Deep Space Network Capabilities for Receiving Weak Probe Signals

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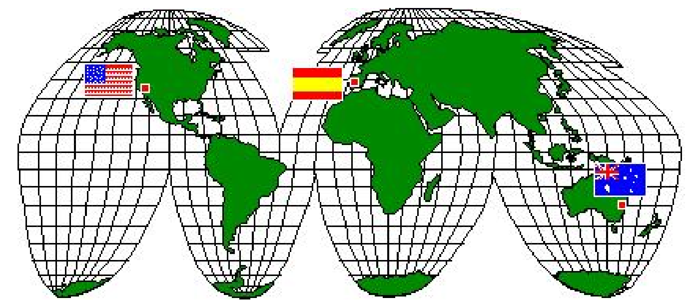
Abstract

- 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



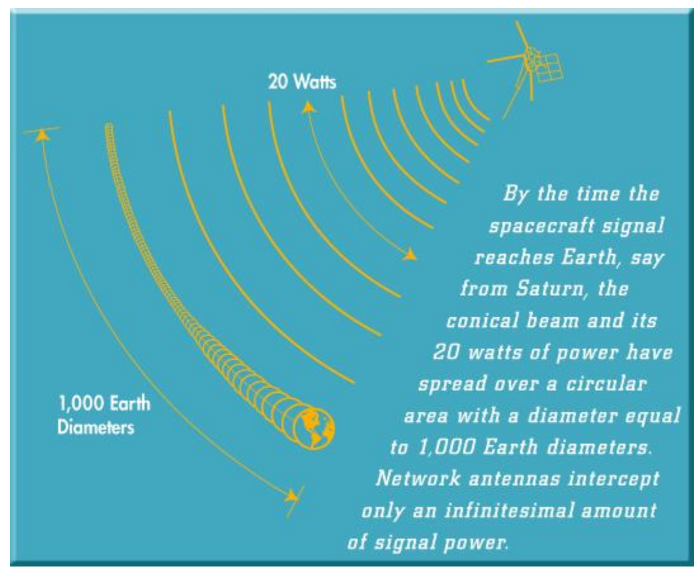
- The Deep Space Network (DSN) is the largest and most sensitive scientific telecommunications facility in the world
- Primary function: provide two-way communication between the Earth and spacecraft exploring the solar system
  - Instrumented with large parabolic reflectors, high-power transmitters, 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

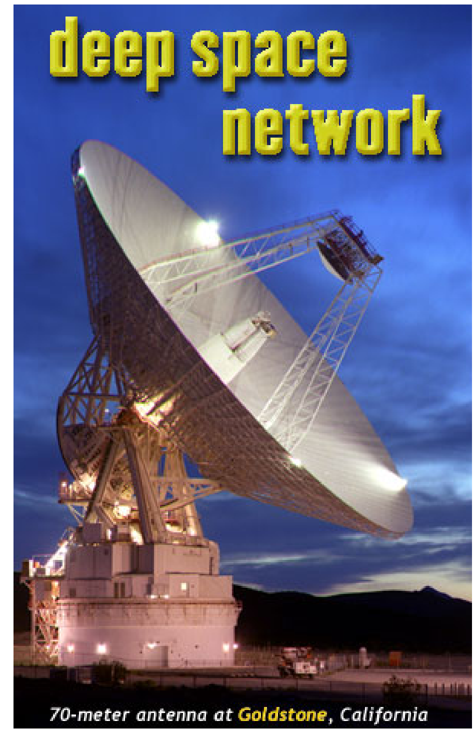
$$P_R = P_T L_T G_T L_{TP} L_S L_A L_P L_{RP} G_R L_R$$

