# Huygens Probe Relay Data Subsystem Anomaly and Recovery

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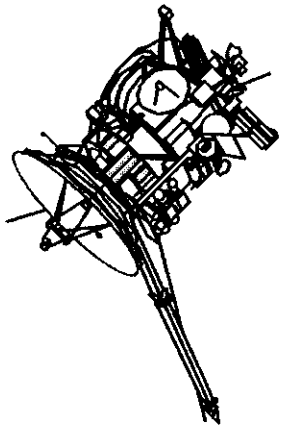
# The Huygens Mission

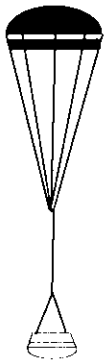
- European Space Agency Mission
  - Designed to study the atmosphere and surface of Saturn's largest satellite, Titan
  - Carried by the Cassini spacecraft which provides
    - Power for support equipment
    - S-band antenna system
    - Data storage and playback
- Six instruments/investigations
  - Aerosol Collector Pyrolyzer (ACP)
    - Study of clouds and aerosols in the Titan atmosphere.
  - Descent Imager and Spectral Radiometer (DISR)
    - Aerosol and cloud optical properties and spectroscopy measurements of Titan's atmosphere and surface.
  - Doppler Wind Experiment (DWE)
    - Study of winds from their effect on the Probe during Titan descent.
  - Gas Chromatograph and Mass Spectrometer (GCMS)
    - Chemical composition of gases and aerosols in Titan's atmosphere.
  - Huygens Atmospheric Structure Instrument (HASI)
    - In-situ study of Titan atmospheric physical and electrical properties.
  - Surface Science Package (SSP)
    - Physical properties of Titan's surface and related atmospheric properties

# Huygens Relay

Huygens avionics on the Cassini orbiter
S-band receiver and data handling



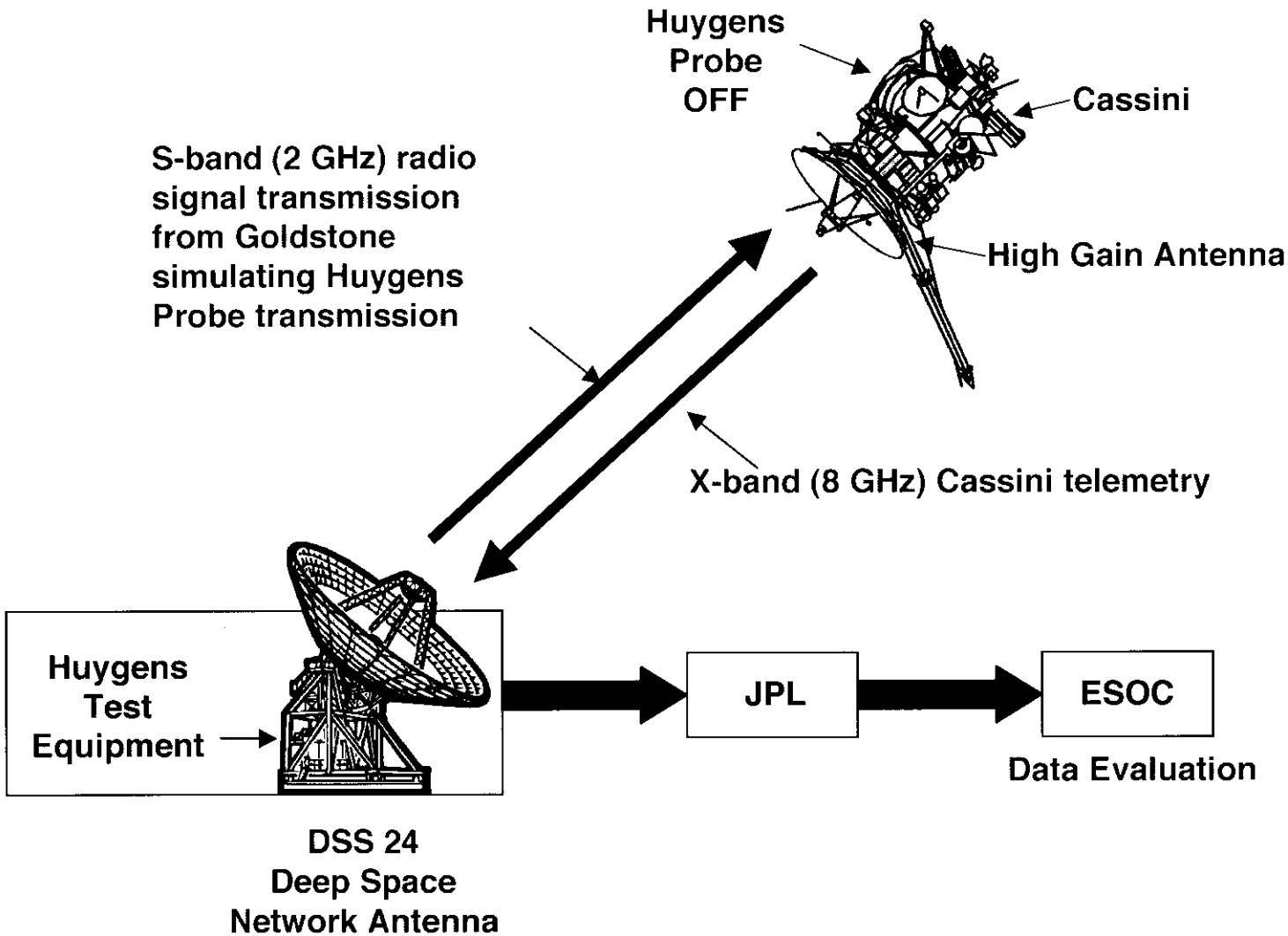
Probe data stored on
Orbiter recorders for
later playback



