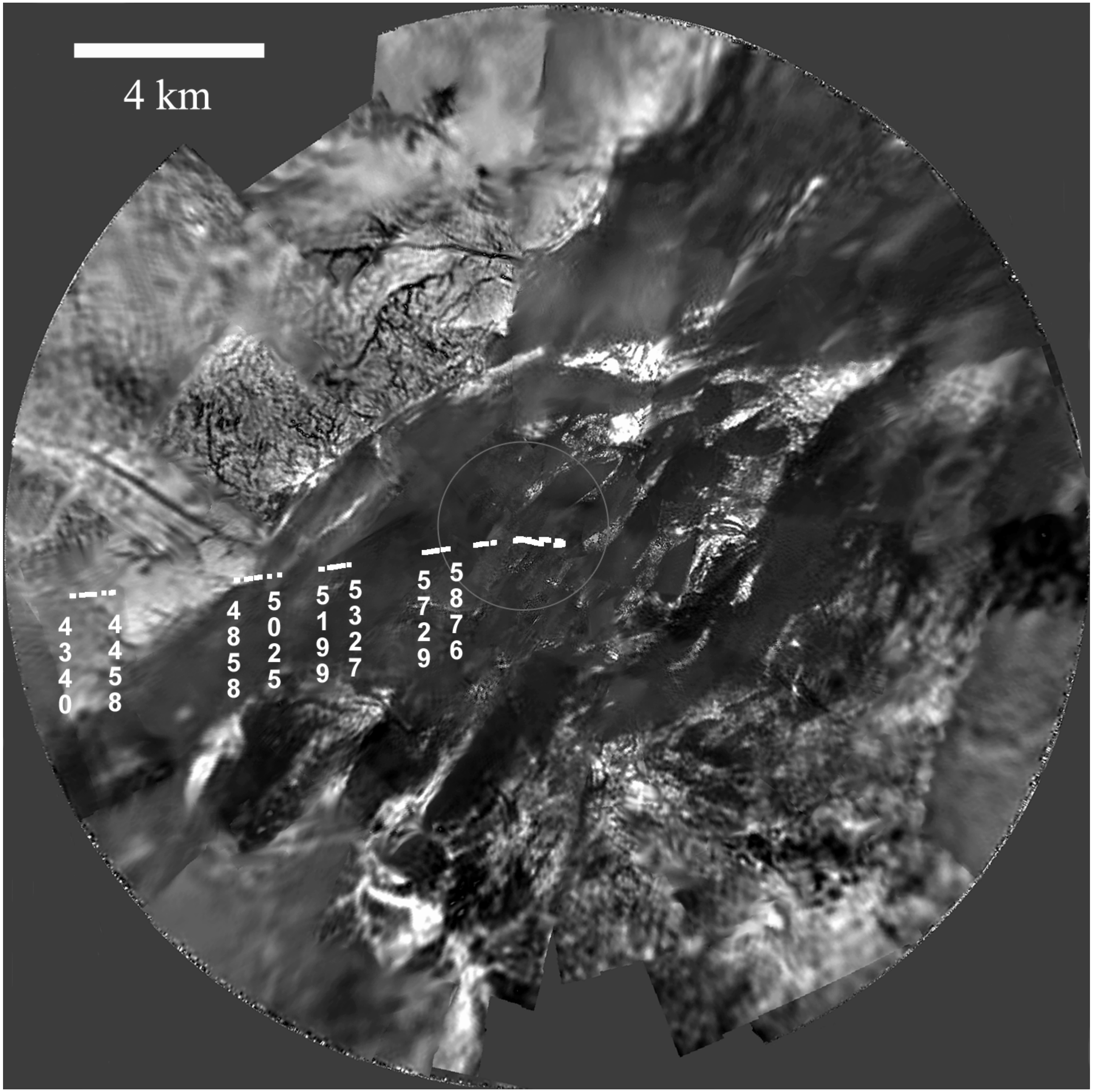
showed zonal winds to be somewhat weaker than expected (image overlap), with a slightly surprising reversal near the surface. Also somewhat unexpected was a layer of strong wind shear, with winds falling to near zero at about 80km altitude.

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)

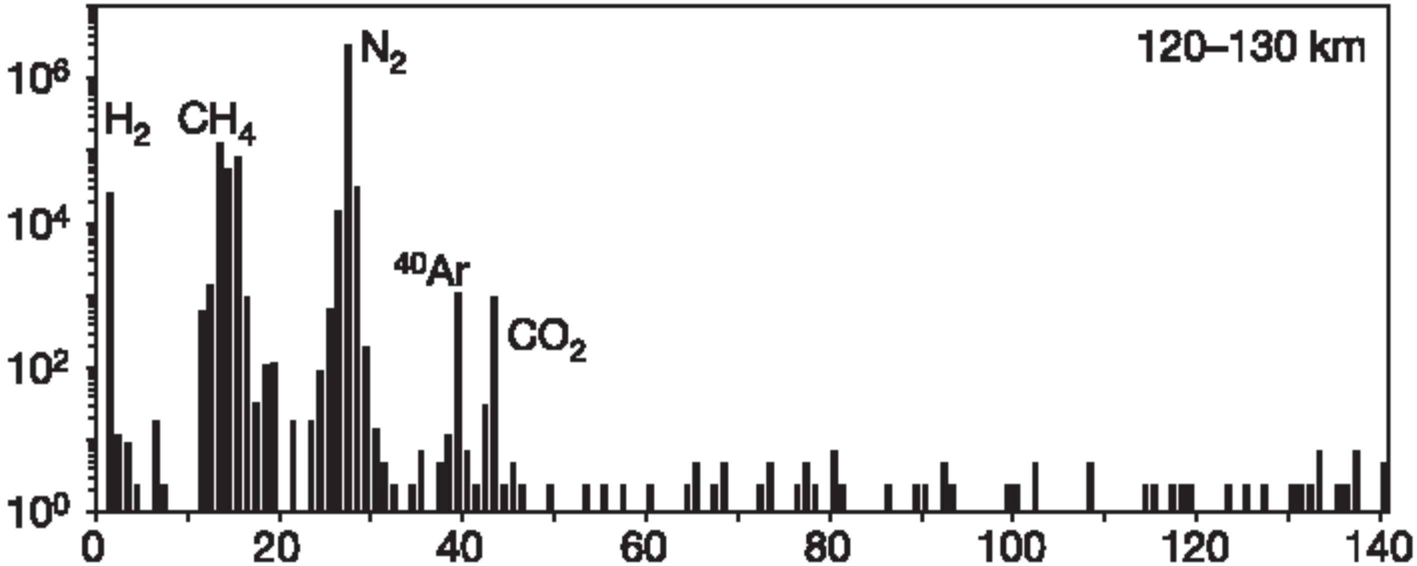




Descent groundtrack fortuitously crossed bright/dark boundary.

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

Flatter, lower, but not smooth dark terrain.

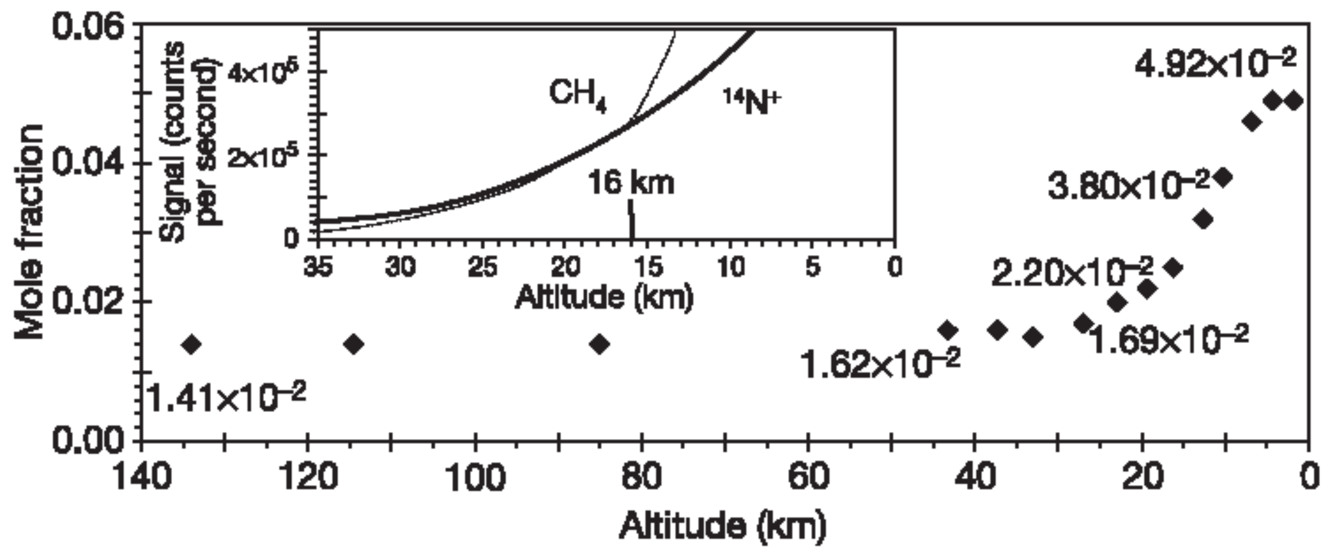


Gas Chromatograph/Mass Spectrometer

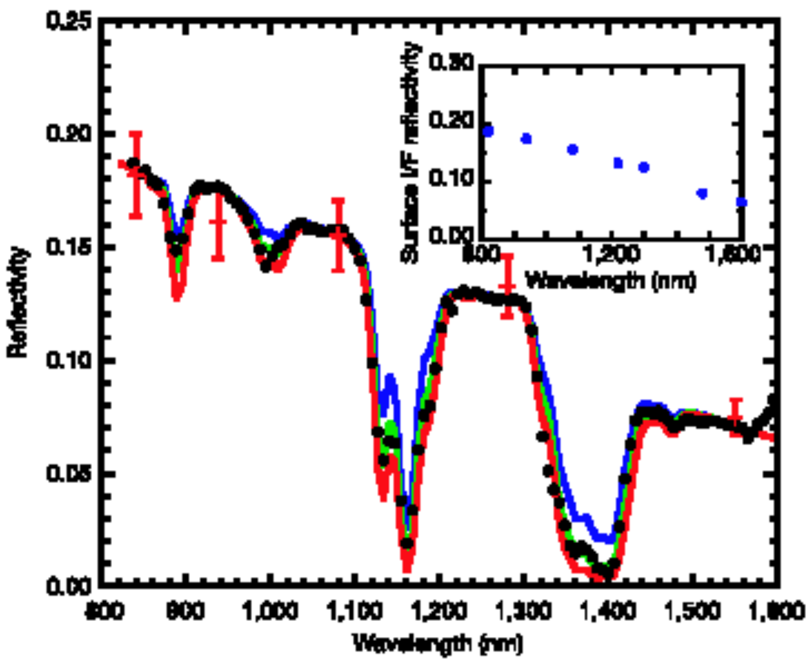
Atmospheric mass spectrum rather sparse

Radiogenic ^{40}Ar was detected at a mole fraction of 4.3×10^{-5}.

No other noble gases. Trace ($\sim 2.8 \times 10^{-7}$) of ^{36}Ar - suggests N_2 was brought to the system as a less volatile species, probably NH_3.
Isotopic ratios $^{12}C/^{13}C$ is 82.3 ; $^{14}N/^{15}N$ is 183 ; D/H is 2.3×10^{-4}
Suggests Nitrogen is fractionated (although fractionation in N_2 is much less than in HCN measured from Earth), carbon is not (Early loss of N_2 during T-Tauri winds ; methane was still sequestered in interior ?)

