



Deep Space Network Capabilities for Receiving Weak Probe Signals

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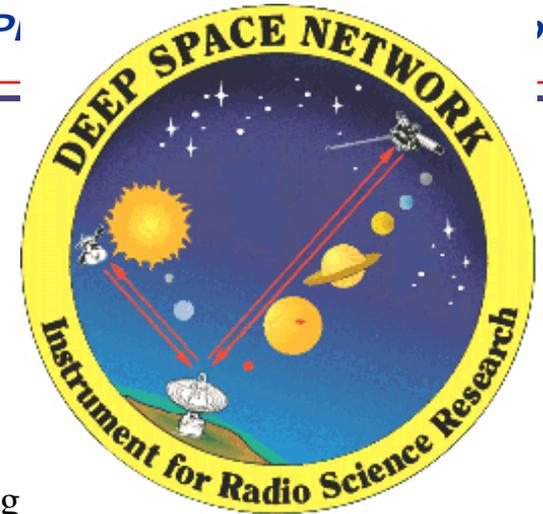
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Presented at NASA Ames Research Center



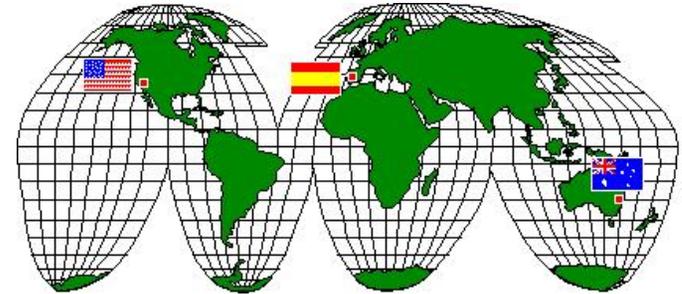
Abstract

- Planetary probes can encounter mission scenarios where communication is not favorable during critical maneuvers or emergencies
 - Launch, initial acquisition, landing, trajectory corrections, safing
- Communication challenges due to sub-optimum antenna pointing or transmitted power, amplitude/frequency dynamics, etc.
 - Prevent lock-up on signal and extraction of telemetry
- Examples: loss of Mars Observer, nutation of Ulysses, Galileo antenna, Mars Pathfinder and Mars Exploration Rovers Entry, Descent, and Landing, and the Cassini Saturn Orbit Insertion.
- A Deep Space Network capability to handle such cases has been used successfully to receive signals to characterize the scenario
- This paper will describe the capability and highlight the cases of the critical communications for the Mars rovers and Saturn Orbit Insertion and preparation radio tracking of the Huygens probe at (non-DSN) radio telescopes.





The Deep Space Network



- The Deep Space Network (DSN) is the largest and most sensitive scientific telecommunications facility in the world
- Primary function: provide two-way communication between the Earth and spacecraft exploring the solar system
 - Instrumented with large parabolic reflectors, high-power transmitters, low-noise amplifiers and receivers, etc.
- Three complexes ~ 120 degrees apart around the world at Goldstone, California; near Madrid, Spain; and near Canberra, Australia



Can You Hear Me Now?

P_R = Received power at receiver input

$$P_R = P_T L_T G_T L_{TP} L_S L_A L_P L_{RP} G_R L_R$$

P_T = Total transmitted power (>20 W)

L_T = Transmission Circuit loss

G_T = Transmitting antenna gain

L_{TP} = Pointing loss of transmitting antenna

L_S = space loss (distance squared)

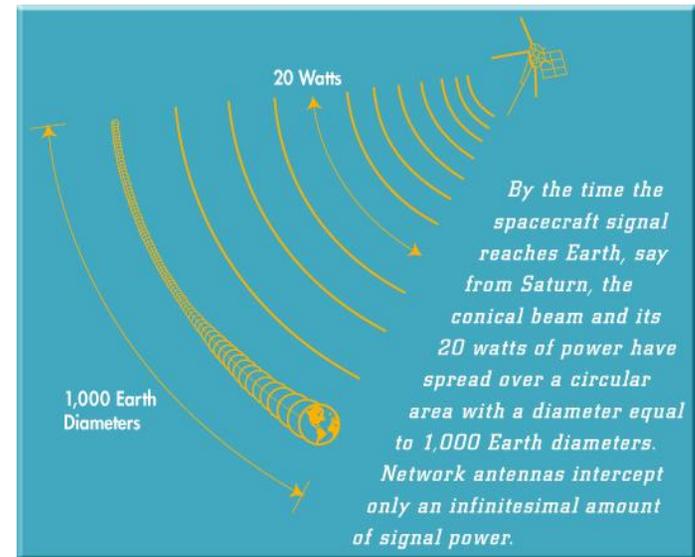
L_A = Atmospheric attenuation

L_P = Polarization loss

L_{RP} = Pointing loss of receiving antenna

G_R = Receiving antenna gain

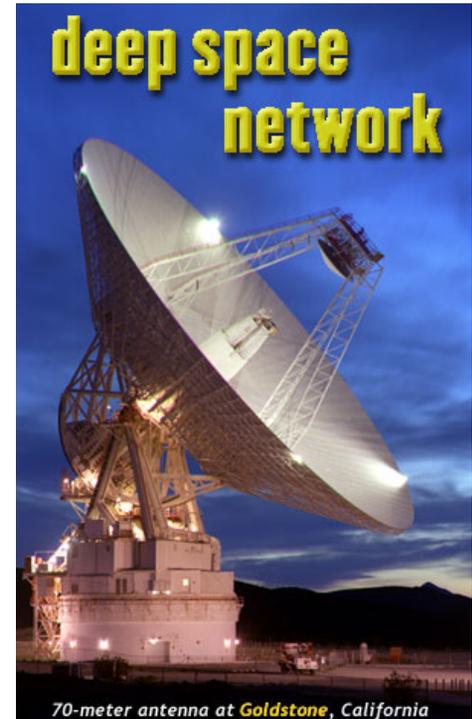
L_R = Receiving circuit loss





DSN Radio Science Receiver

- Independent of tracking receiver
- Open-loop down-conversion
- Tuned by “predicts” generated from navigation information
- Frequency predictions generated by Radio Science Systems Group can include model of planet’s atmosphere
- Remotely operated from JPL
- Features
 - Better stability
 - Capture signal dynamics
 - Capture multi-path
 - Choices of bandwidth and sampling
 - Higher quantization
 - Creative post-pass processing
 - Arraying
 - Tone processors
 - *Capture multiple sampling rates/bandwidths simultaneously*
 - *Capture multiple predict scenarios simultaneously*
 - *Capture multiple polarizations*