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***

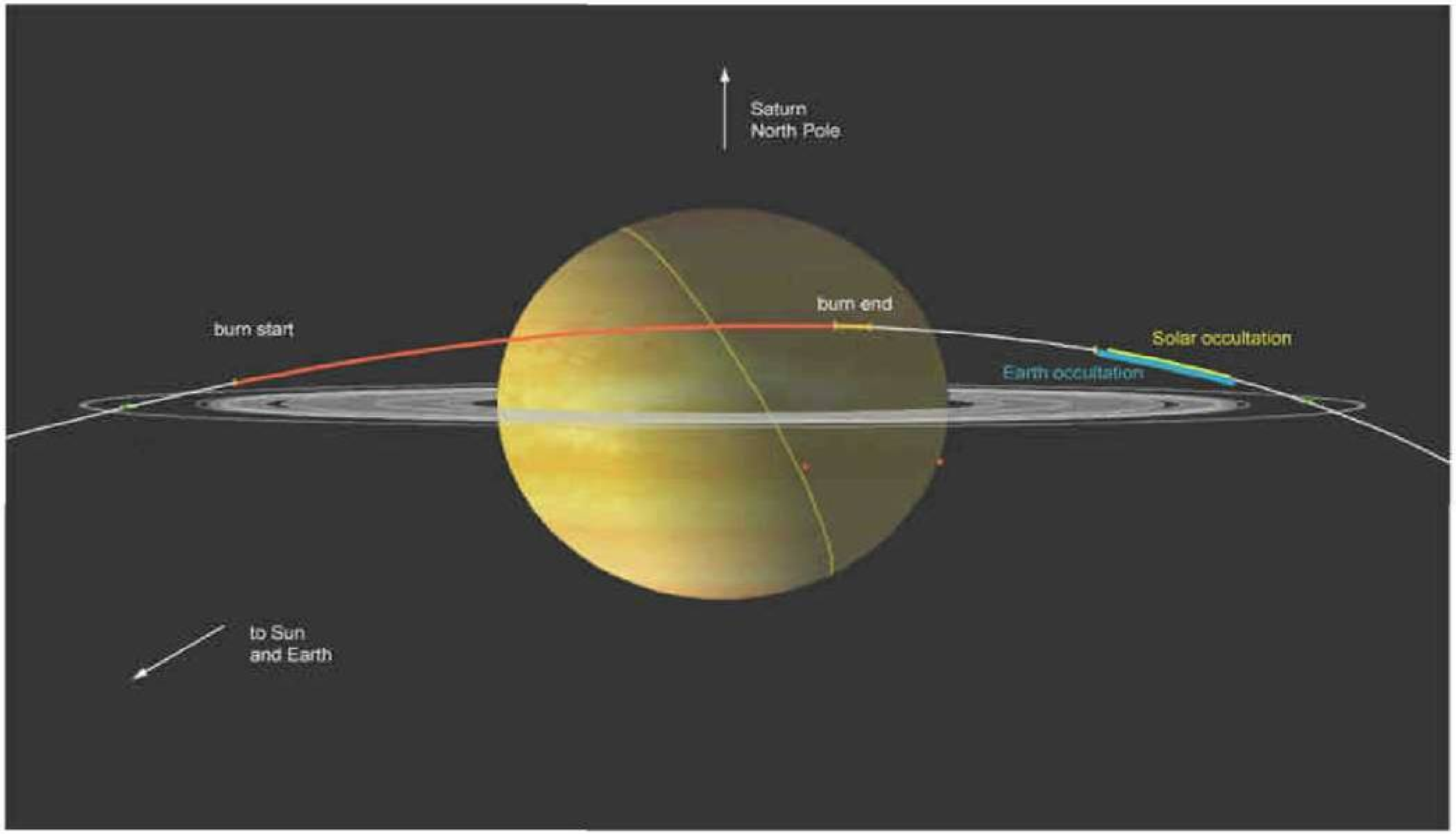
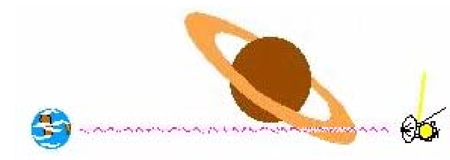