Doppler Shifted
Link

Huygens Probe has two S-band channels
- ~10W power
- Active after front shield separation

# Data System End to End Checkout
# (Feb. 2000)



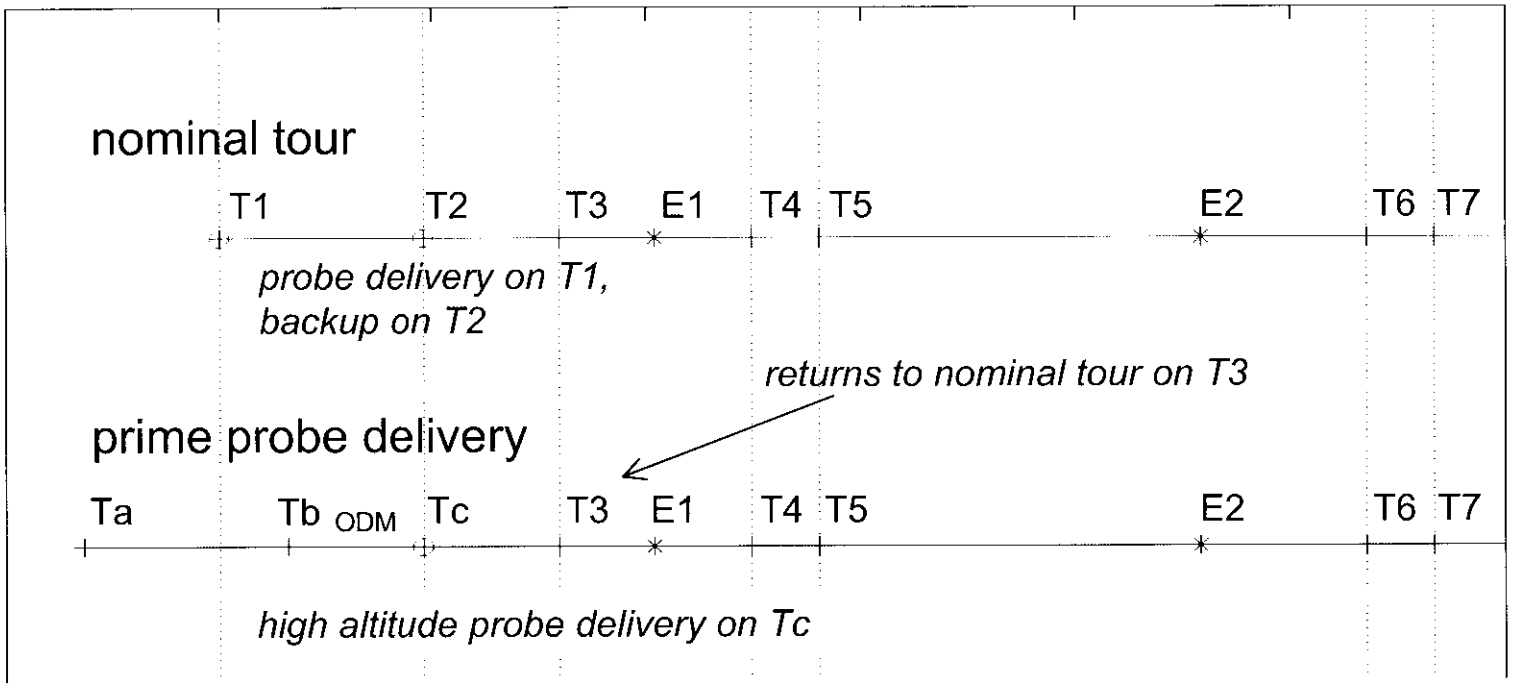
# Anomaly Identified During End to End Checkout