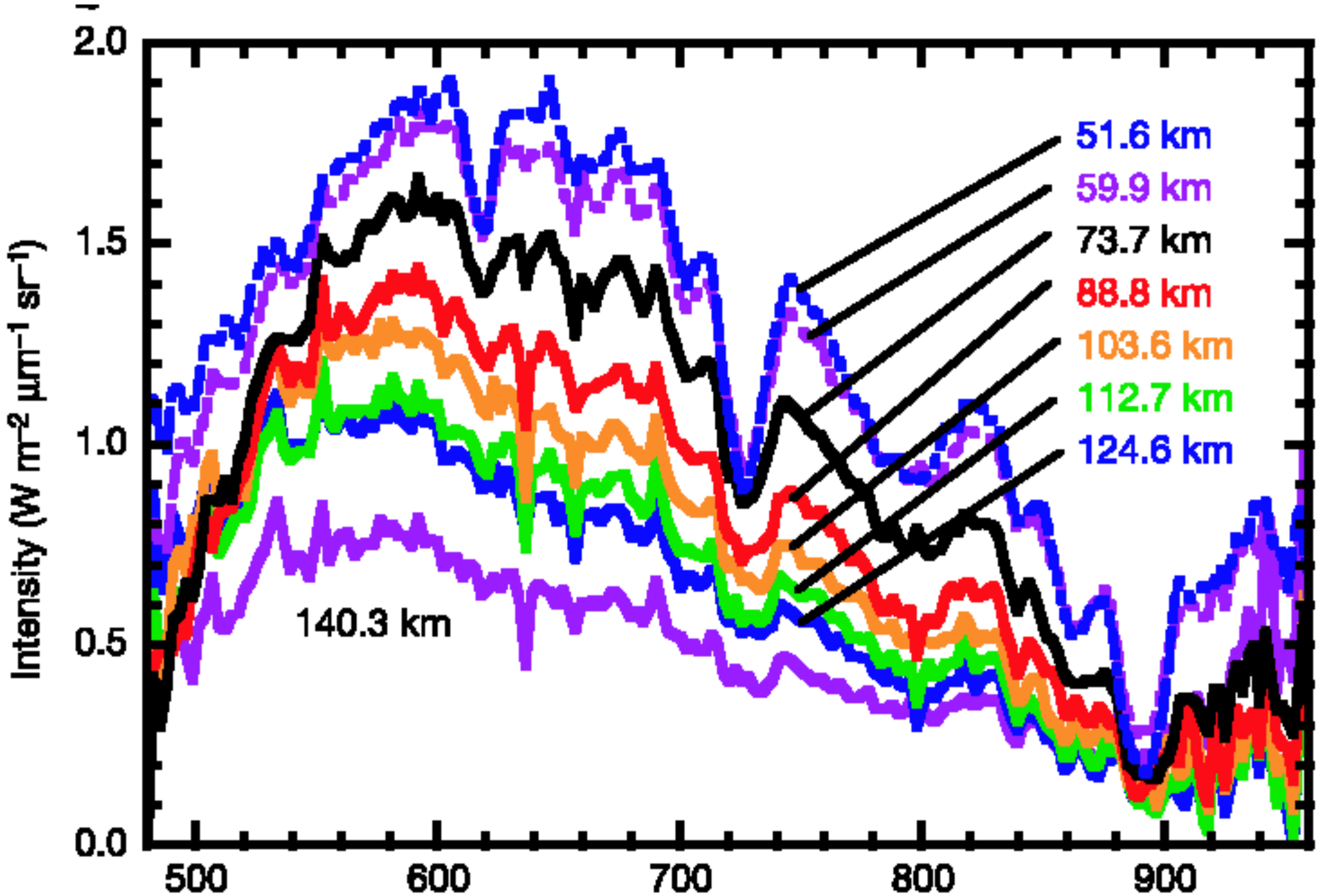


GCMS data show rise in CH_4 mole fraction (cf water on Earth) towards surface. Abundance ~1.4% at tropopause cold trap; ~5% (~50% relative humidity) at surface



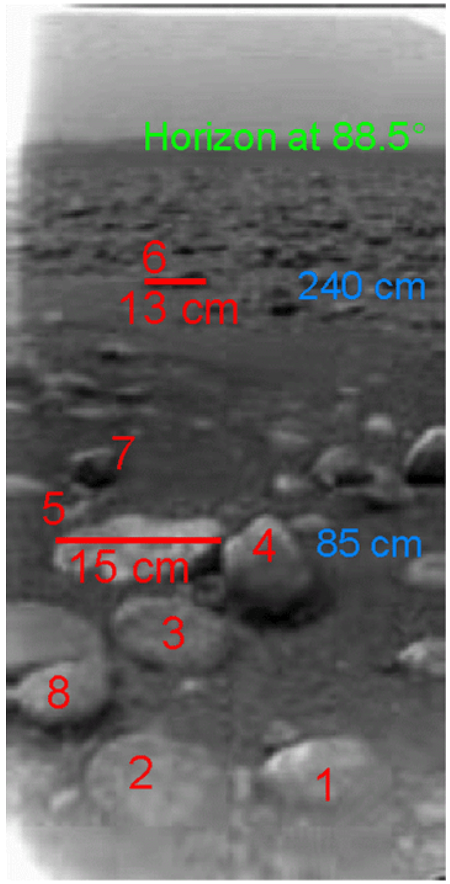
DISR derivation of methane mole fraction. Lamp-only downward looking spectrum from altitude of 21m (black data points). This spectrum is compared to three models: 3% (blue), 5% (green), and 7% (red) methane mole fractions. These models make use of surface reflectivity at seven wavelengths (blue dots in inset)

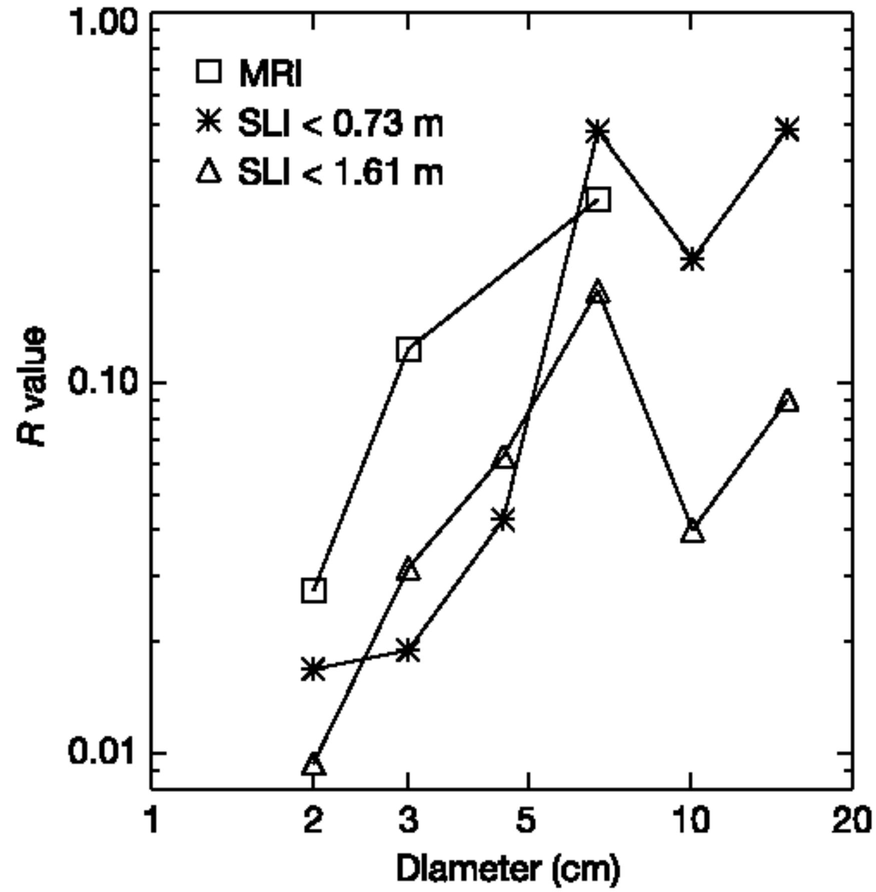
Useful to have independent means of measuring crucial parameters



Descent Imager / Spectral Radiometer

example - upward looking spectrometer (looking away from sun) As probe descends, sky gets brighter, as on Earth, but methane bands get deeper. These data will allow recovery of haze abundance with altitude, haze particle size, etc. and greatly improve interpretation of Cassini orbiter spectra



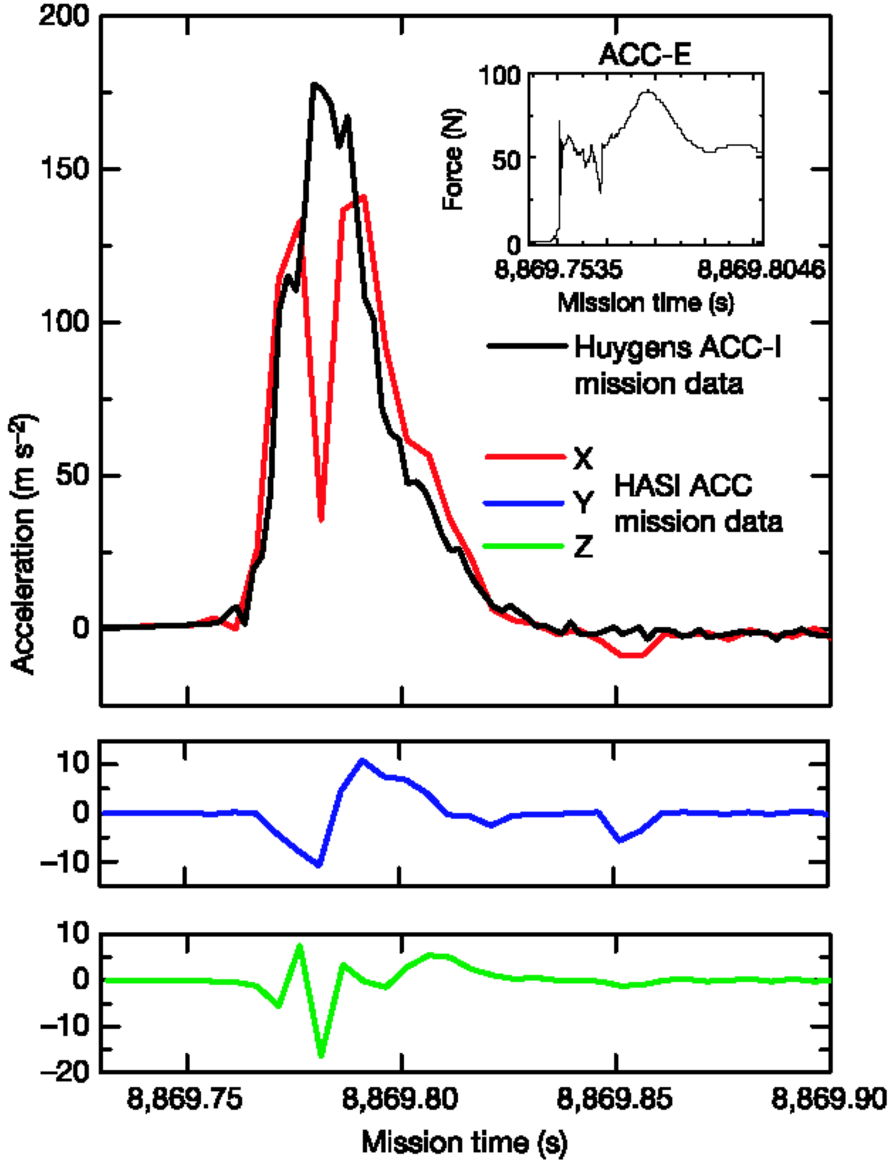


Surface Images

(Roughly pointed due south, judging from shadows and extrapolation of pre-impact spin rate)

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

Impact!



Hit Soft solid surface. (Like wet or dry sand; wet clay; packed snow)

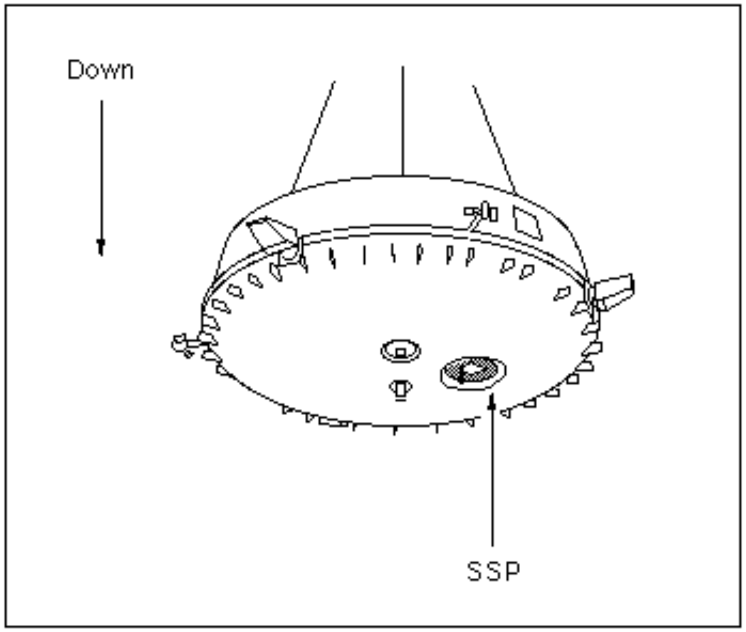
Delta Vel = 4.63 m/s for ACC-I.

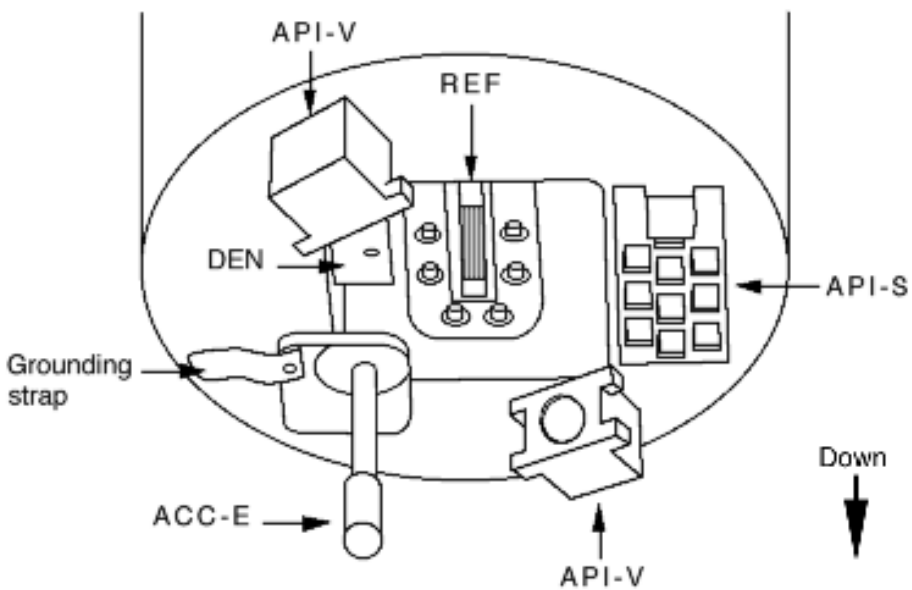
Delta Vel = 4.33 m/s for PZR-X.