Figure 7.3 SOI Geometry

SOI Communication Conditions

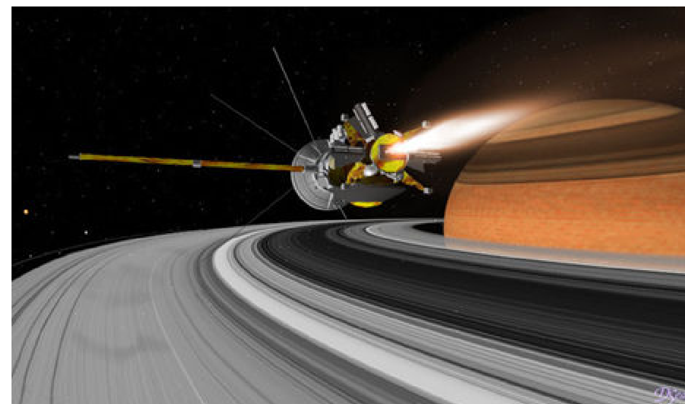
- Low signal levels
  - Low gain antenna
    - Attitude optimized for engine burn not for antenna pointing
  - Interruptions during occultation by rings



- 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

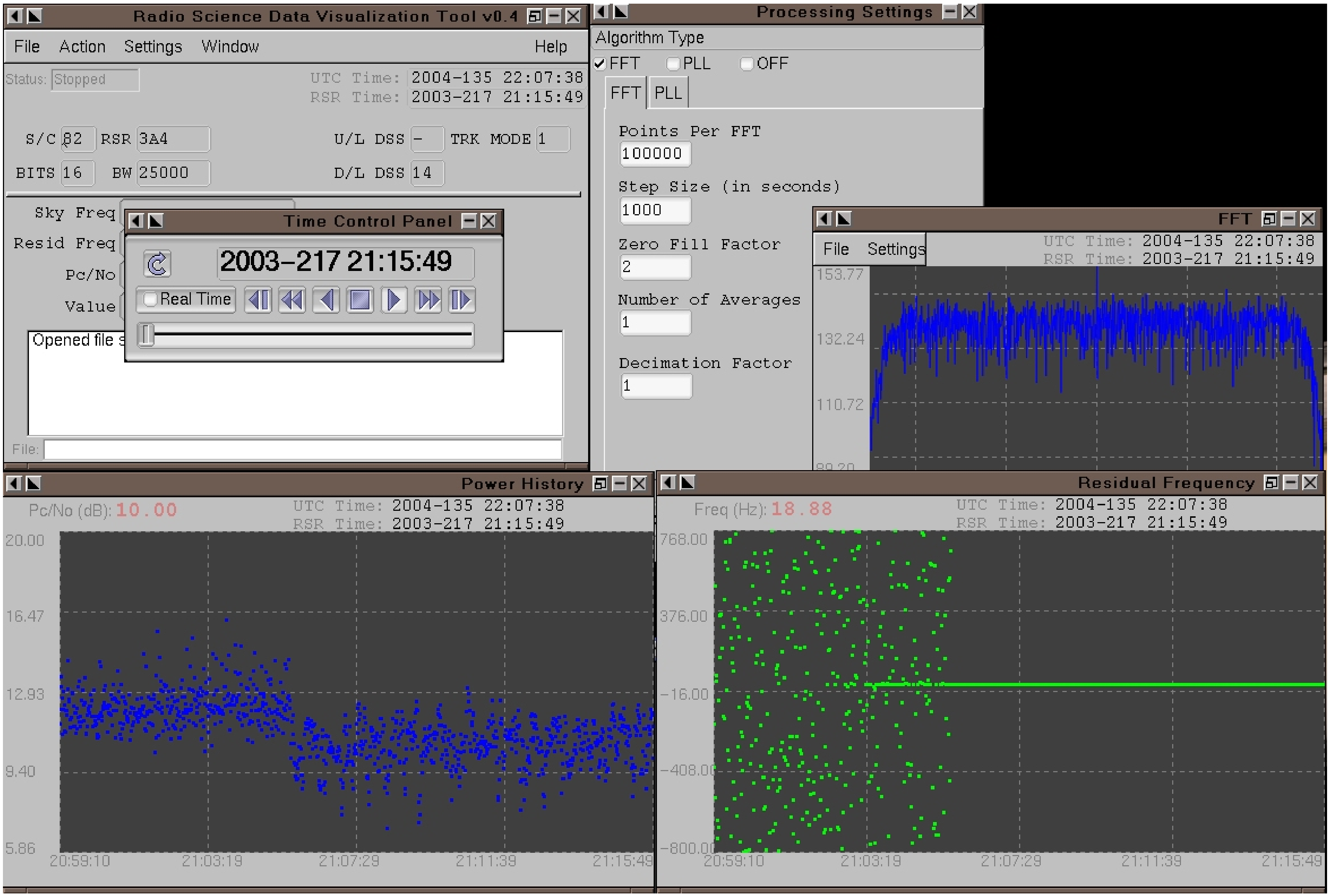
- Standard services of Deep Space Network
  - Tracking receiver
    - May lose lock if level drops below threshold
  - Radio Science Receiver (RSR)
    - Open-loop receiver tuned by prediction file