- Large number of corrupted frames and dump packets which could not be explained by the test analysis
- ESA formed a Board of Inquiry
- Receiver Anomaly
  - The S-Band orbiter receivers can easily acquire and track both the carrier and the sub-carrier throughout the mission
  - The problem lies in the design of the digital circuitry that receives the demodulated data.
  - At design level signal energy over noise levels ($E_s/N_0$), tests indicate that it does not have sufficient tracking bandwidth to accurately track the Doppler shifted demodulated symbol stream
  - Performance of the bit synchronizer is much better at frequencies nearer the rest frequency (less Doppler shift)
  - At increased $E_s/N_0$ (up to a point) performance of the bit synchronizer improves
- The result is data corruption, synchronization failures, and ground decoding failures
    - The "majority" of the probe mission would be lost

# Anomaly Resolution

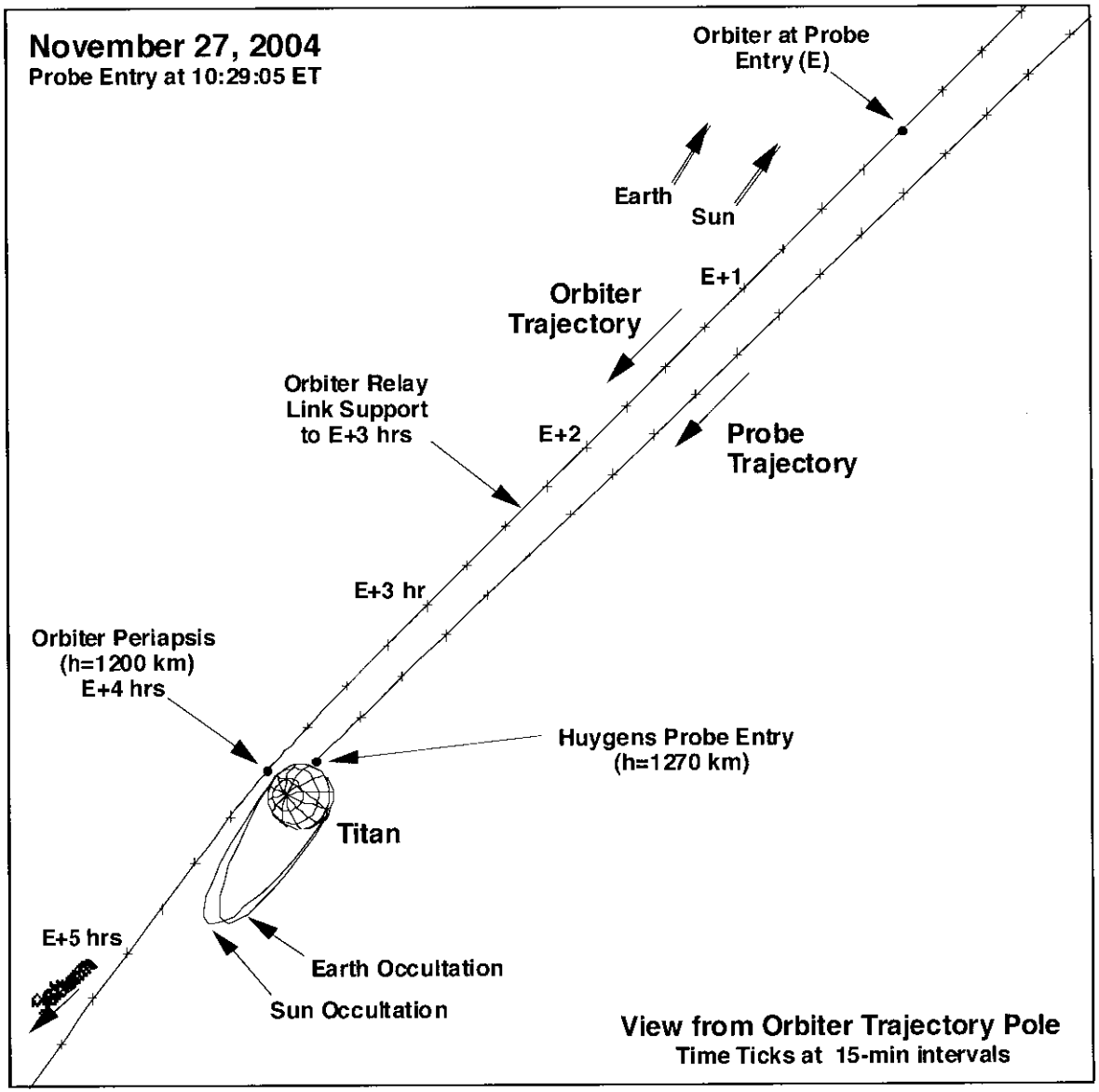
- A joint NASA/ESA Huygens Recovery Task Force was formed to identify potential solutions
  - Multidisciplinary experts from JPL and ESA(ESTEC/ESOC)
  - Worked for eighteen months
- Relatively few options available
  - All relevant control parameters/algorithms in the receivers are hardwired
- Three variables could be controlled
    - Doppler shift (delta-f)
    - Signal strength ($E_s/N_0$)
    - Bit transition (instruments did a very good job of data compression)
- Solution
  - Insert a high altitude flyby of Titan, thus reducing the Doppler effect to a acceptable level
  - Replaces the first two Titan encounters, T1 and T2, with three Titan encounters, Ta, Tb, and Tc.
    - Cost is ~100 m/s is additional mission $\Delta V$
- Other aspects
  - Improved ground processing software to retrieve corrupted data
  - Pre-heating of the probe electronics prior to entry.
    - Slows down the data system oscillators which results in a lower frequency