The Cassini Saturn Orbit Insertion Challenge

- Cassini launched in 1997 with mission design in place
- SOI maneuver optimized for capture while using minimum amount of fuel
 - Fuel is a valuable consumable for such a long mission
 - One third of fuel used for SOI engine burn
- Communications was to include a 5-hours gap
- Problems with other missions after 1997 created a new mandate: “Do not perform critical maneuvers without communications”
 - Specially the most advanced and most expensive interplanetary spacecraft
- Cassini Program appreciated value of information in carrier signal only
 - Did not require telemetry
- ***Extracting a weak carrier from noise ==> Radio Science***



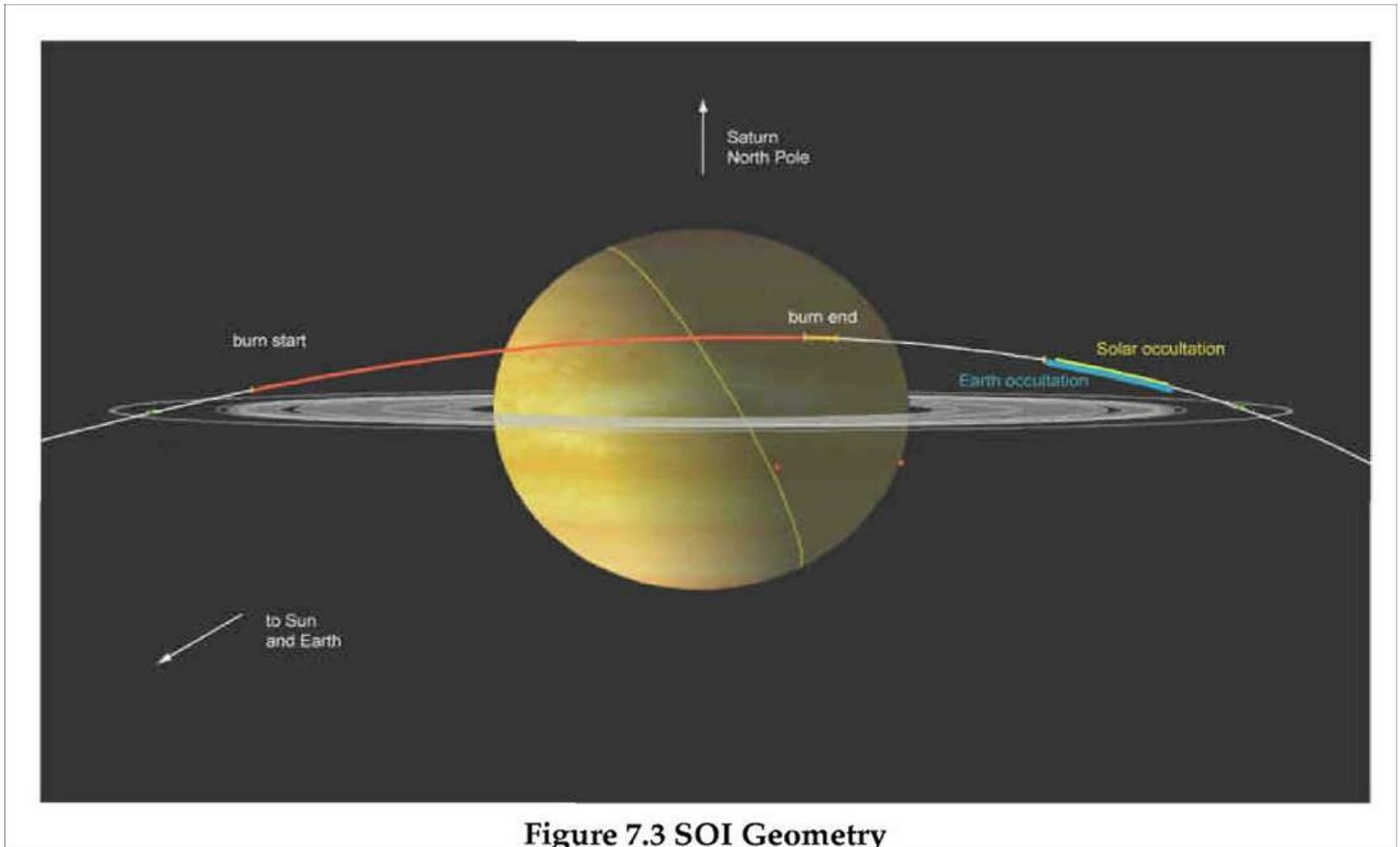
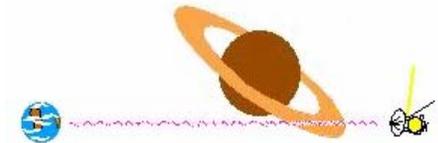