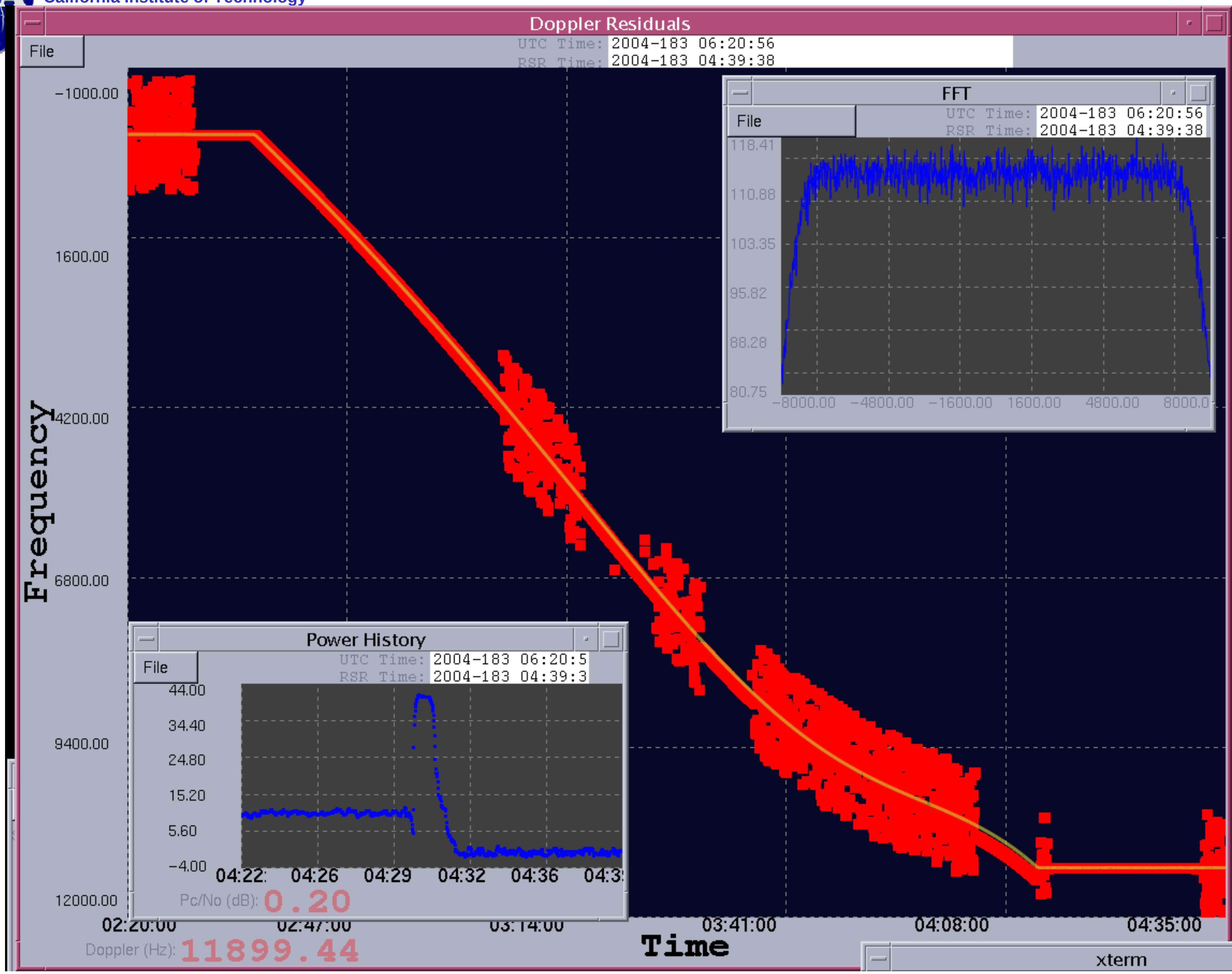


- Enhanced Radio Science Processor
  - Custom-made for SOI enhanced visualization & monitoring at JPL