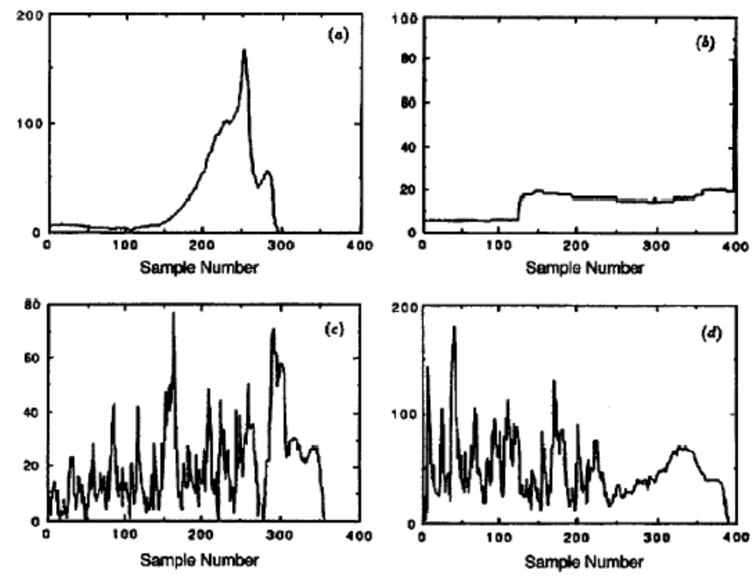
Possible slight 'bounce' (few cm)

Peak deceleration ~15g, implies bearing strength of ~50 kPa. Rapid onset suggests material did not need to be compacted before resisting - i.e. not fluffy. Analogs - damp sand, clay, packed snow

The Penetrometer on the Huygens Probe

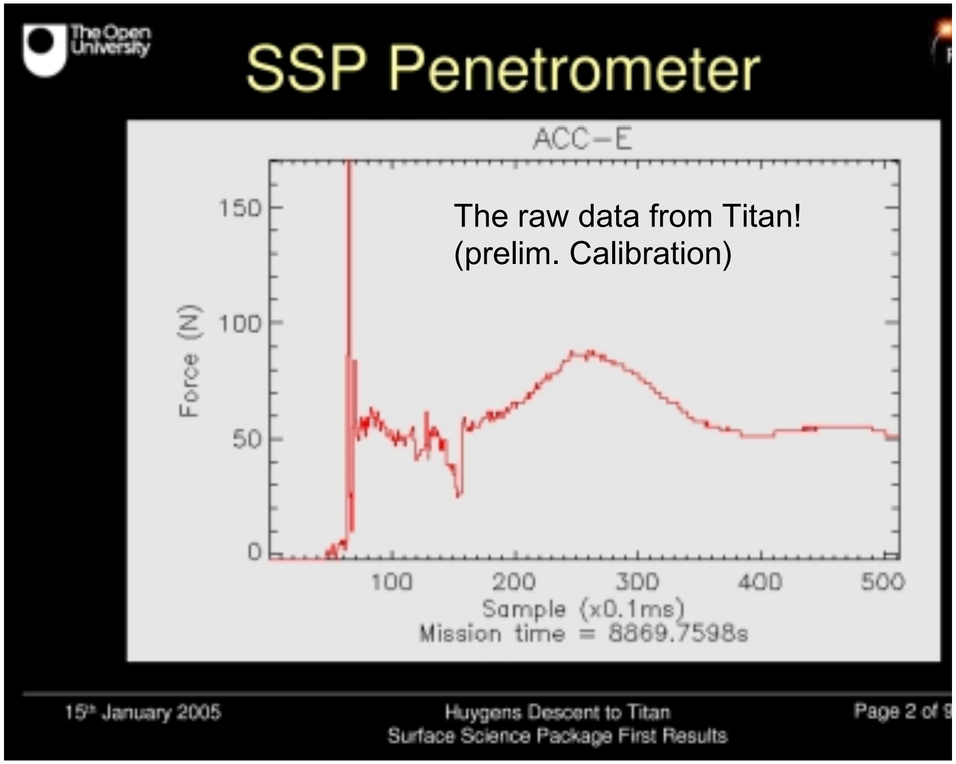


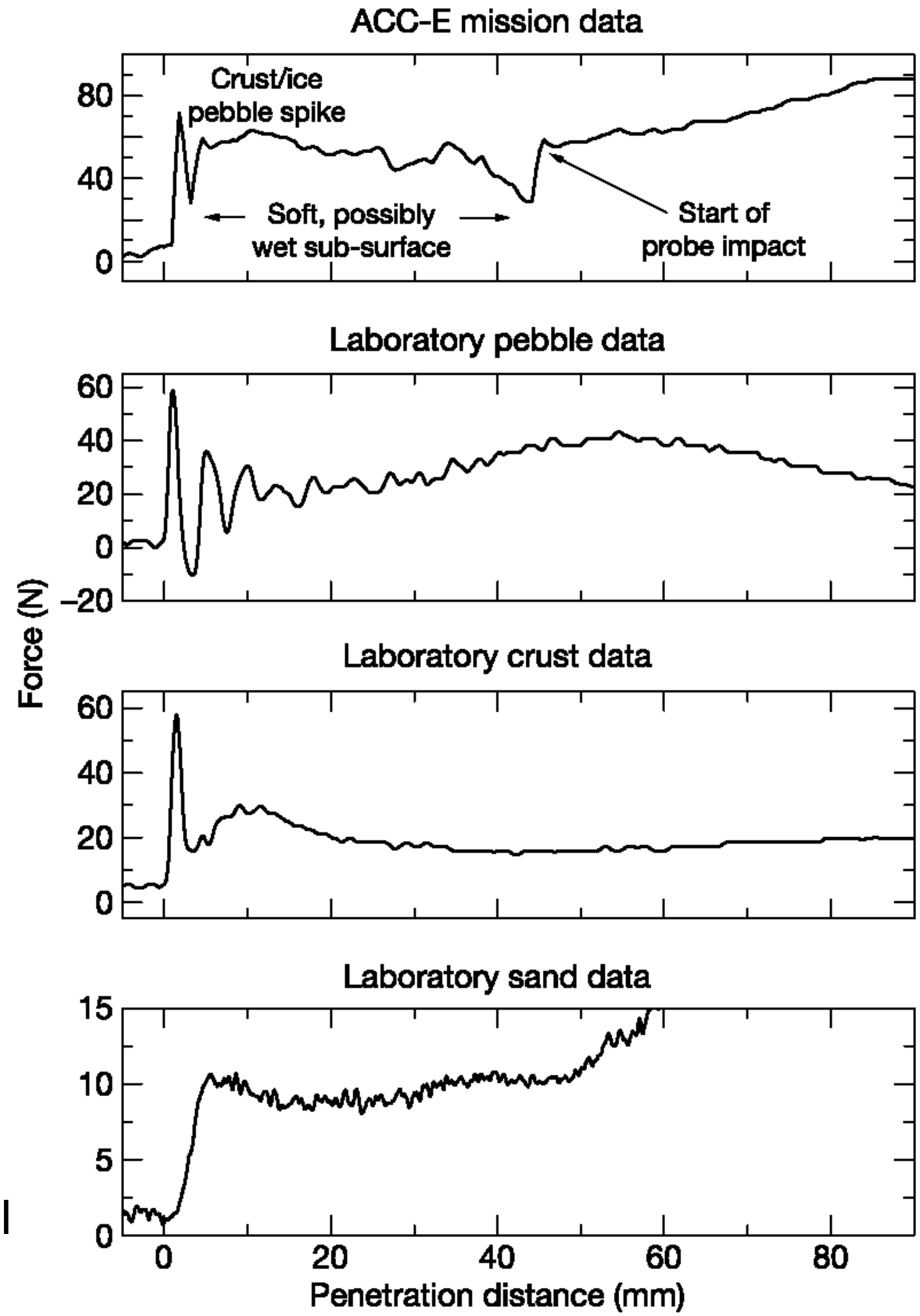




Data taken in the lab in 1994 – (a) dry sand (b) wet clay (c) fine gravel (d) coarse gravel (from *R. D. Lorenz,et al 'An Impact Penetrometer for a Landing Spacecraft', Measurement Science and Technology, vol.5 pp.1033-1041, 1994* also at **http://www.lpl.arizona.edu/~rlorenz**