Figure 7.3 SOI Geometry



SOI Communication Conditions

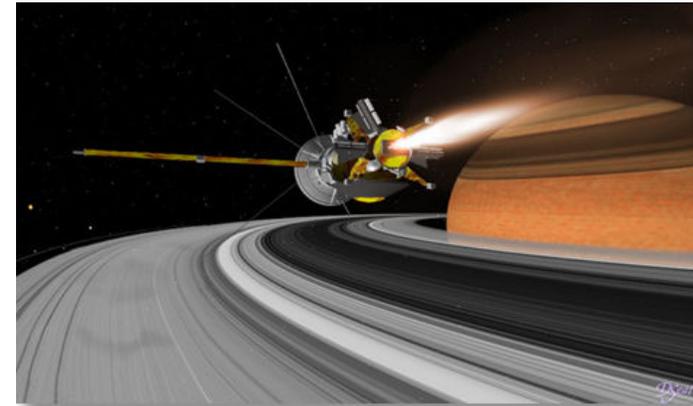
- Low signal levels
 - Low gain antenna
 - Attitude optimized for engine burn not for antenna pointing
 - Interruptions during occultation by rings
- Frequency Dynamics
 - Gravity of Saturn: *Doppler shift* ~ 400 kHz
 - Engine burn: *Doppler shift* ~ 11 kHz at ~ 2.5 Hz/sec
- Timing errors manifested as deviations from predicted signal frequency
 - Minimizing timing uncertainties allow using narrower receiver bandwidth
- Other conditions:
 - One-way light time ~ 1 hour and 24 minutes
 - Near solar conjunction