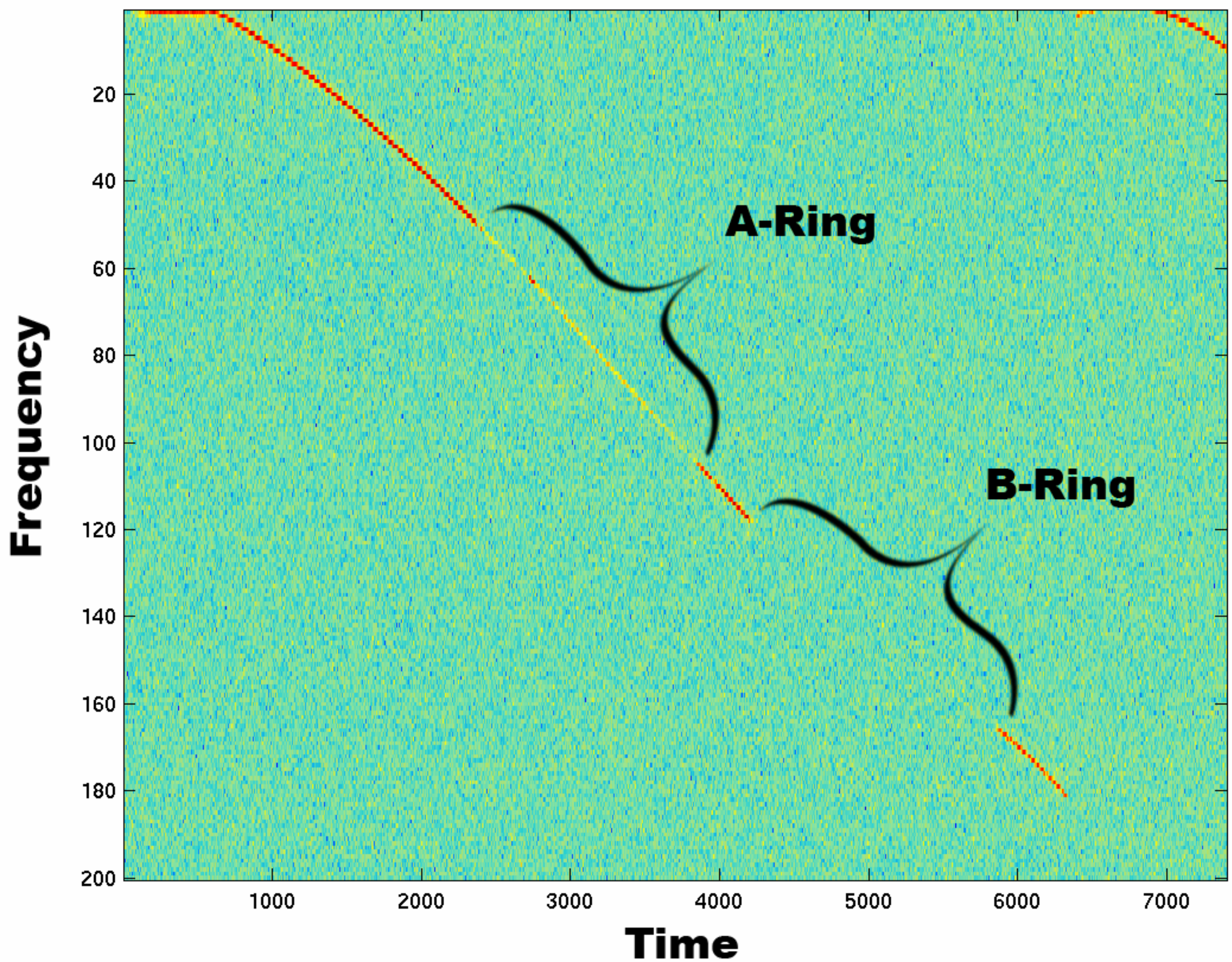
- Backup: special application processor
  - Fast FFT computations of RSR data