# Timelines

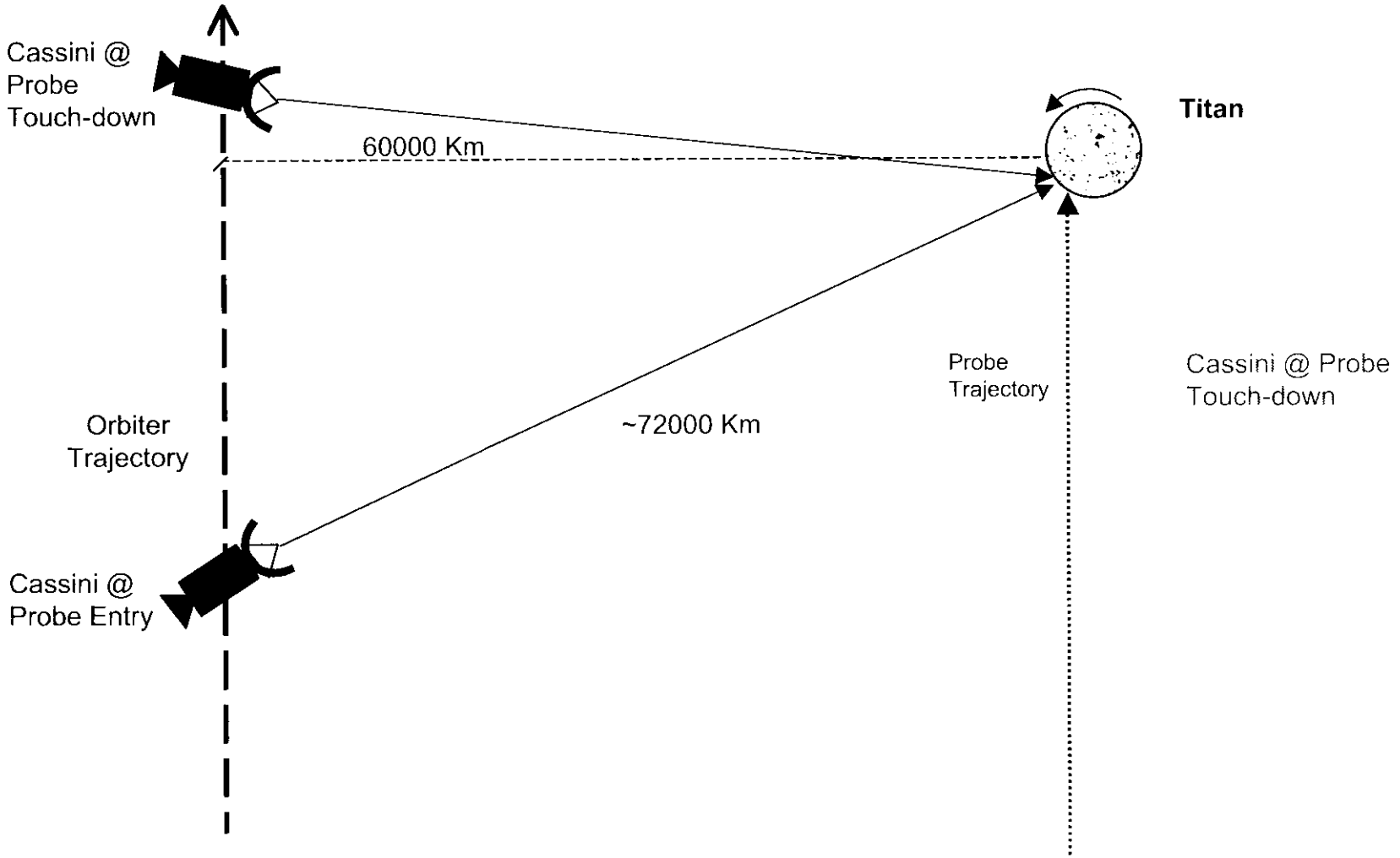

nominal tour
T1
T2
T3
E1
T4
T5
E2
T6
T7
probe delivery on T1,
backup on T2
returns to nominal tour on T3
prime probe delivery
Ta
Tb ODM
Tc
T3
E1
T4
T5
E2
T6
T7
high altitude probe delivery on Tc

# Old Probe Mission

# Flyby Geometry

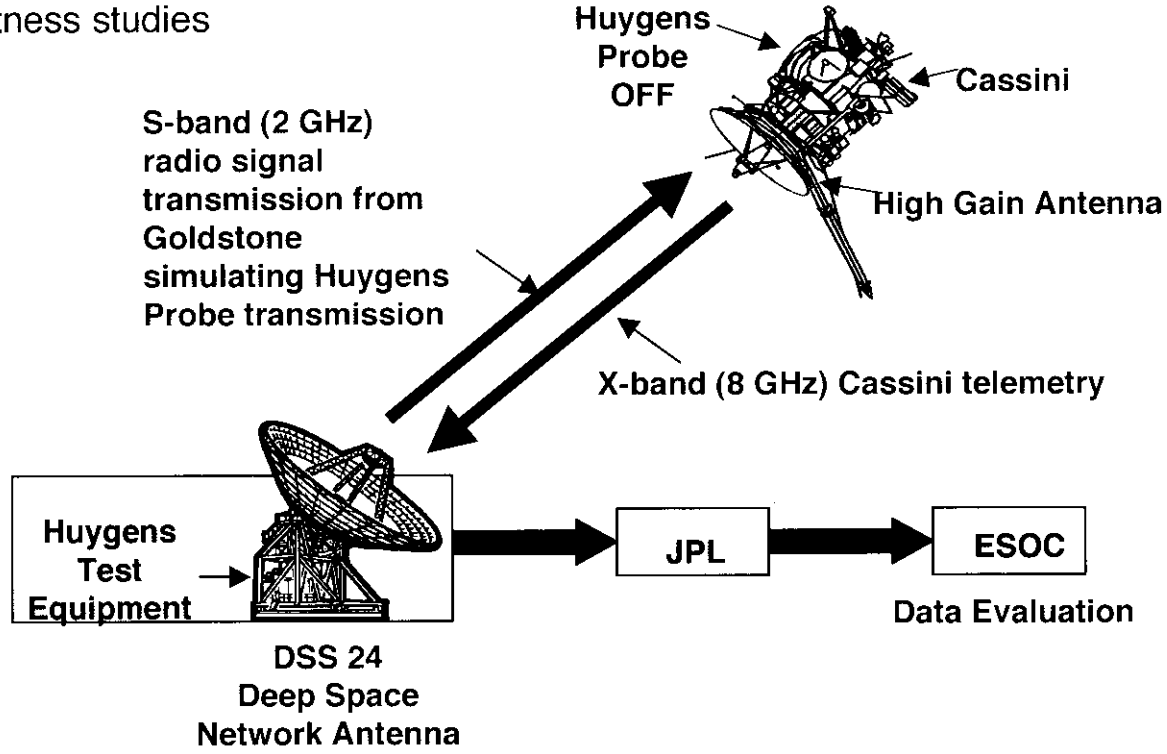


# New Probe Mission



# Solution V&V

- Tests, tests, and then more tests
  - Validated new descent profiles with engineering model at the Huygens Probe Operations Centre at ESOC.
  - Used the DSN and flight article exactly as in mission
    - Four complete end-end tests of descent profile
    - Robustness studies




  - Use flight testbed at JPL to validate

# Lessons Learned

- Test to all requirements
  - Design flaw got through test program
- Keep testbeds operational throughout mission
  - Huygens EM was essential component in the redesign
- Never discard data
  - Post processing of garbled packets could mitigate data loss
- Maintain reconfigurabilty options during flight
  - The ability to change a few key parameters would have completely solved the problem
  - Cost/performance/risk driver
- Never stop testing!
  - Even after launch
- Ref. Huygens Recovery Task Force Final Report