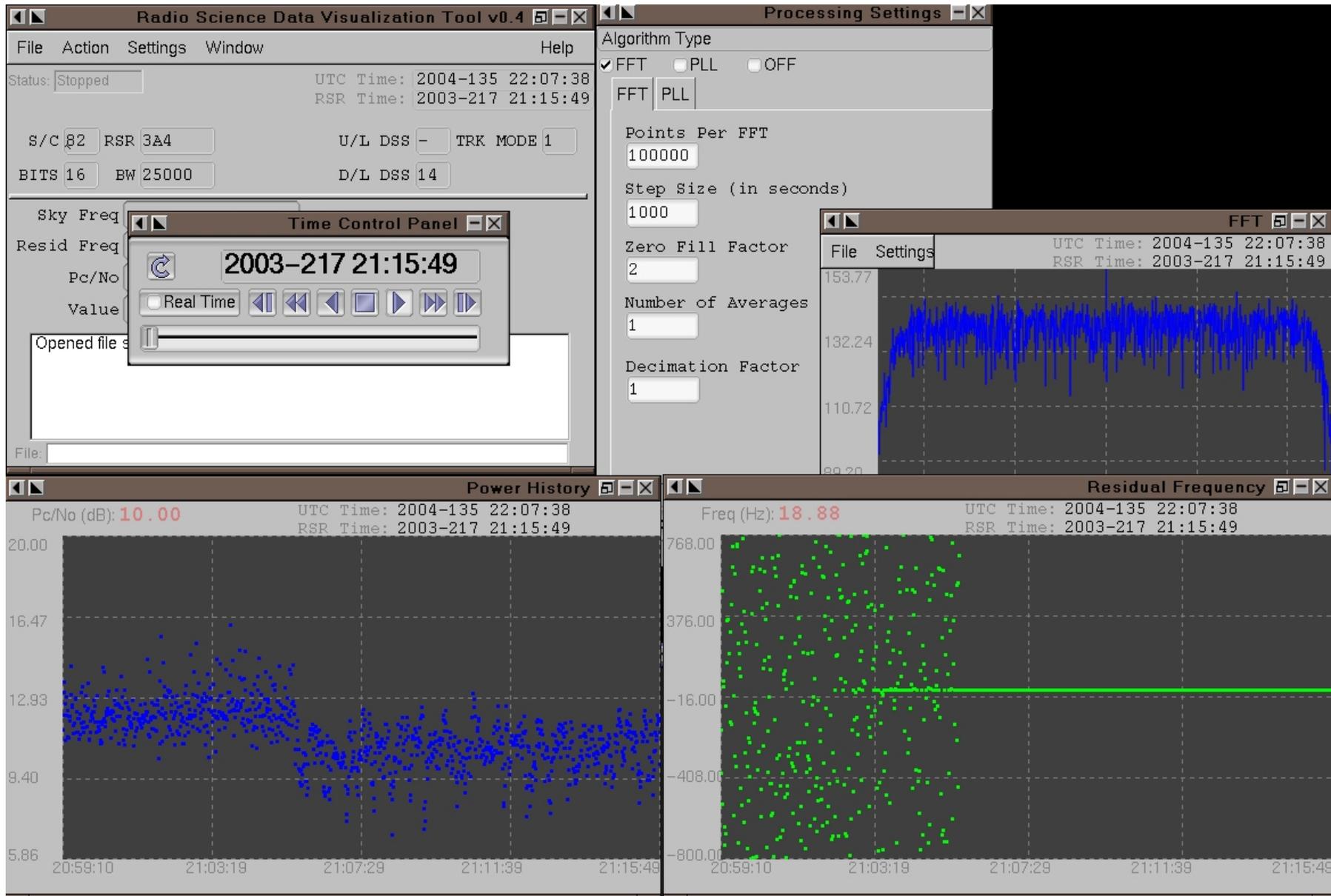


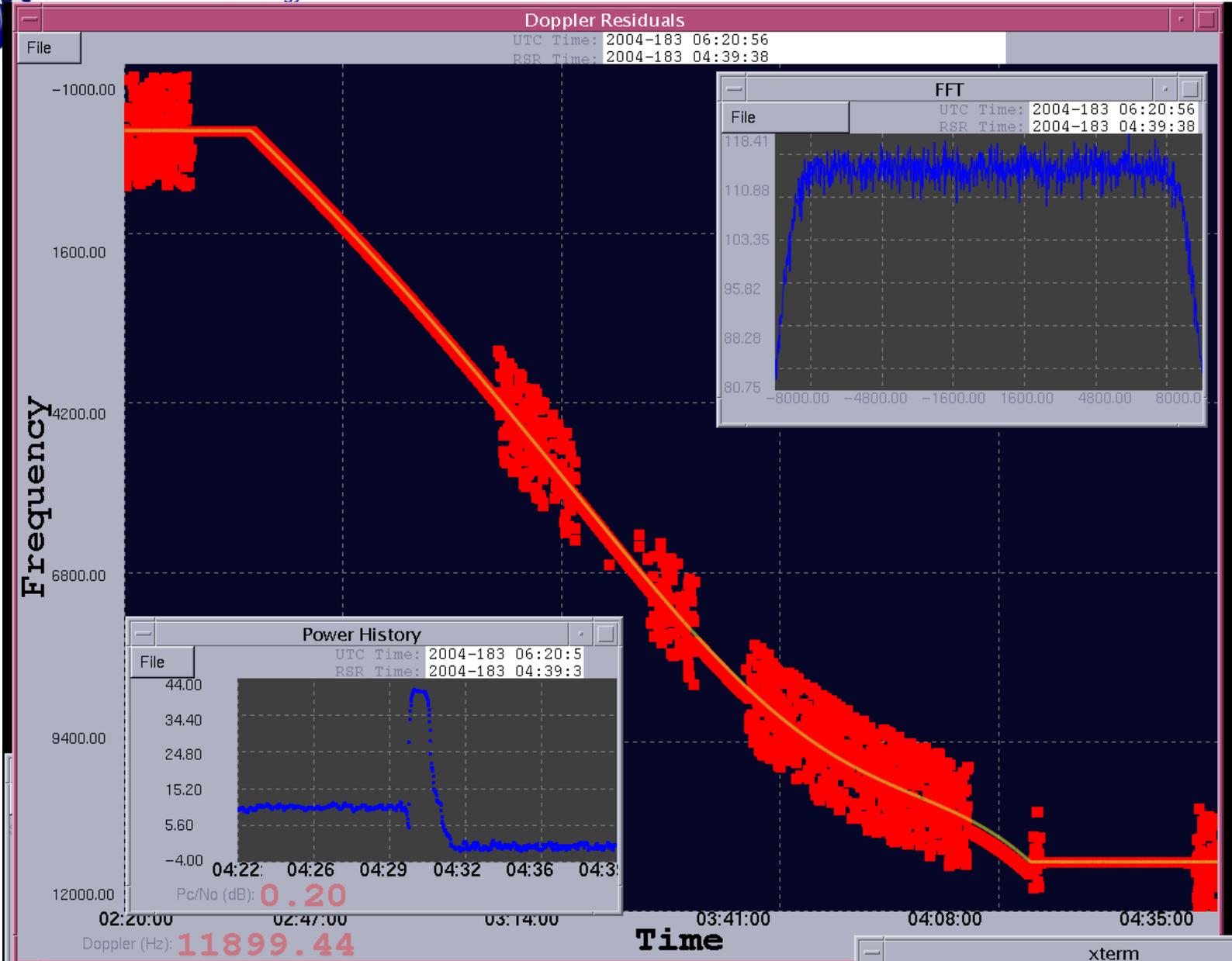


SOI Signal Acquisition Strategy

- Standard services of Deep Space Network
 - Tracking receiver
 - May lose lock if level drops below threshold
 - Radio Science Receiver (RSR)
 - Open-loop receiver tuned by prediction file
- Enhanced Radio Science Processor
 - Custom-made for SOI enhanced visualization & monitoring at JPL
- Backup: special application processor
 - Fast FFT computations of RSR data
- Carrier arraying
 - 70-m + 2 34-m stations. Increase ~1.5 dB