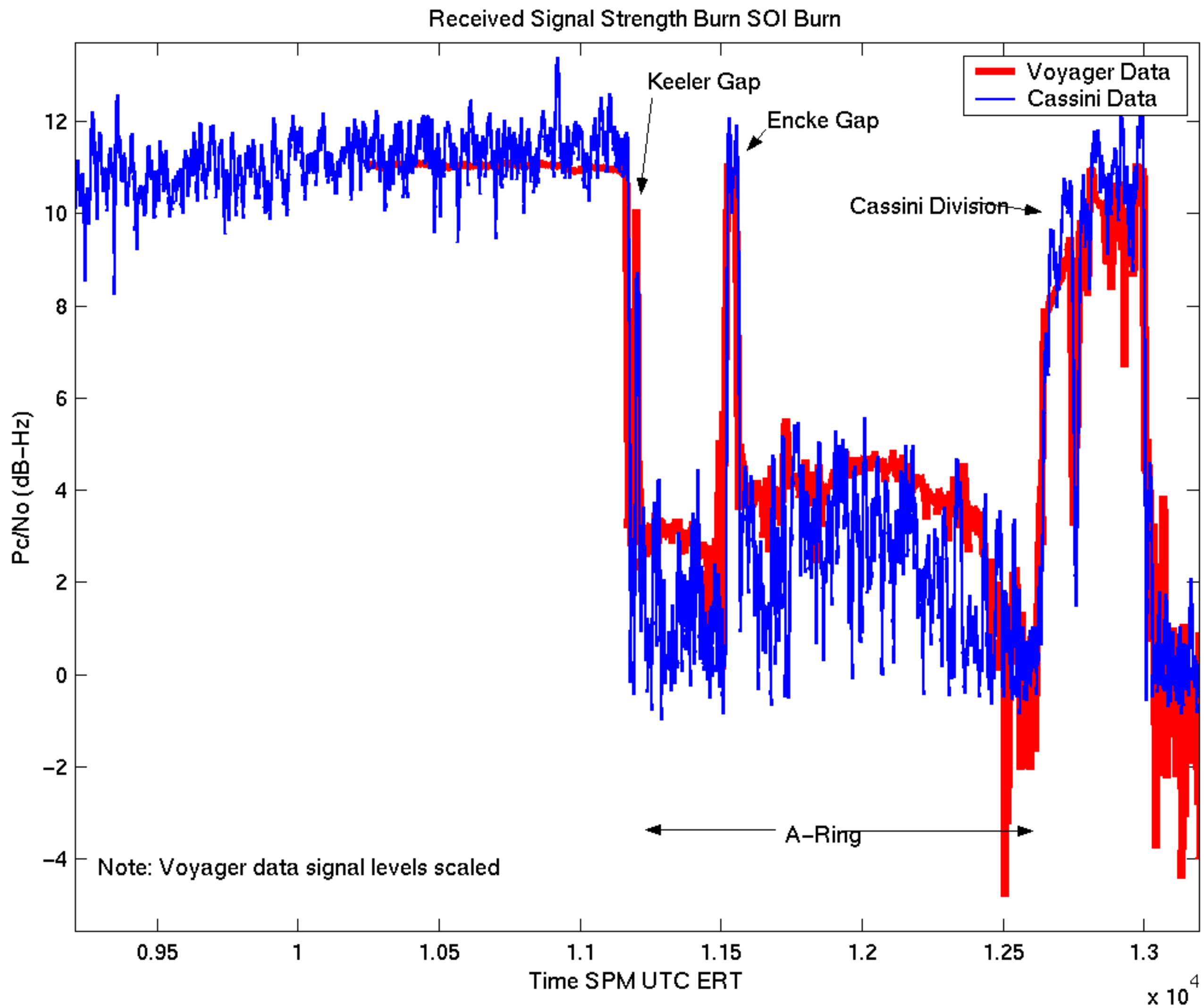
- Carrier arraying
  - 70-m + 2 34-m stations. Increase ~1.5 dB