The Penetrometer on the Huygens Probe



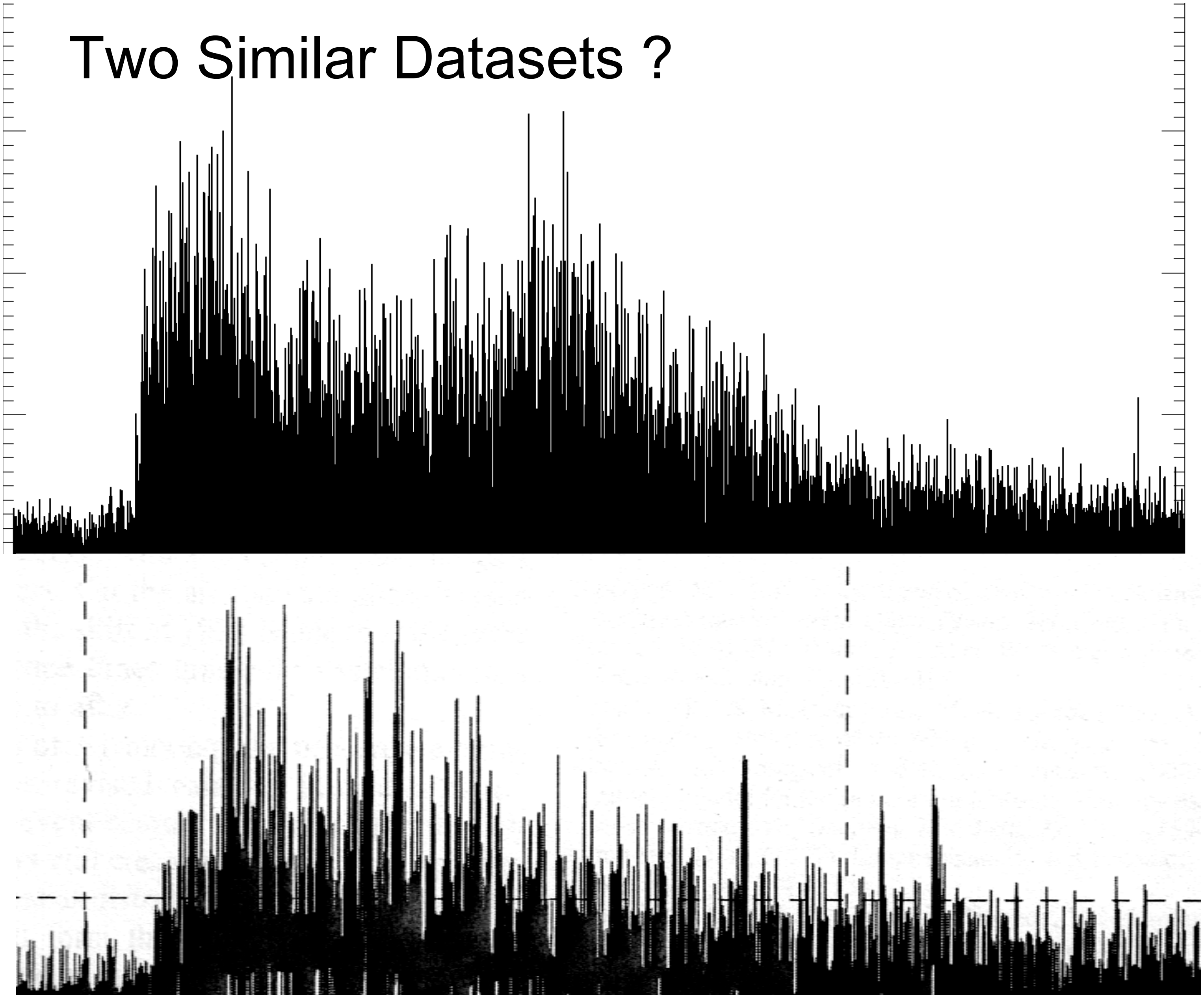


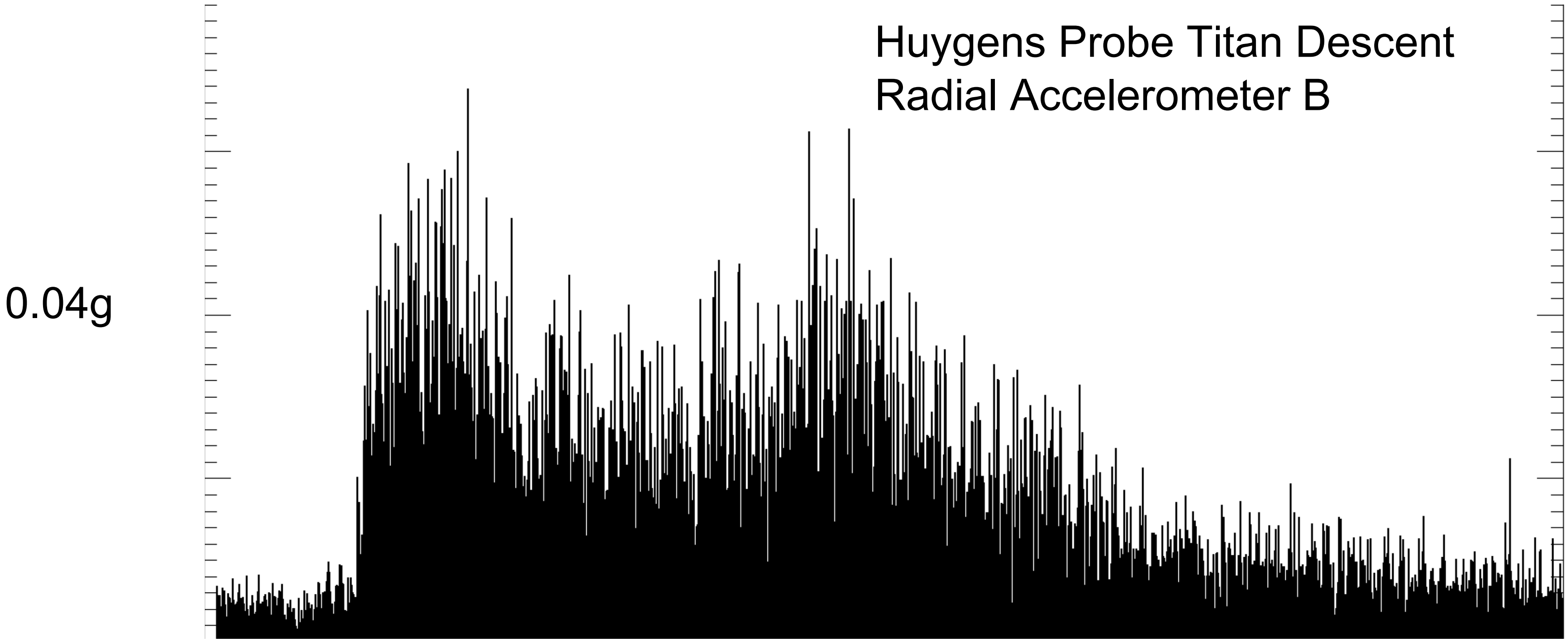
near-constant force, plus spike at onset ('creme brulee') 50N/2cm^2 ~ 250kPa. Not consistent with dry sand.

Penetrometer struck a pebble ?

Note shallow onset – few mm of soft material on pebble ? (See Atkinson et al., submitted)

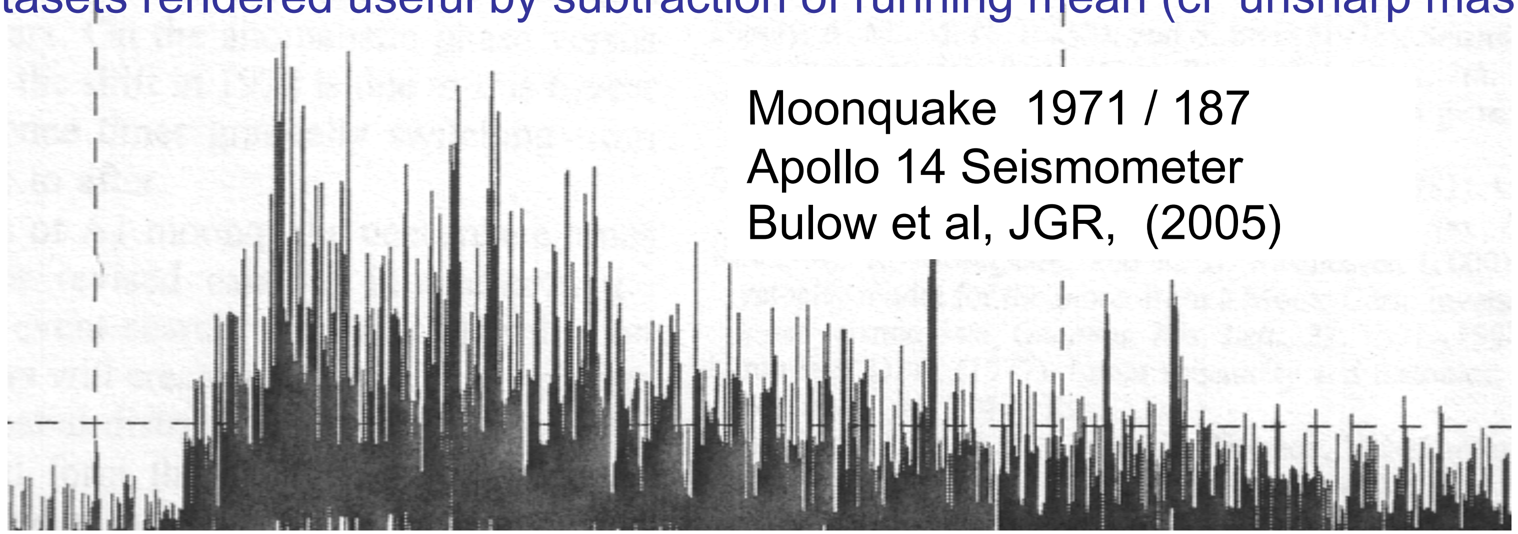
Two Similar Datasets ?





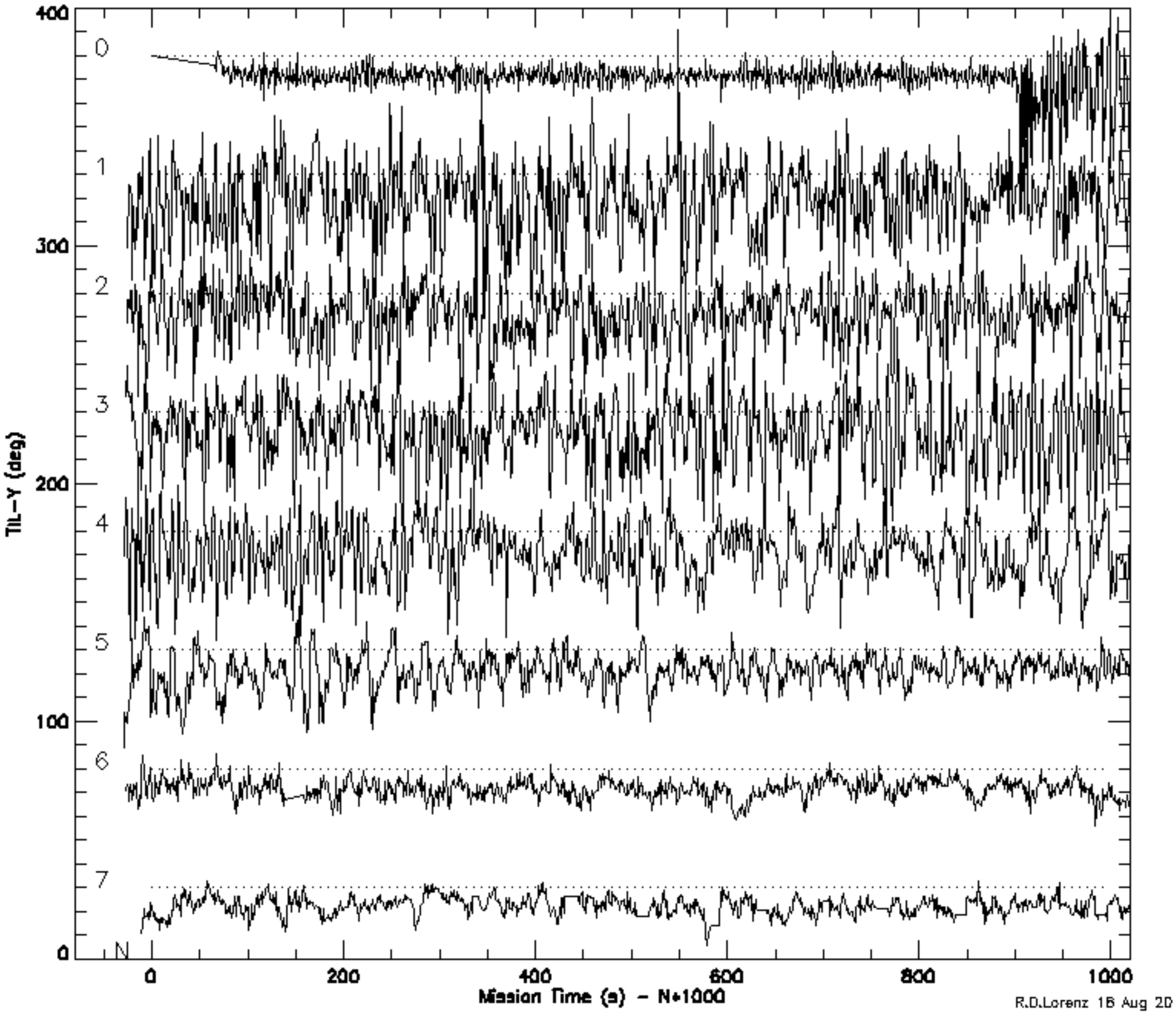
150 mins

Both datasets rendered useful by subtraction of running mean (cf ‘unsharp mask’)



32 mins

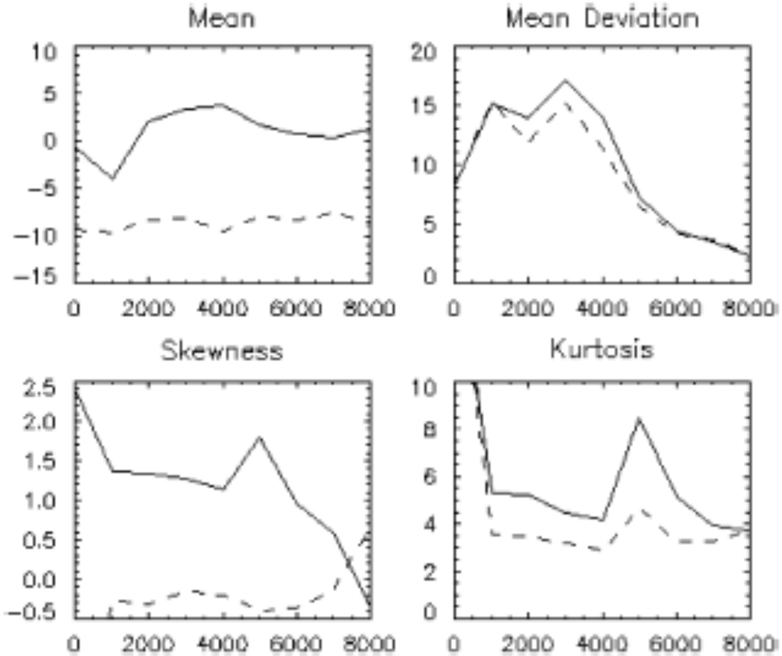
TILT SENSOR DATA FROM SSP EXPERIMENT



Y-TIL data is obviously rich in content. But how to extract/interpret ?

Evident changes in character at 900s and after ~5200s. Maybe also a change around 4500s ?

Actual tilts of probe to Titan reference frame are much smaller than this indicated tilt, which includes a dynamic component



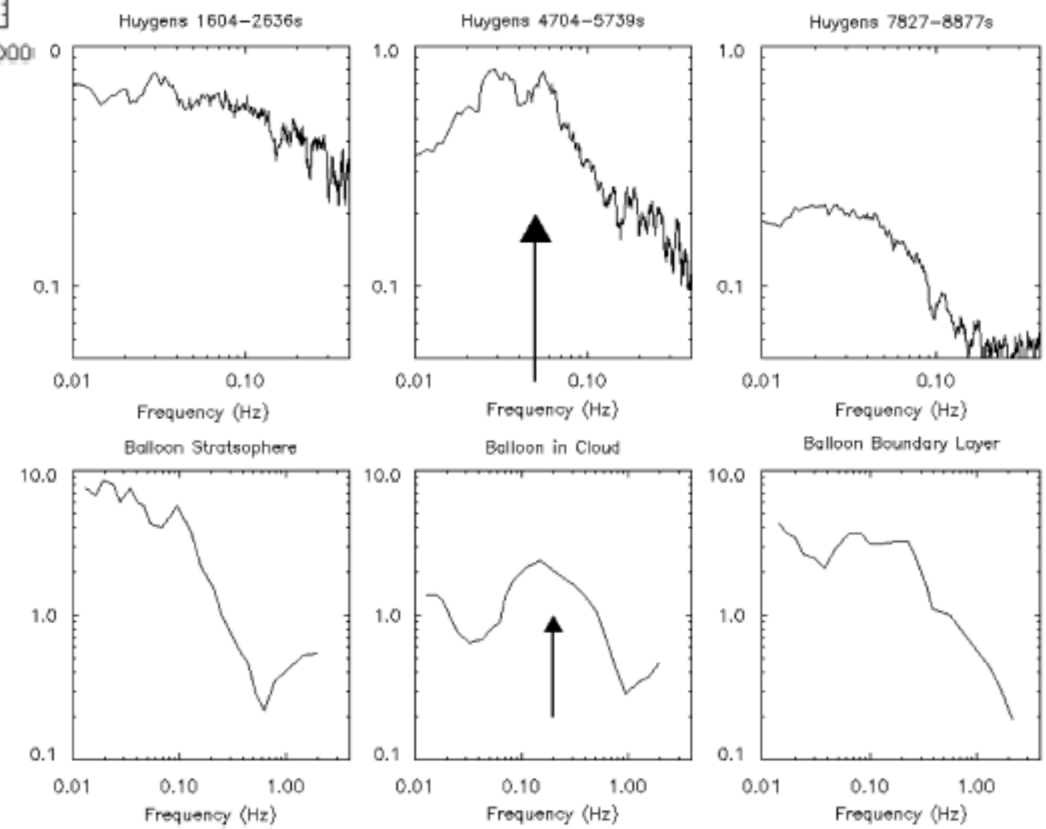
Statistical moments of probe motion from tilt sensor show pronounced excursion around 5000s