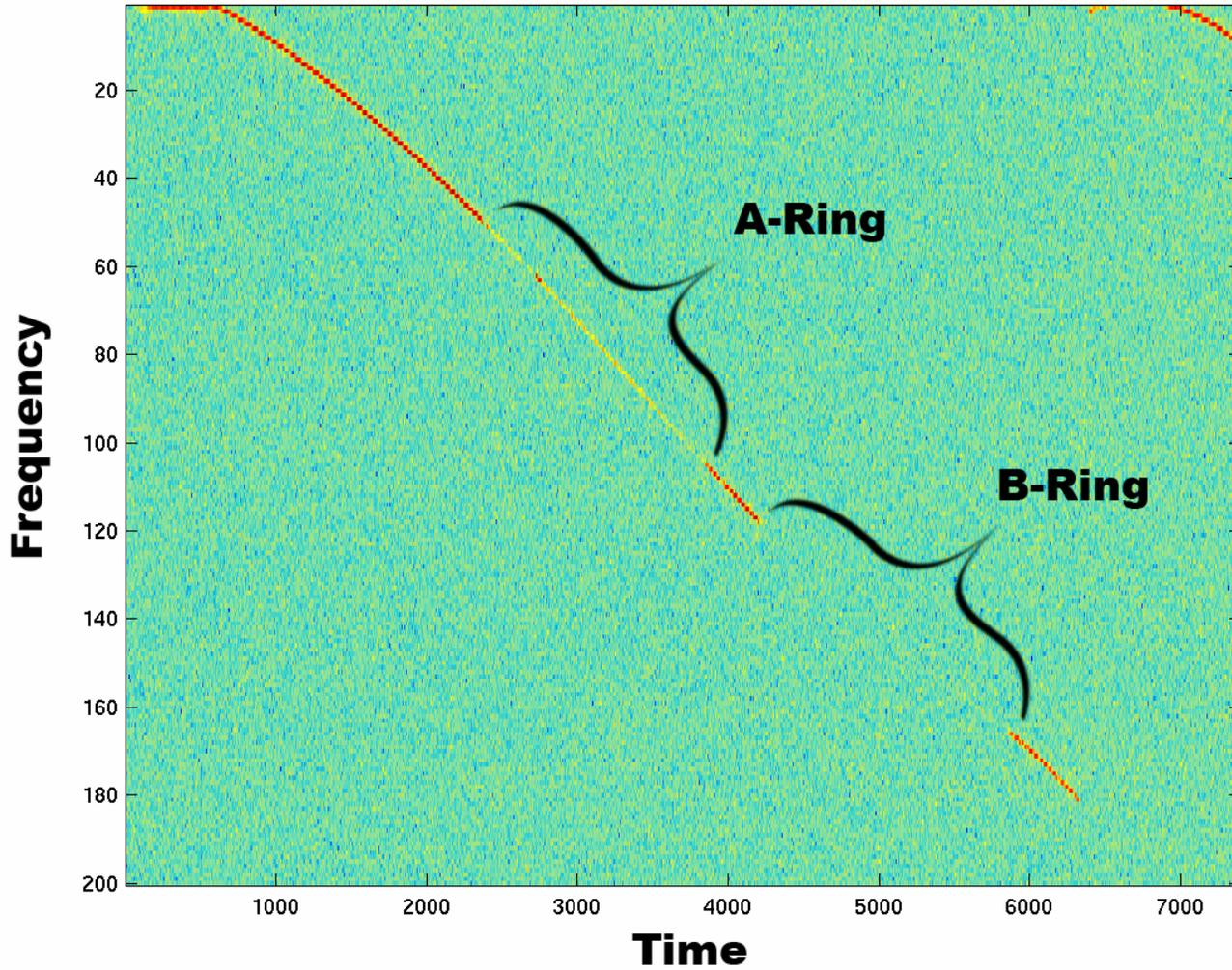


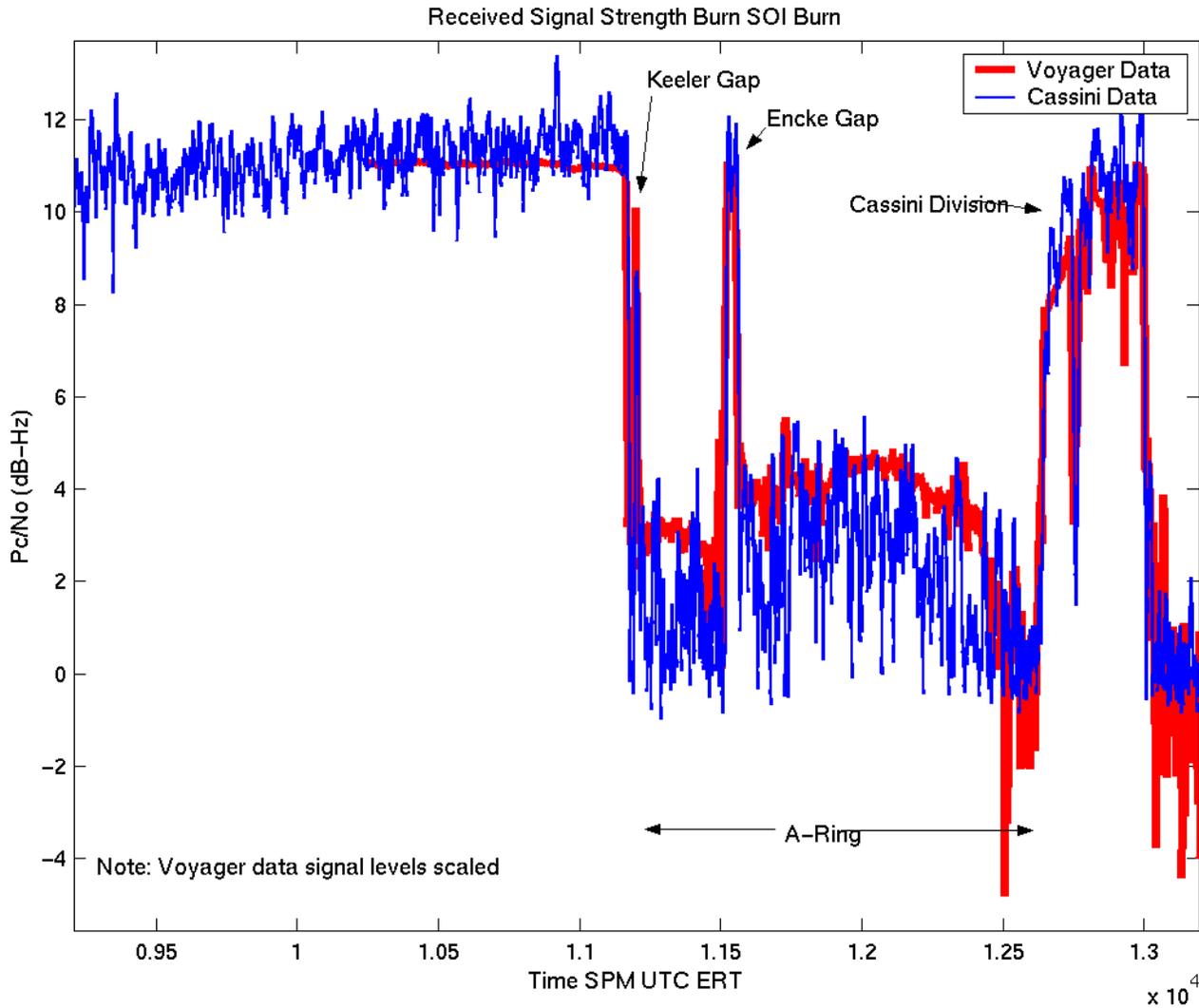




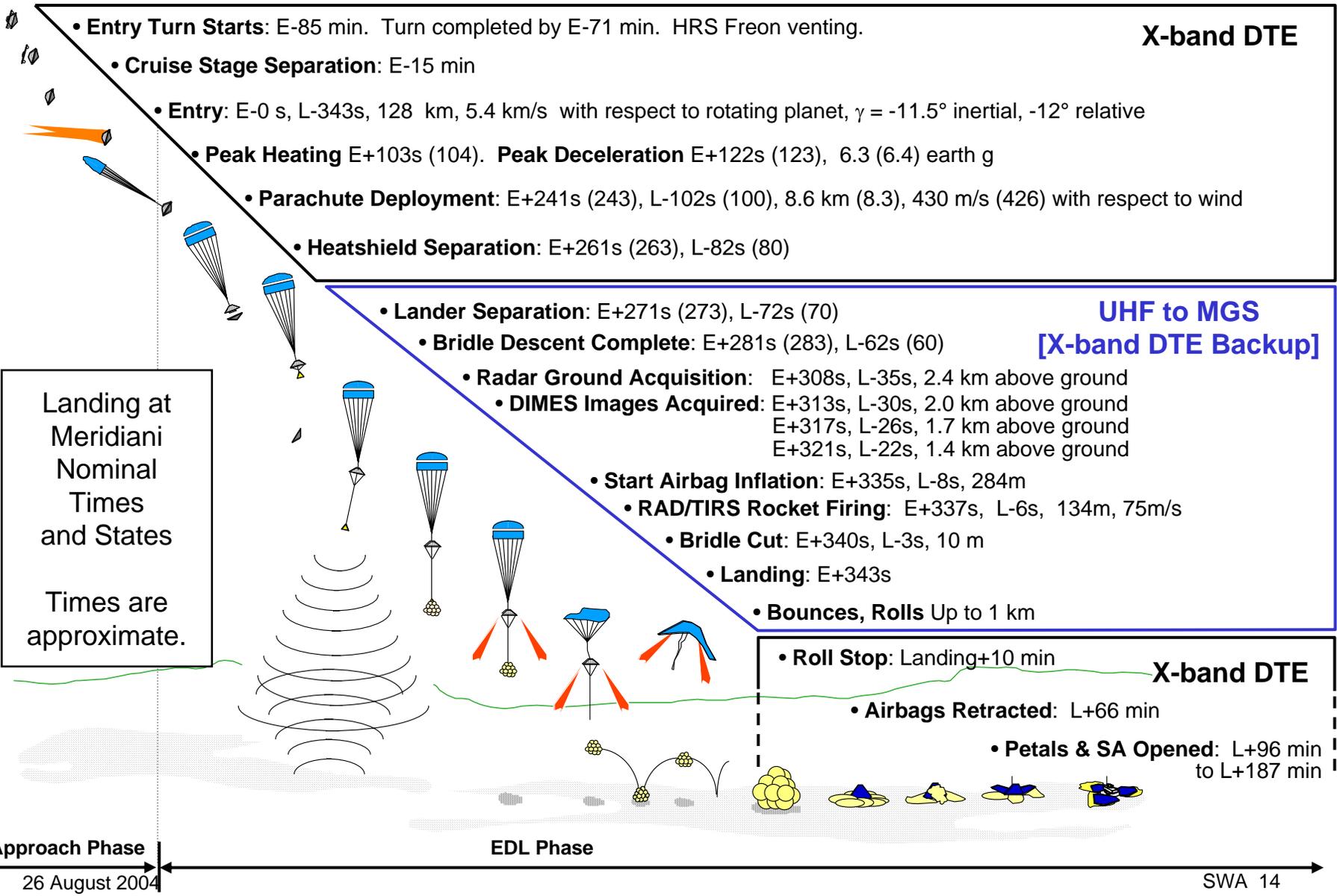


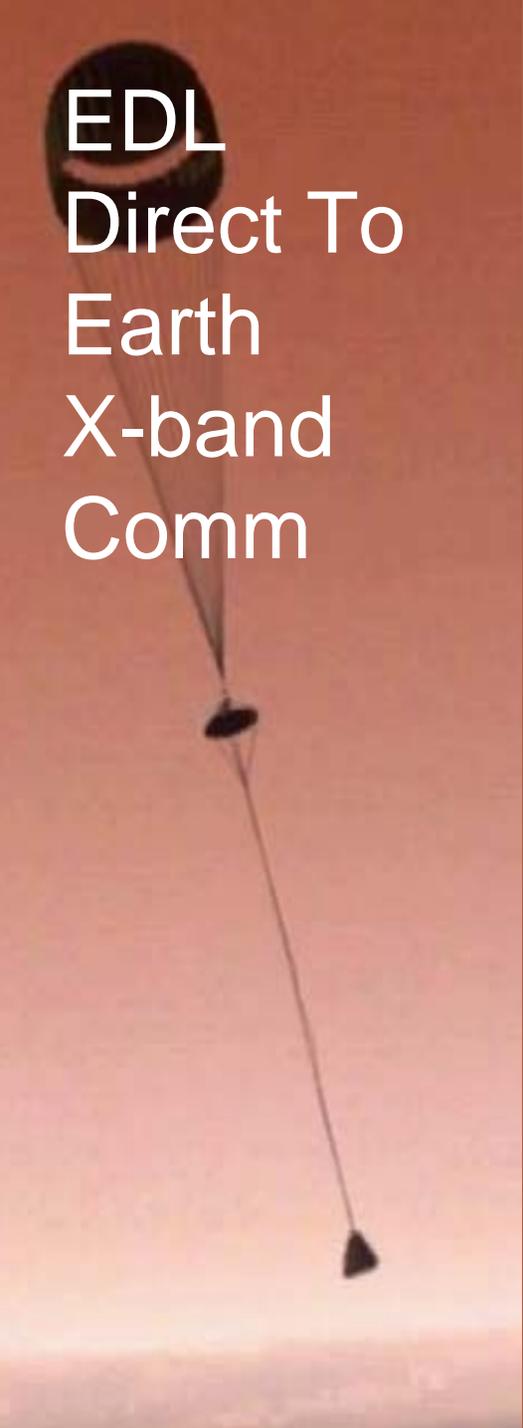
SOI Signal Spectrogram





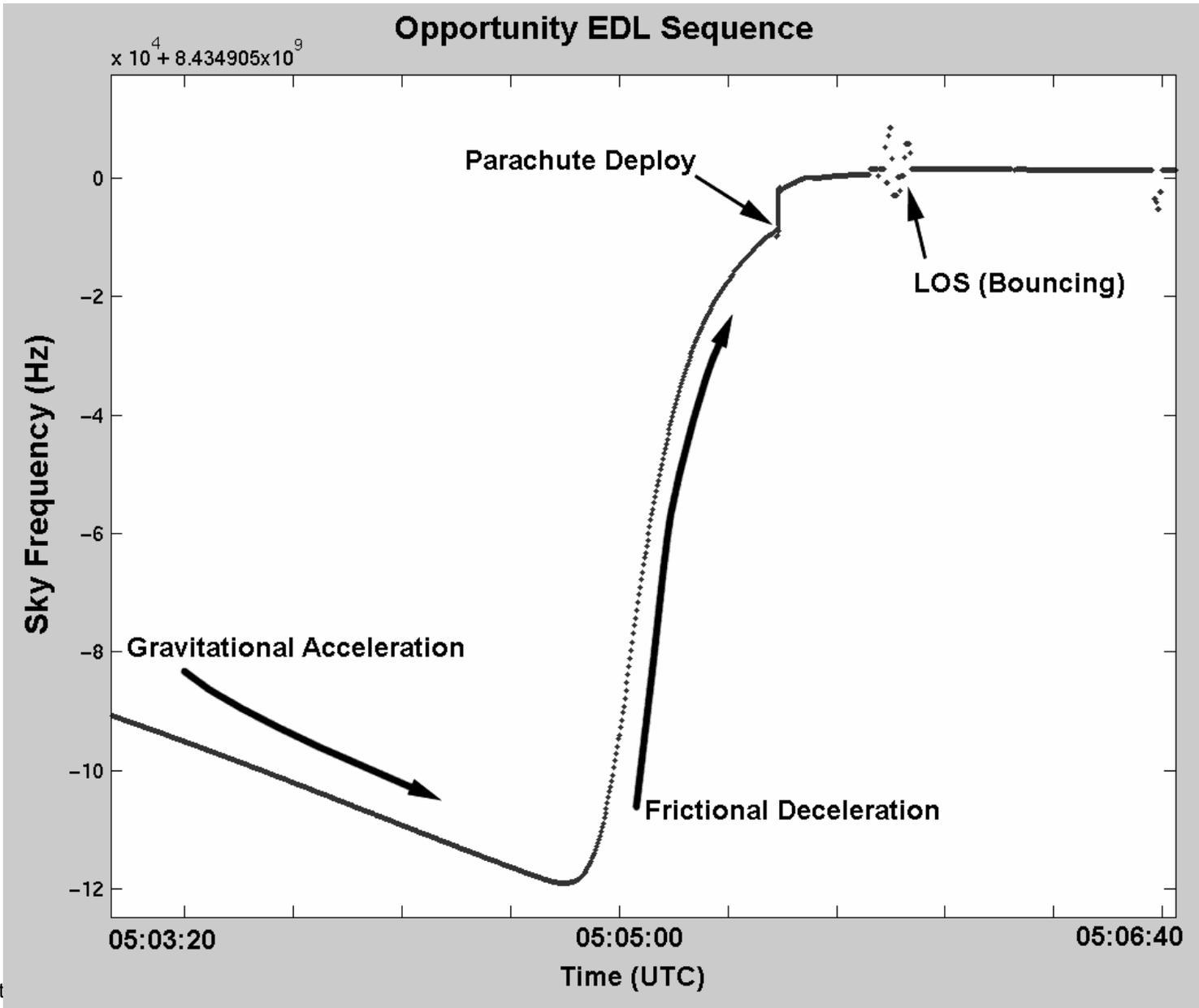
MER EDL Timeline





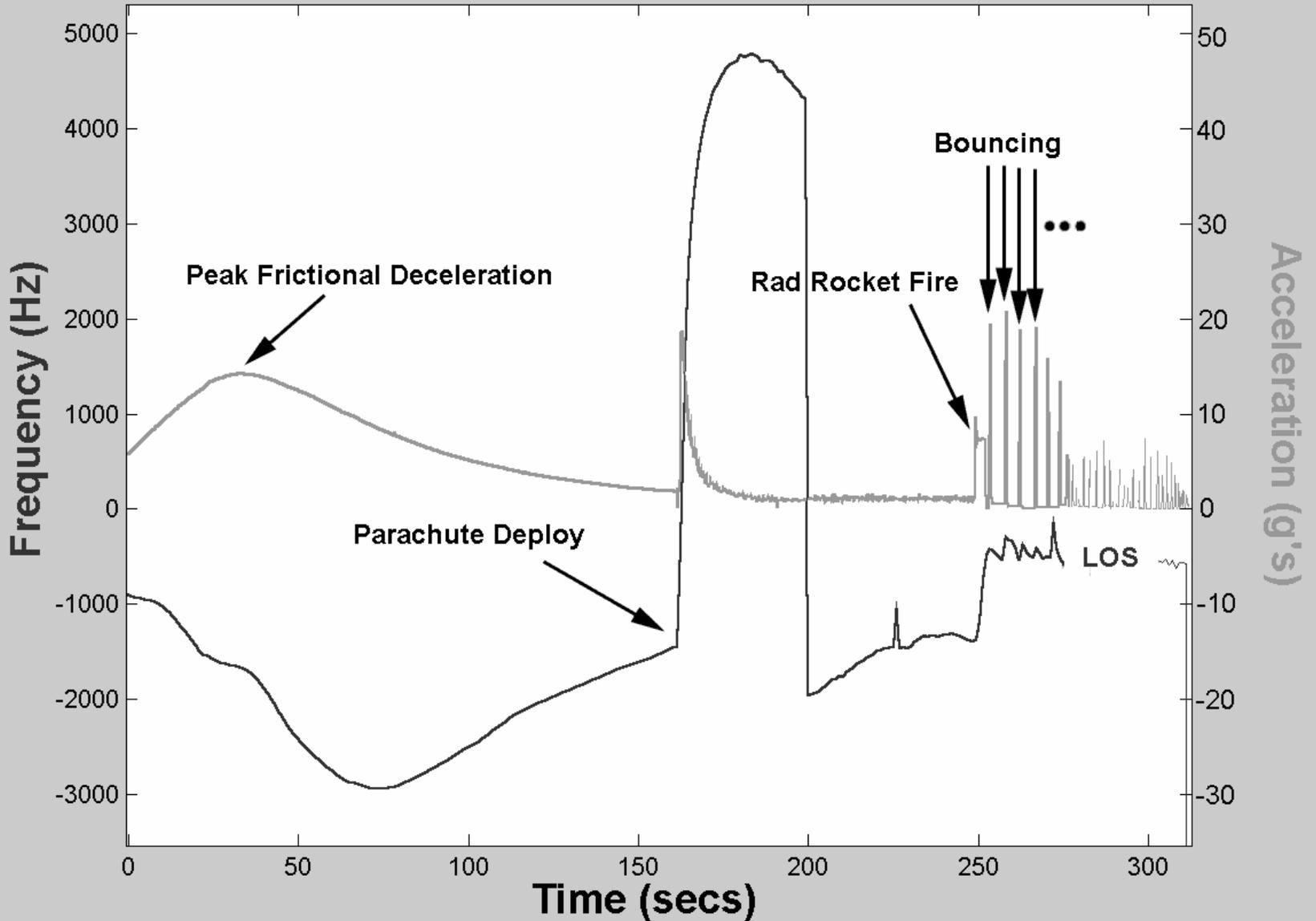
EDL Direct To Earth X-band Comm

- 256 MFSK tones transmitted as sub-carriers.
- Between 5 and 15 KHz, 40Hz apart
- MER uses only 105 of these tones (25 after landing)
- First tone transmitted at ~E-16min.