Radio Science Data Visualization Tool v0.4
File Action Settings Window Help
Status: Stopped
UTC Time: 2004-135 22:07:38
RSR Time: 2003-217 21:15:49
S/C 82 RSR 3A4
U/L DSS - TRK MODE 1
BITS 16 BW 25000
D/L DSS 14
Sky Freq
Resid Freq
Pc/No
Value
Opened file s
File:
Time Control Panel
2003-217 21:15:49
Real Time
Processing Settings
Algorithm Type
FFT PLL OFF
FFT PLL
Points Per FFT
100000
Step Size (in seconds)
1000
Zero Fill Factor
2
Number of Averages
1
Decimation Factor
1
FFT
File Settings
UTC Time: 2004-135 22:07:38
RSR Time: 2003-217 21:15:49
153.77
132.24
110.72
Power History
Pc/No (dB): 10.00
UTC Time: 2004-135 22:07:38
RSR Time: 2003-217 21:15:49
20.00
16.47
12.93
9.40
5.86
20:59:10
21:03:19
21:07:29
21:11:39
21:15:49
Residual Frequency
Freq (Hz): 18.88
UTC Time: 2004-135 22:07:38
RSR Time: 2003-217 21:15:49
768.00
376.00
-16.00
-408.00
-800.00
20:59:10
21:03:19
21:07:29
21:11:39
21:15:49


Doppler Residuals
File
UTC Time: 2004-183 06:20:56
RSR Time: 2004-183 04:39:38
Frequency
-1000.00
1600.00
4200.00
6800.00
9400.00
12000.00
02:20:00
02:47:00
03:14:00
03:41:00
04:08:00
04:35:00
Time
Doppler (Hz): 11899.44
FFT
File
UTC Time: 2004-183 06:20:56
RSR Time: 2004-183 04:39:38
118.41
110.88
103.35
95.82
88.28
80.75
-8000.00
-4800.00
-1600.00
1600.00
4800.00
8000.0
Power History
File
UTC Time: 2004-183 06:20:5
RSR Time: 2004-183 04:39:3
44.00
34.40
24.80
15.20
5.60
-4.00
04:22
04:26
04:29
04:32
04:36
04:3
Pc/No (dB): 0.20
xterm

SOI Signal Spectrogram




Received Signal Strength Burn SOI Burn
Voyager Data
Cassini Data
Keeler Gap
Encke Gap
Cassini Division
A–Ring
Note: Voyager data signal levels scaled
Pc/No (dB–Hz)
12
10
8
6
4
2
0
–2
–4
0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
Time SPM UTC ERT
x 10^4