Motions substantially self-excited during descent (not very turbulent – 0.15 m/s

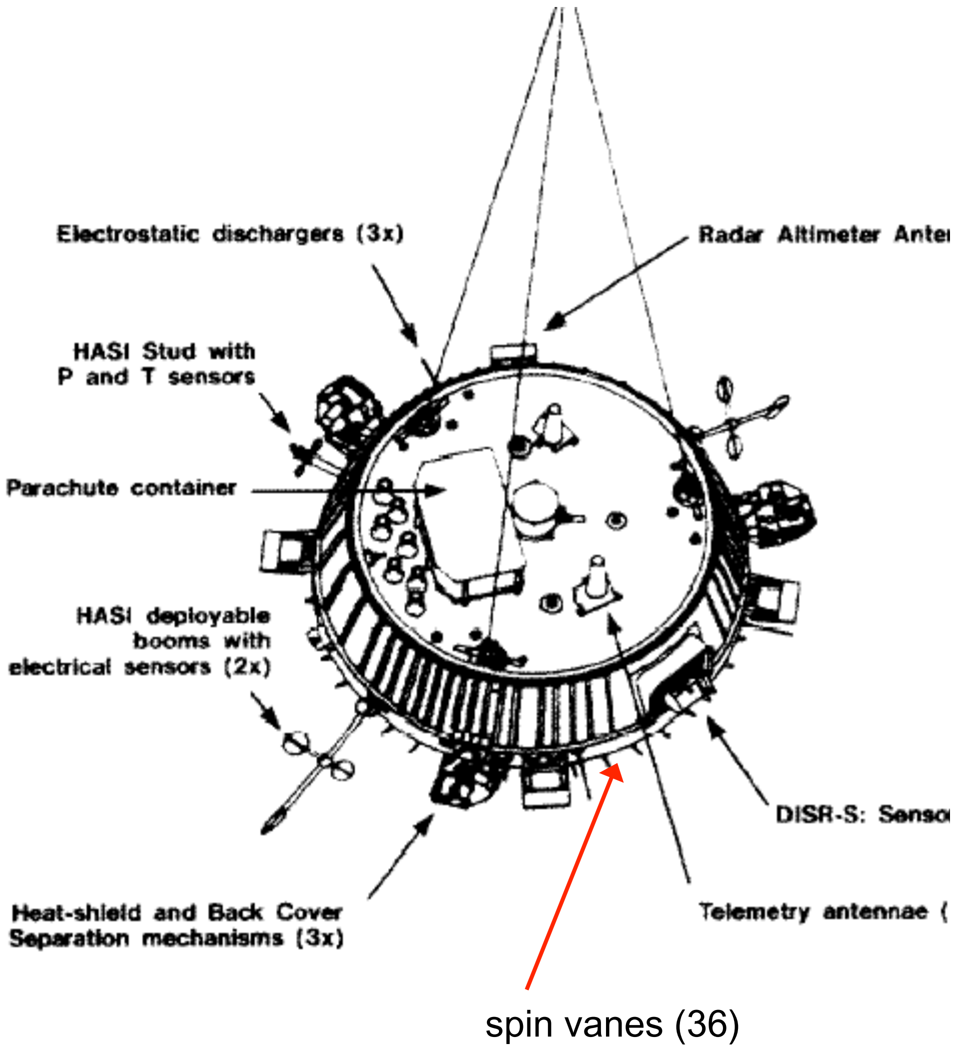
See Planet. Space. Sci., 55, 1936

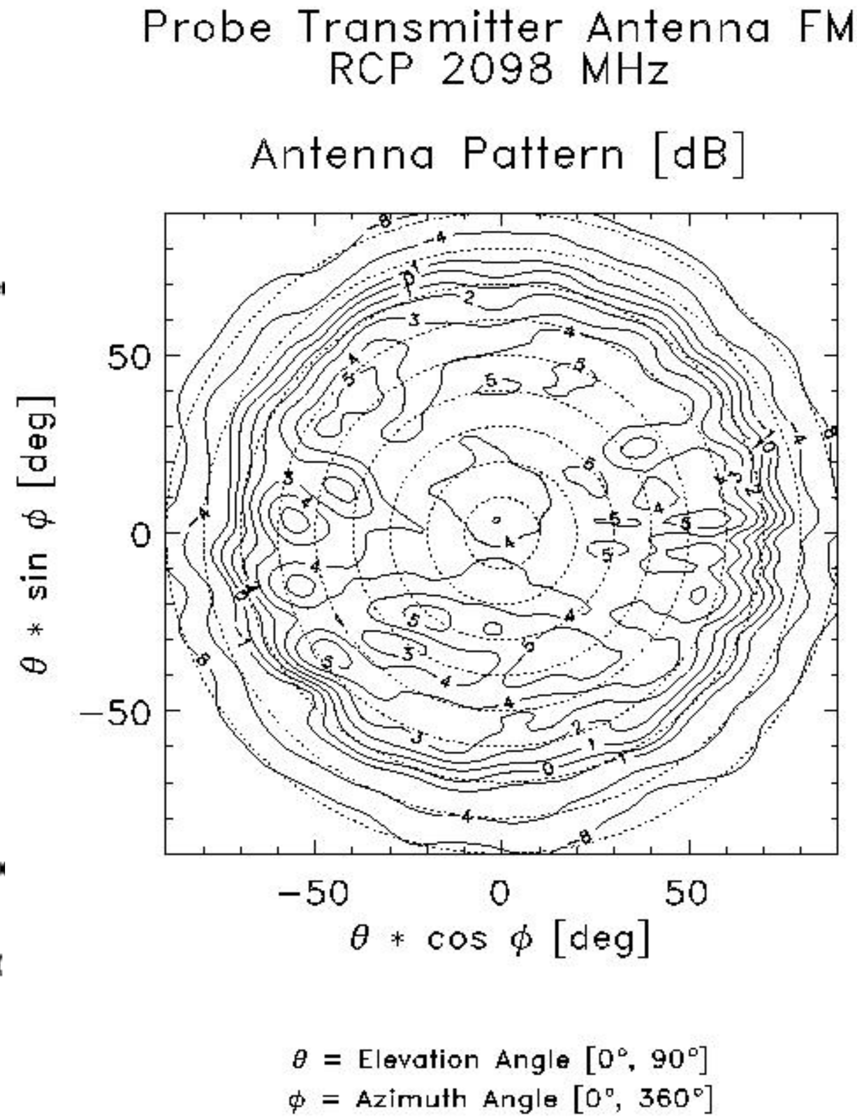
Frequency spectrum shows distinctive peak close to pendulum period during this interval.

Similar spectrum seen in instrumented balloon data on Earth - peaked spectrum seen in freezing/precipitating cloud layer

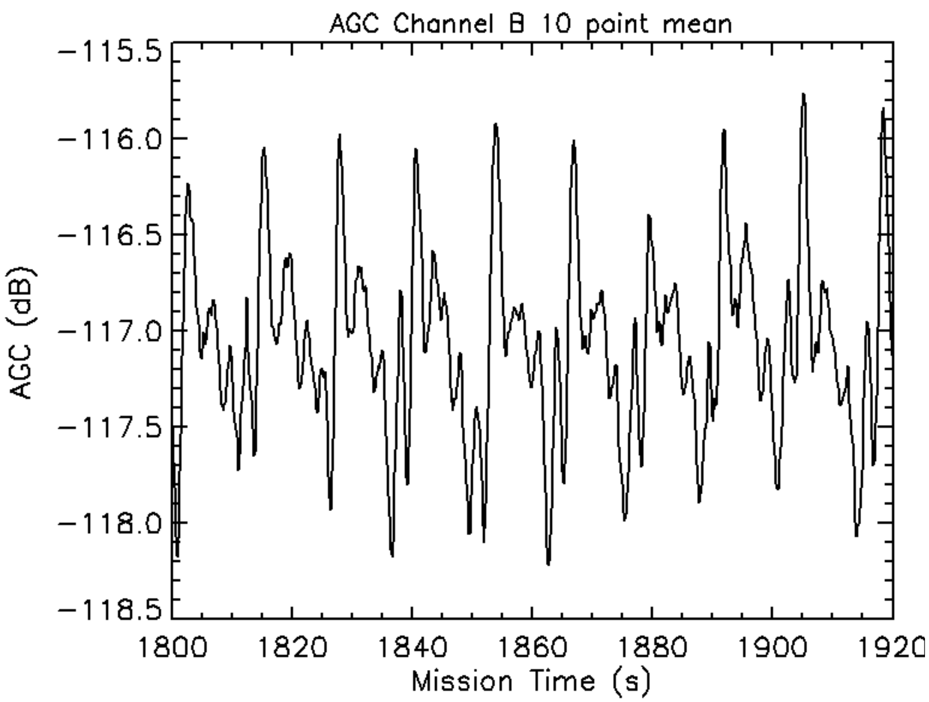


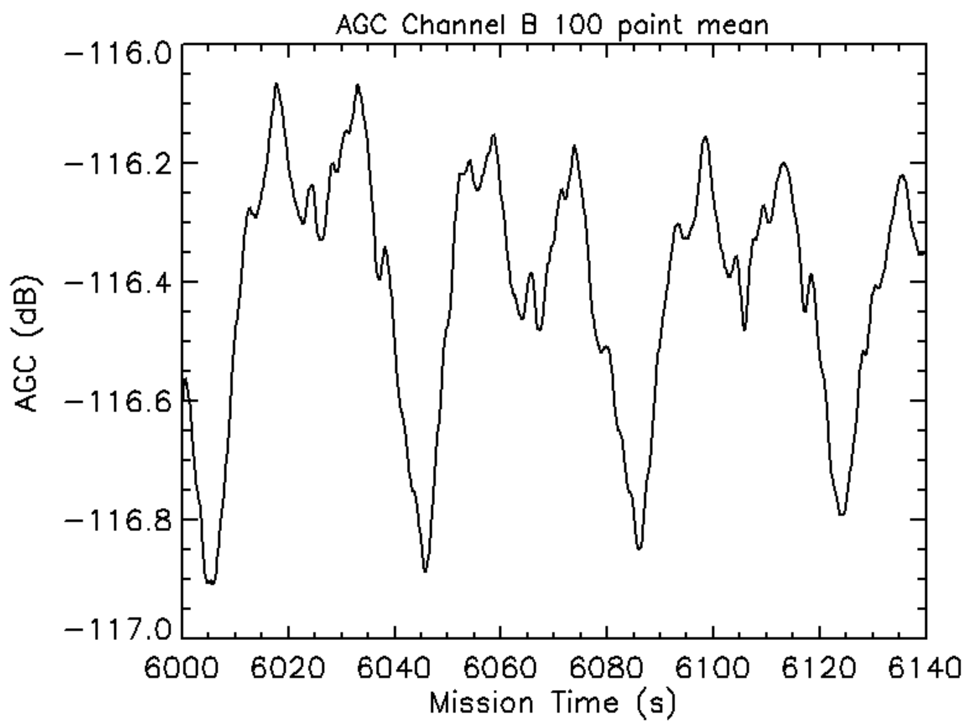
Probe Transmitter signal strength varies slightly with azimuth as well as elevation : some fluctuations expected due to probe spin