- Each tone is transmitted for 10s and then a priority queue is consulted for the next tone
 - Priority 1: Parachute open
 - Priority 2: Events (note: Tones indicate that the command was issued -- not a confirmation that the event took place).
Radar solution (20 no sol./12 sol.)
 - Priority 3: Fault Tones
 - Priority 4: Deceleration tones
 - Priority 5: Calibration tones
- After the lander descent on the bridle (@ L-75s), no tone reception is certain because the lander sways.





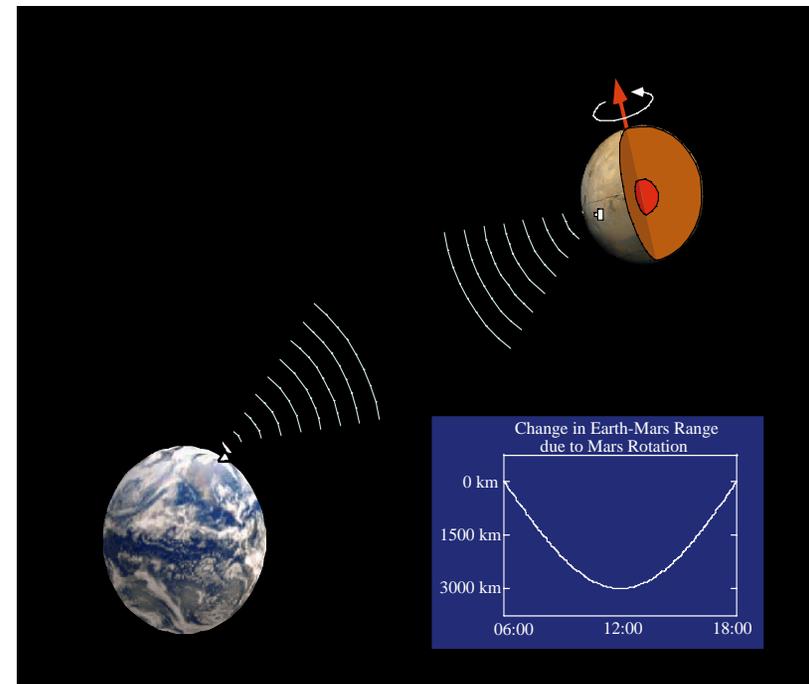
Spirit EDL Sequence





Huygens Probe

- Link at 2040 MHz to Cassini orbiter during Huygens descent to Titan
 - Telemetry and Doppler Wind Experiment
- Designed for spacecraft-to-spacecraft link
 - Not for Huygens to Earth communication
- Frequency outside deep space band
- Can not be received by DSN without modification
- Plans are underway to utilize other radio telescopes and VLBI stations
- Plan to send DSN Radio Science Receiver to Green Bank Telescope
 - Expect to reconstruct carrier Doppler
- Benefit Doppler Wind Experiment by receiving data at a different angle





Conclusions

- Probe mission concepts take communications into account for design of critical events
- Successful support of MER and Cassini SOI allowed missions to conserve consumables
- Receiver instrumentation designed for Radio Science experiments such as atmospheric occultations and relativity experiments, etc. utilized for critical engineering applications

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration