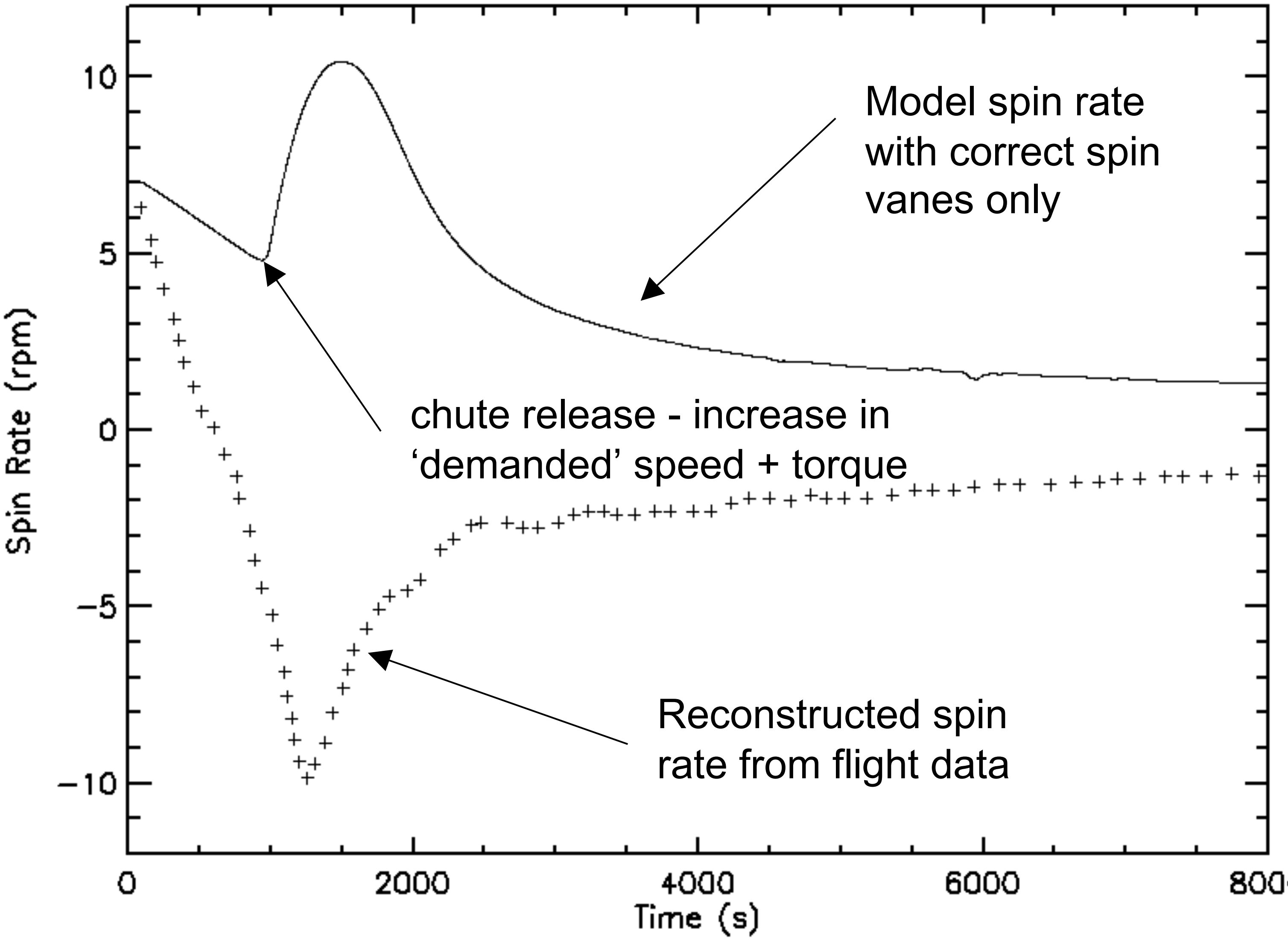
Periodic Spin modulation of AGC allows diagnosis of spin rate and direction



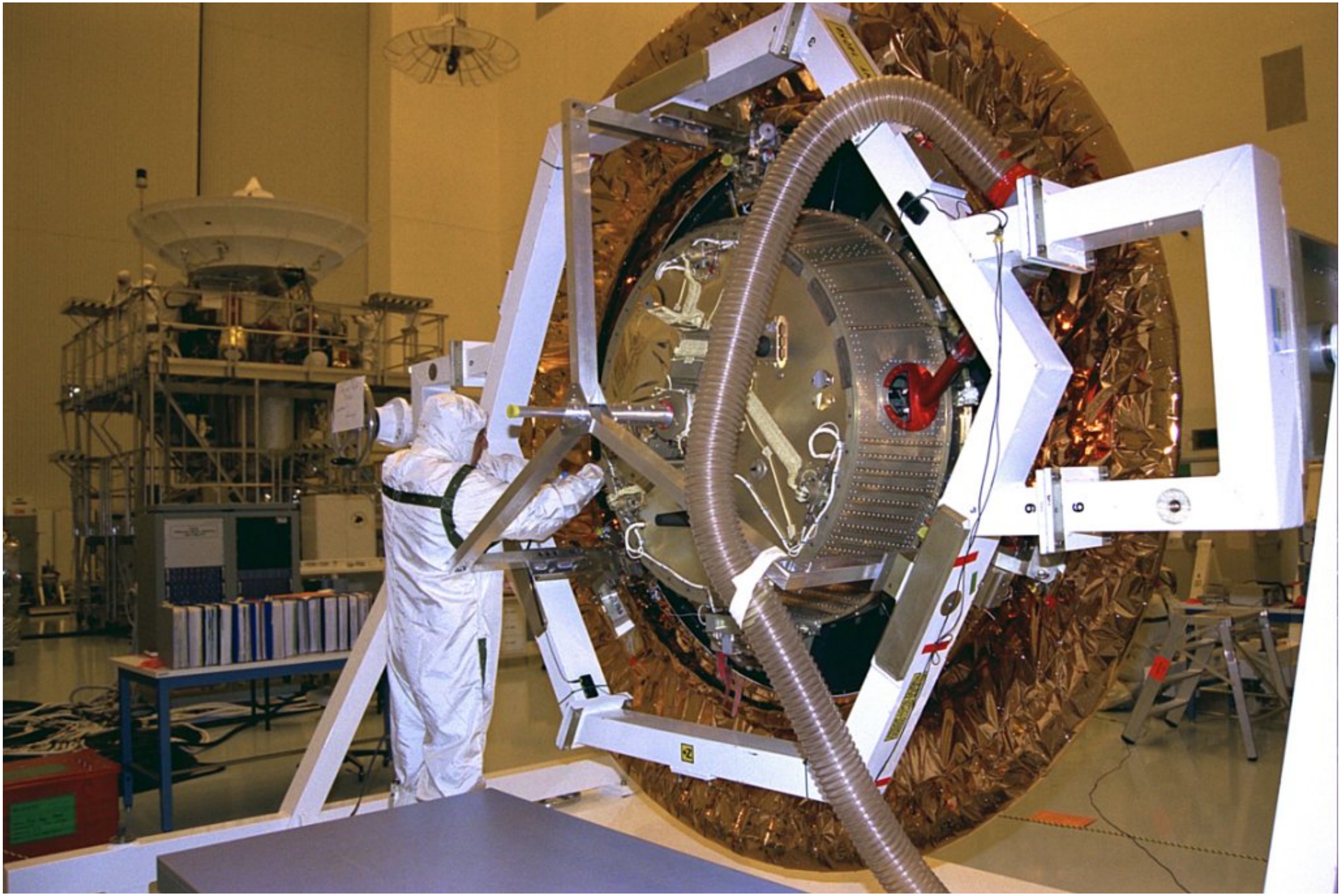


Signal strength history recorded on Cassini proved to be very rich and useful diagnostic of probe motion

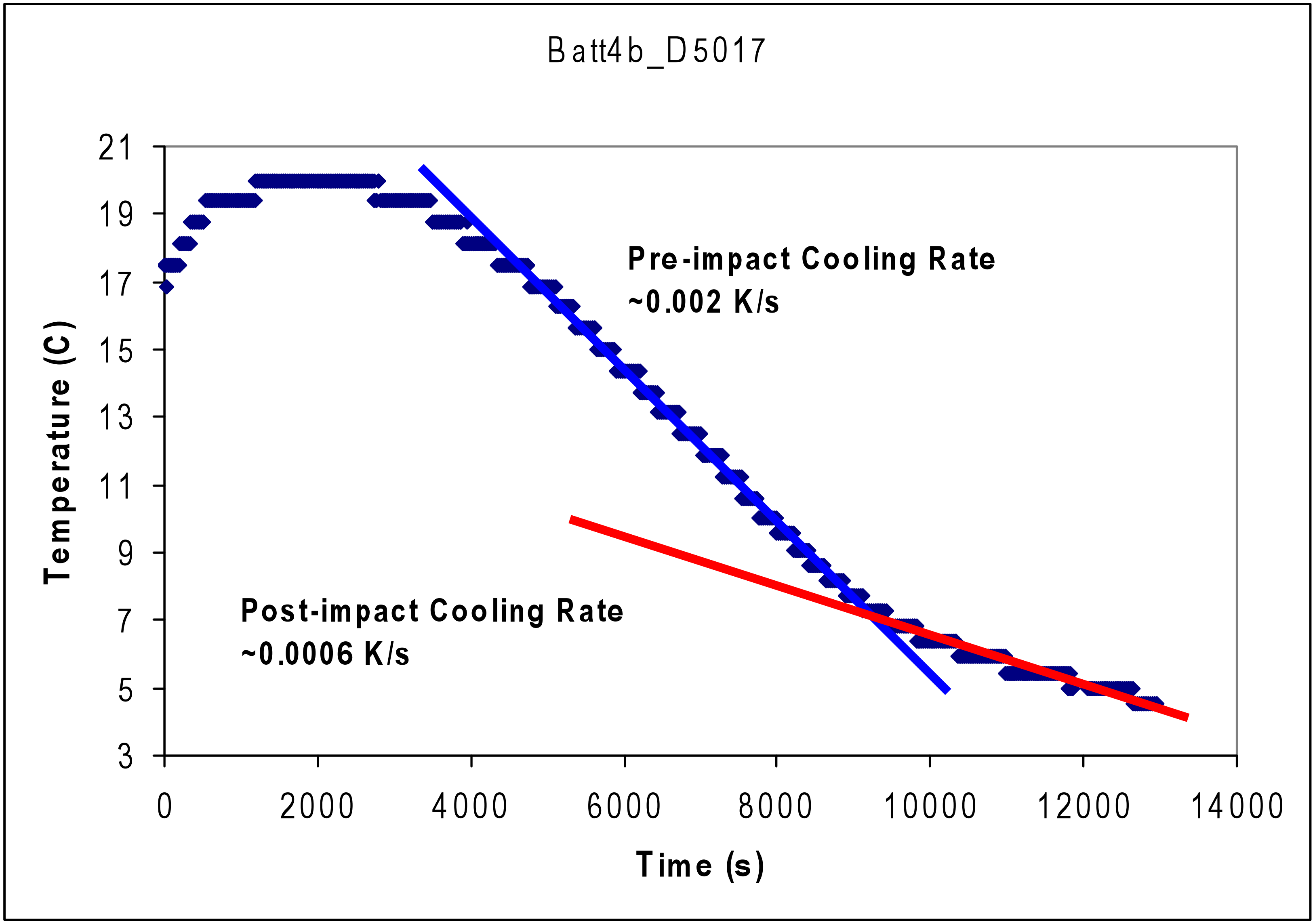
Mission did not follow expected profile



Reason for spin reversal still not fully understood, but suspected to be due to torque from attach fittings . See also J. Brit. Interplan. Soc., 59, 273, 2006



Huygens probe at KSC (Cassini in background). Note cold-air hose to remove heat from probe inside. KSC photo

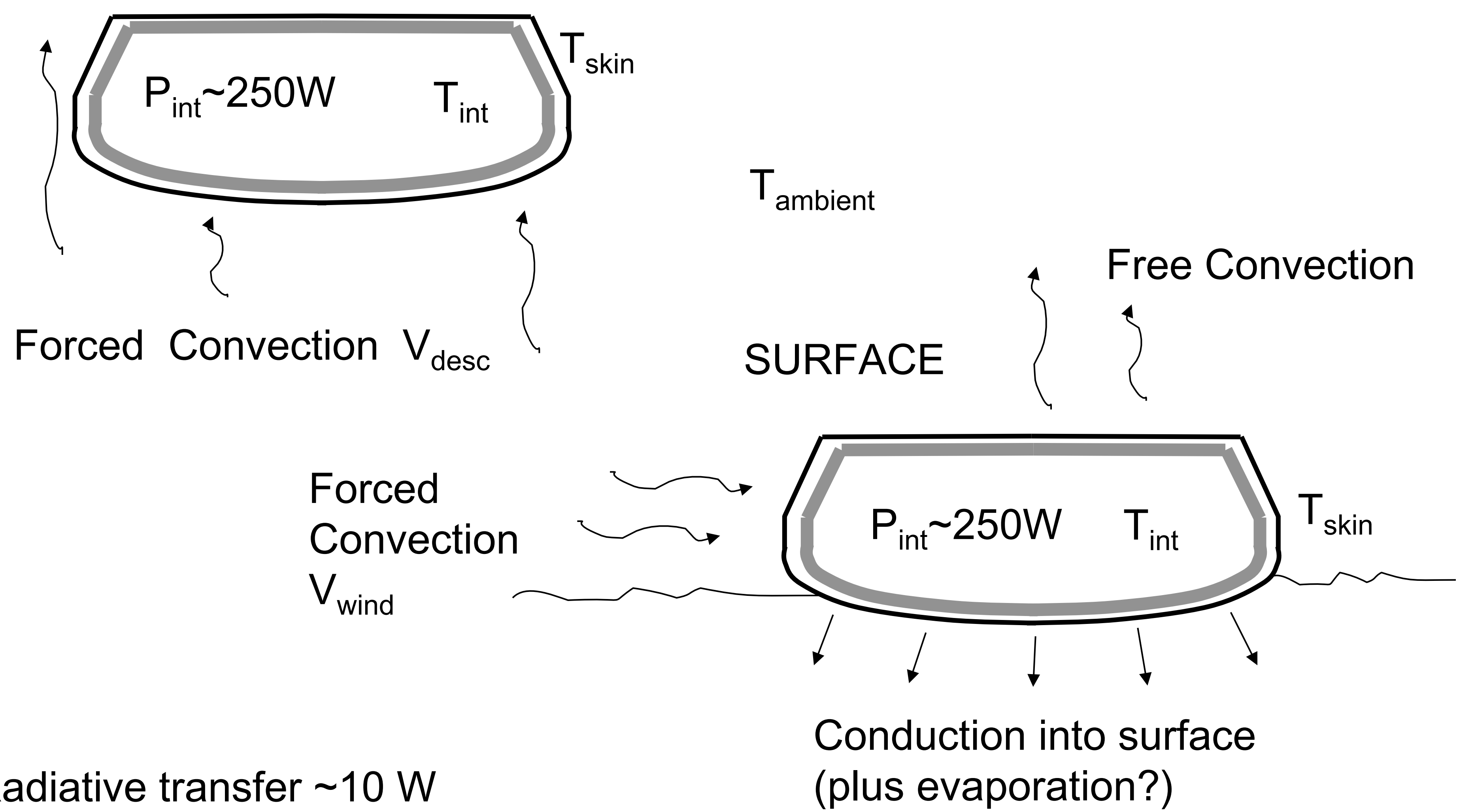


Batt4b_D5017
Pre-impact Cooling Rate
~0.002 K/s
Post-impact Cooling Rate
~0.0006 K/s
Temperature (C)
Time (s)
21
19
17
15
13
11
9
7
5
3
0
2000
4000
6000
8000
10000
12000
14000

Huygens Thermal Budget

DESCENT

See Icarus, 182, 559-566, 2006



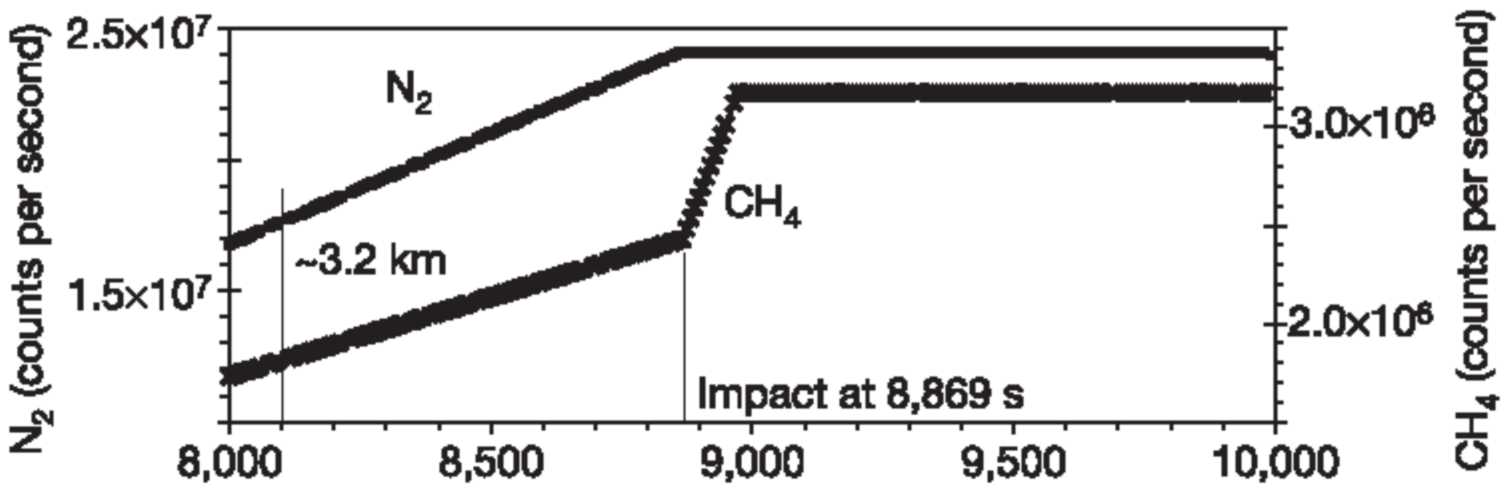
Radiative transfer ~10 W
not considered

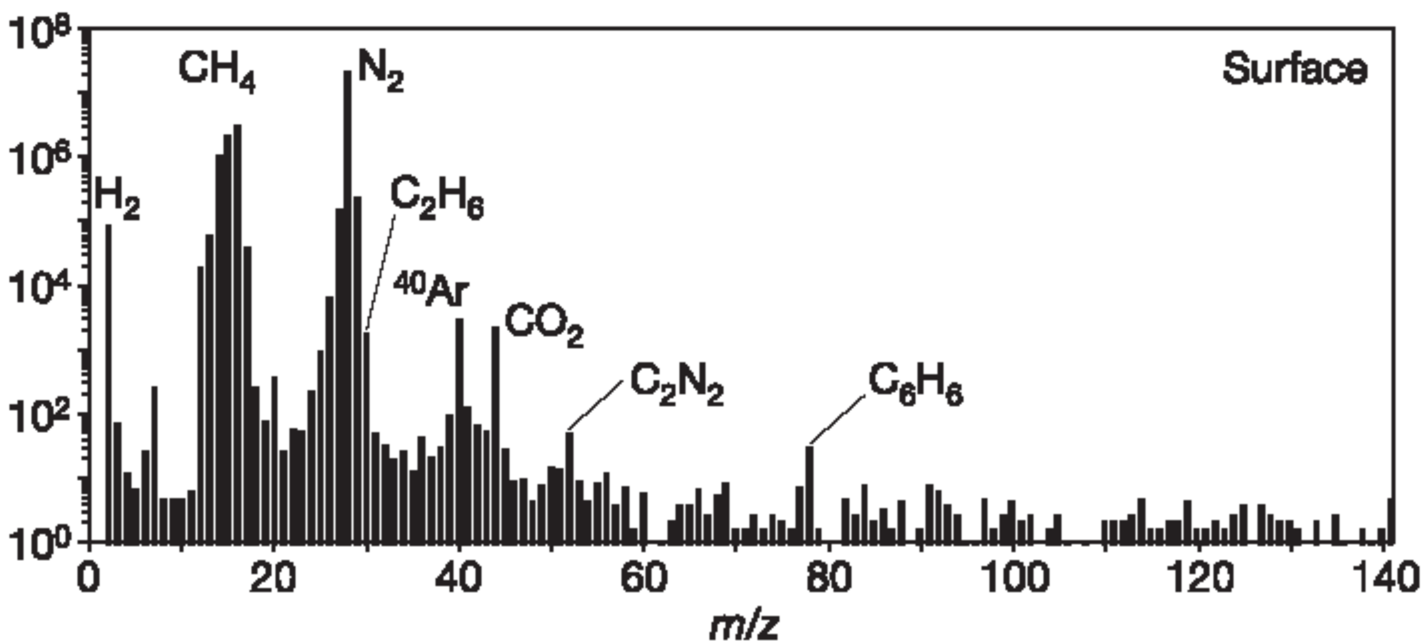
Wind-Chill during and after Descent

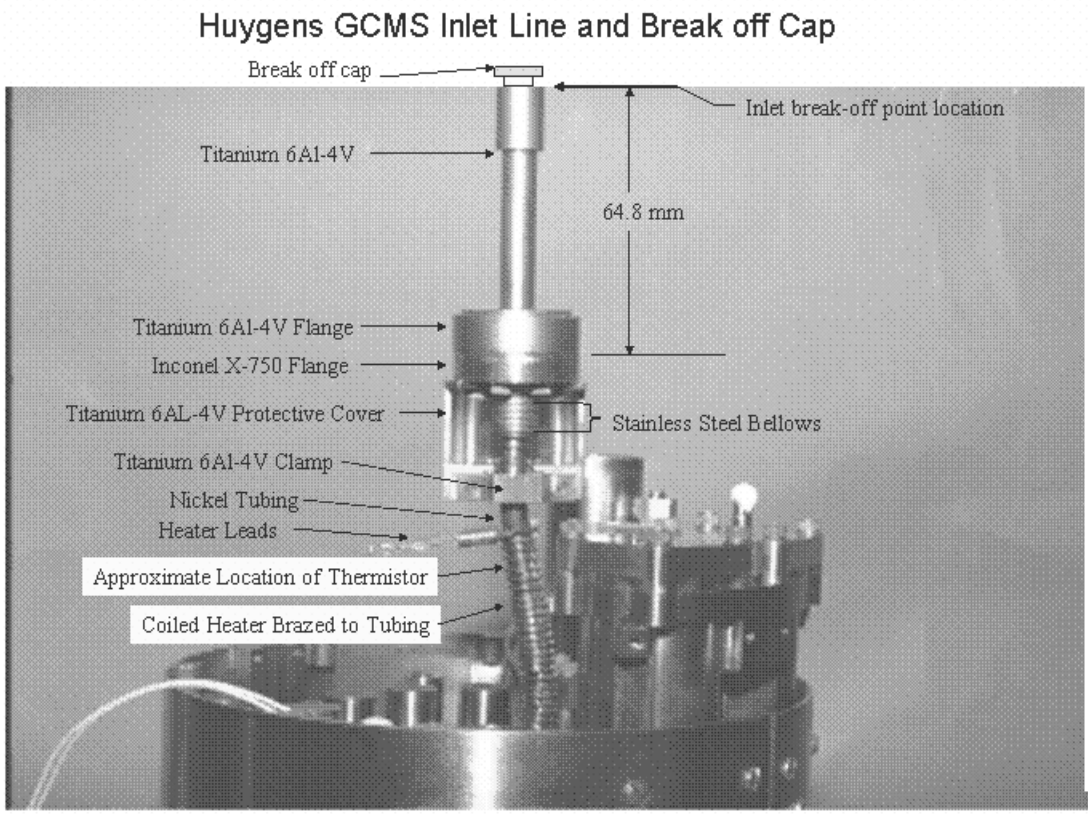
- Interpretation needs foam insulation and internal heat generation to be taken into account.
- Total area ~ $4m^2$. Heat transfer coefficient given by $h \sim 0.37(k/D)\ Re^{0.6}$ where Re is Reynolds #, increasing throughout descent. Reaches ~ 30 $Wm^{-2}K^{-1}$ prior to impact.
- Cooling of 0.002K/s means a net loss of 600 W or 150 Wm^{-2}, thus air:skin $\Delta T \sim 5$ K ;$T_{skin} \sim 100$ K
- On ground 350 W or ~90 Wm^{-2} . Taking change in internal heat transfer into account requires $h<4\ Wm^{-2}K^{-1}$ so to get coefficient h 8x lower than during descent at 5 m/s requires surface winds <~0.2 m/s

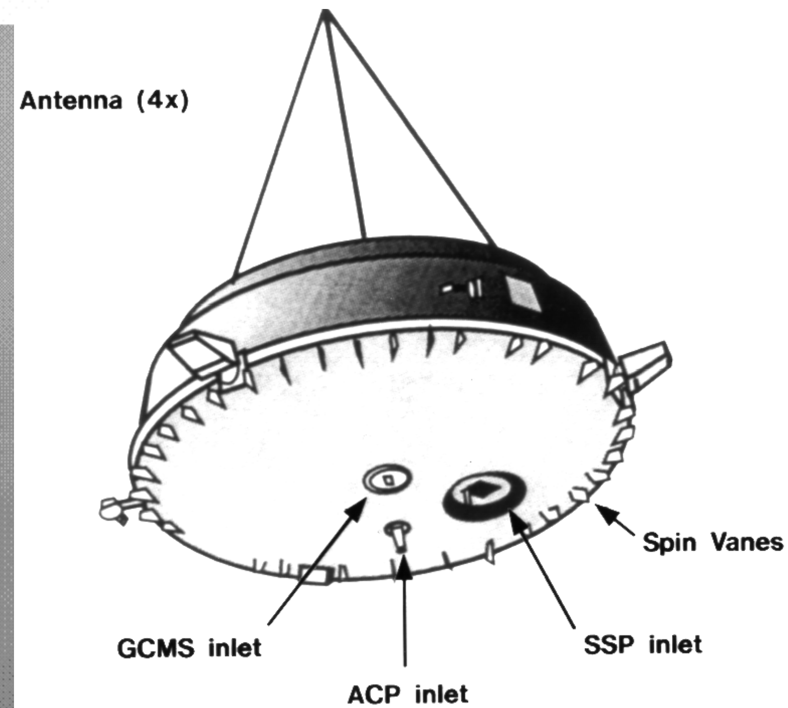
GCMS Heated inlet - volatilized surface materials. Jump in methane abundance - plus rich spectrum for surface material.

Analysis is underway to determine temperature history of inlet (not measured directly)



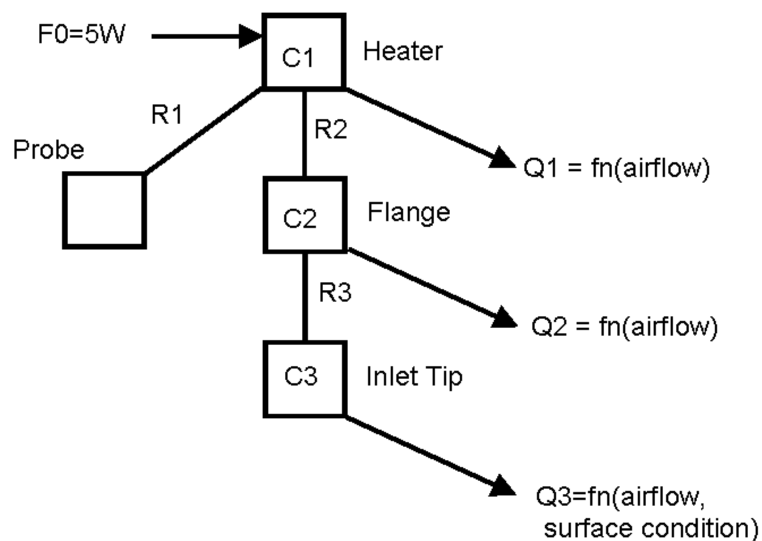


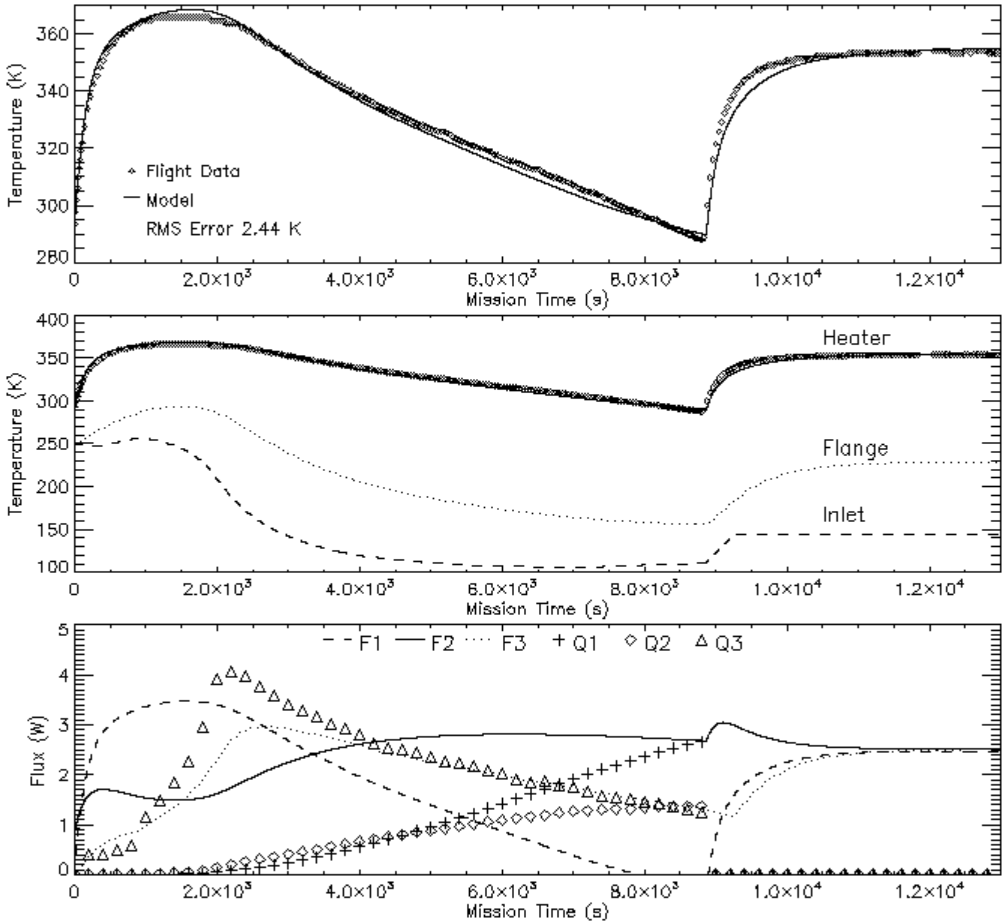




3.5 node model needed to reconstruct the temperature history

Meteoritics and Planetary Science, 41, 1705-1714, 2007



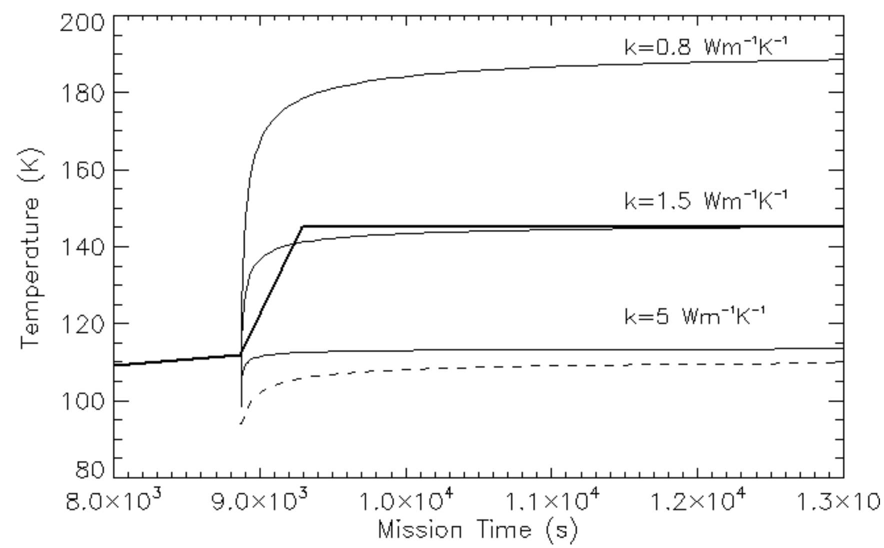


Free parameters in model can be tuned to reproduce descent history of inlet heater temperature.

Asymptotic inlet temperature (and thus effective surface thermal conductivity) is the result

Inferred 1-2 $Wm^{-2}K^{-1}$ conductivity is too high for dry granular material – implies heat loss was enhanced by ethane/ methane moisture causing convection/ evaporation (ground was damp)

Note clathrate decomposition temperature is not reached – evolved methane must have been present as a liquid.

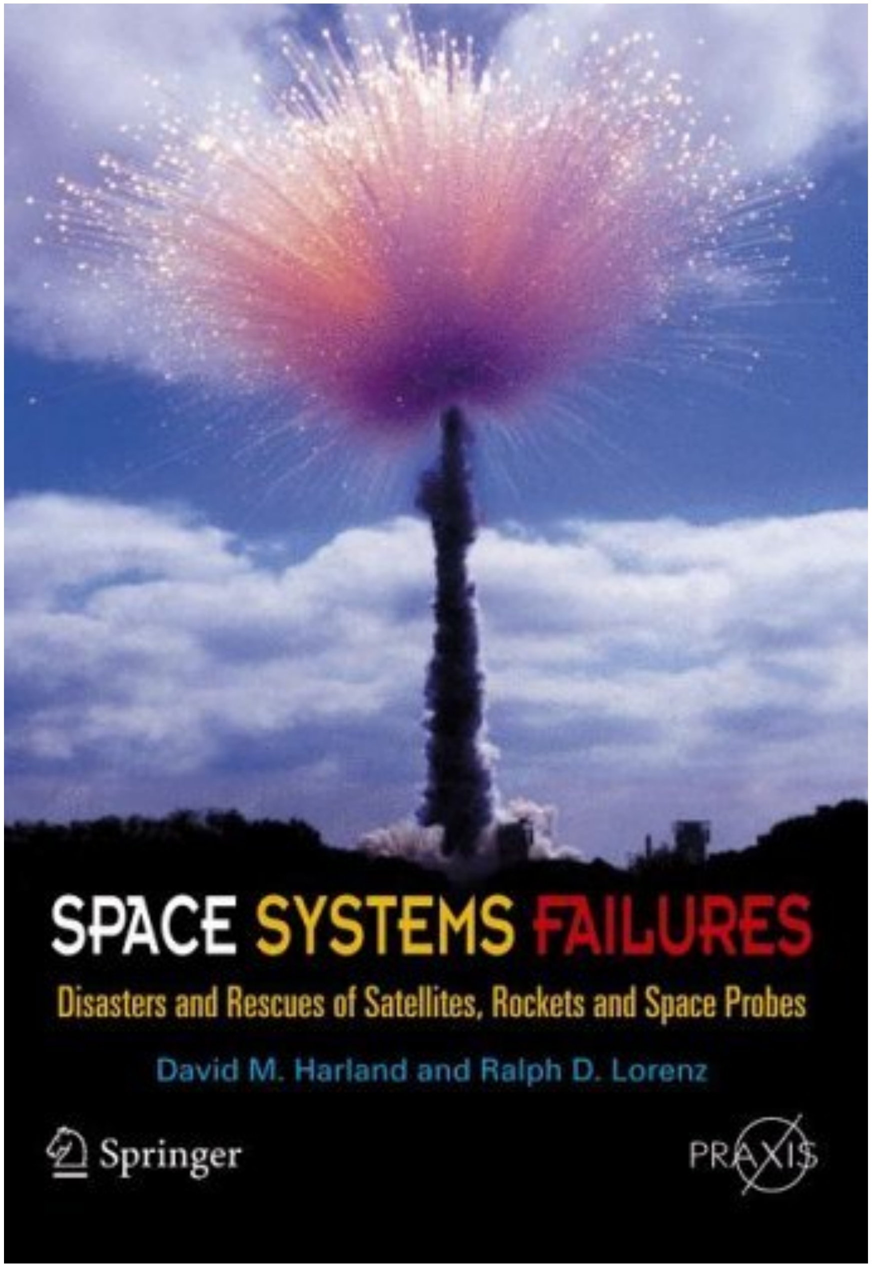


Coordinated Huygens Publications

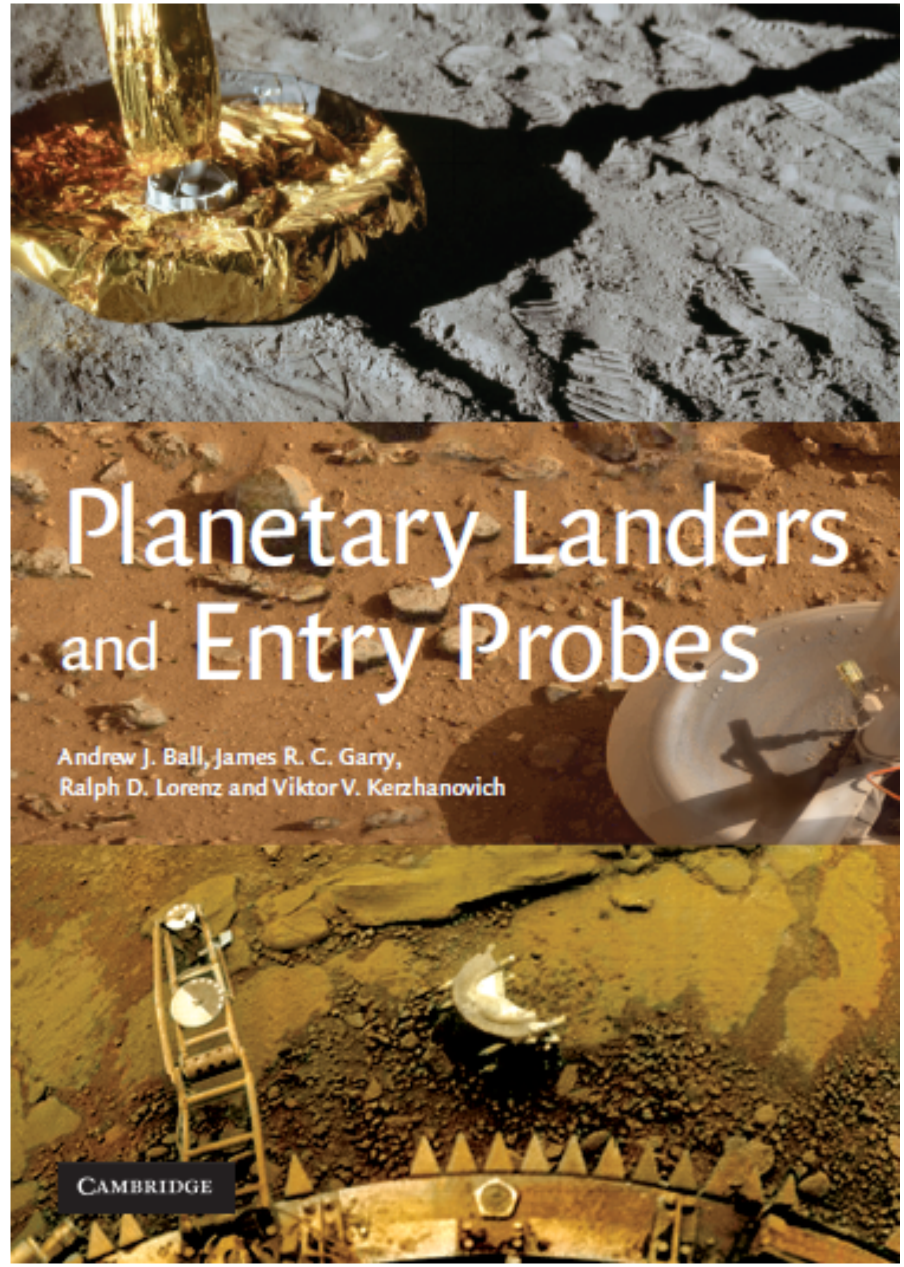
- Nature, 8 Dec 2005, Vol 405
- Planetary and Space Science, Titan as seen from Huygens, Vol 55, Issue 13, November 2007
- Planetary and Space Science, Titan as seen from Huygens, Volume 56, Issue 5, April 2008, Pages 573-585
- Huygens archived data set on ESA's PSA (http://www.rssd.esa.int/PSA)
  mirrored to NASA PDS atmospheric node: http://atmos.nmsu.edu/

But indeed all the whole story of Comets and Planets, and Production of the World, is founded upon such poor and trifling grounds, that I have often wonder'd how an ingenious man could spend all that pains in making such fancies hang together. For my part, I shall be very well contented, and shall count that I have done a great matter, if I can but come to any knowledge of the nature of things, as they now are, never troubling my head about their beginning, or how they were made, knowing that to be out of the reach of human Knowledge, or even Conjecture.

Christiaan Huygens, 1698



Springer 2005. Chinese edition 2010



CUP 2007. Chinese edition forthcoming