MER EDL Timeline

X-band DTE

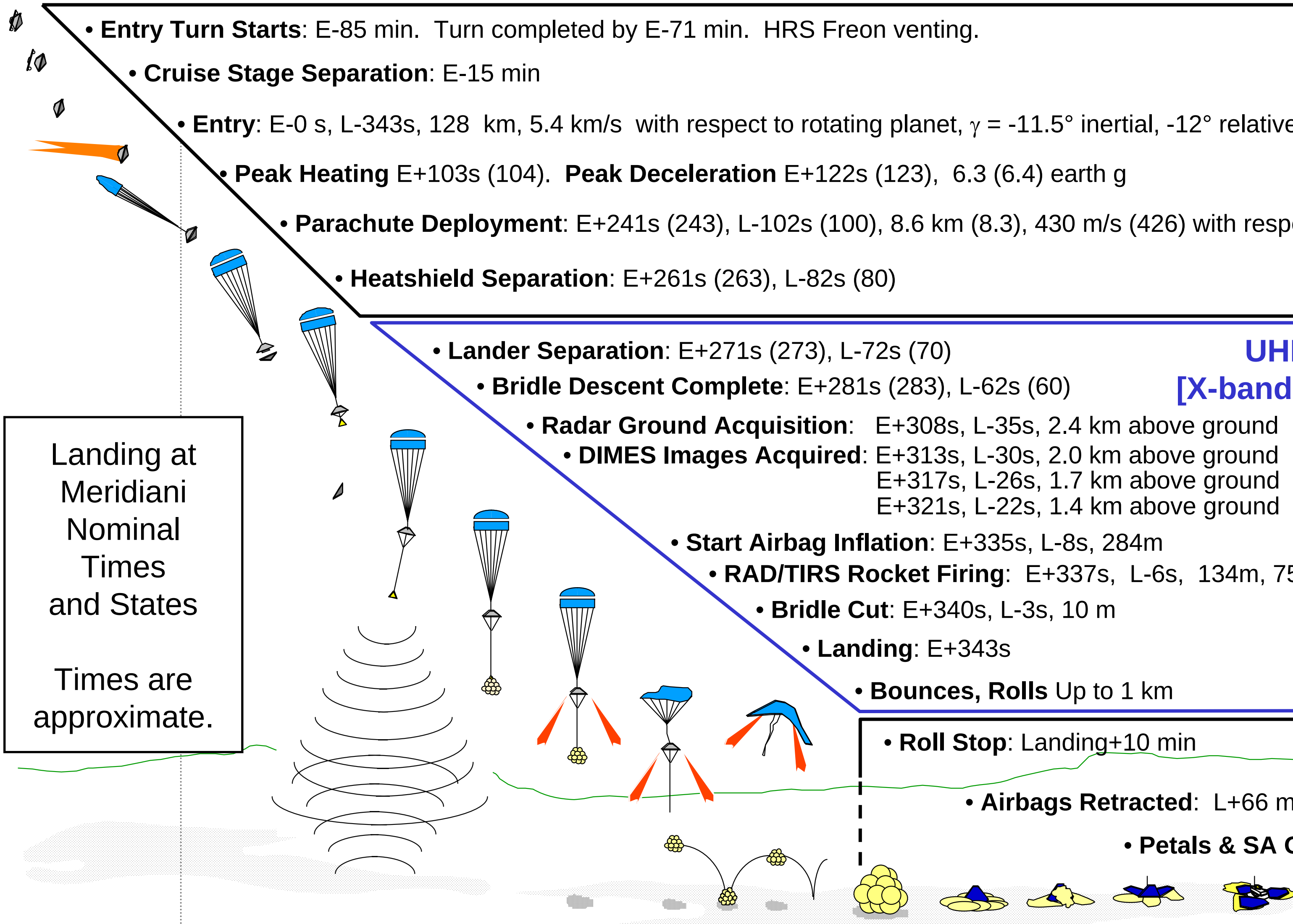
- **Entry Turn Starts**: E-85 min. Turn completed by E-71 min. HRS Freon venting.
- **Cruise Stage Separation**: E-15 min
- **Entry**: E-0 s, L-343s, 128 km, 5.4 km/s with respect to rotating planet, γ = -11.5° inertial, -12° relative
- **Peak Heating** E+103s (104). **Peak Deceleration** E+122s (123), 6.3 (6.4) earth g
- **Parachute Deployment**: E+241s (243), L-102s (100), 8.6 km (8.3), 430 m/s (426) with respect to wind
- **Heatshield Separation**: E+261s (263), L-82s (80)

UHF to MGS
[X-band DTE Backup]

- **Lander Separation**: E+271s (273), L-72s (70)
- **Bridle Descent Complete**: E+281s (283), L-62s (60)
- **Radar Ground Acquisition**: E+308s, L-35s, 2.4 km above ground
- **DIMES Images Acquired**: E+313s, L-30s, 2.0 km above ground
  E+317s, L-26s, 1.7 km above ground
  E+321s, L-22s, 1.4 km above ground
- **Start Airbag Inflation**: E+335s, L-8s, 284m
- **RAD/TIRS Rocket Firing**: E+337s, L-6s, 134m, 75m/s
- **Bridle Cut**: E+340s, L-3s, 10 m
- **Landing**: E+343s
- **Bounces, Rolls** Up to 1 km

X-band DTE

- **Roll Stop**: Landing+10 min
- **Airbags Retracted**: L+66 min
- **Petals & SA Opened**: L+96 min to L+187 min



Landing at Meridiani Nominal Times and States

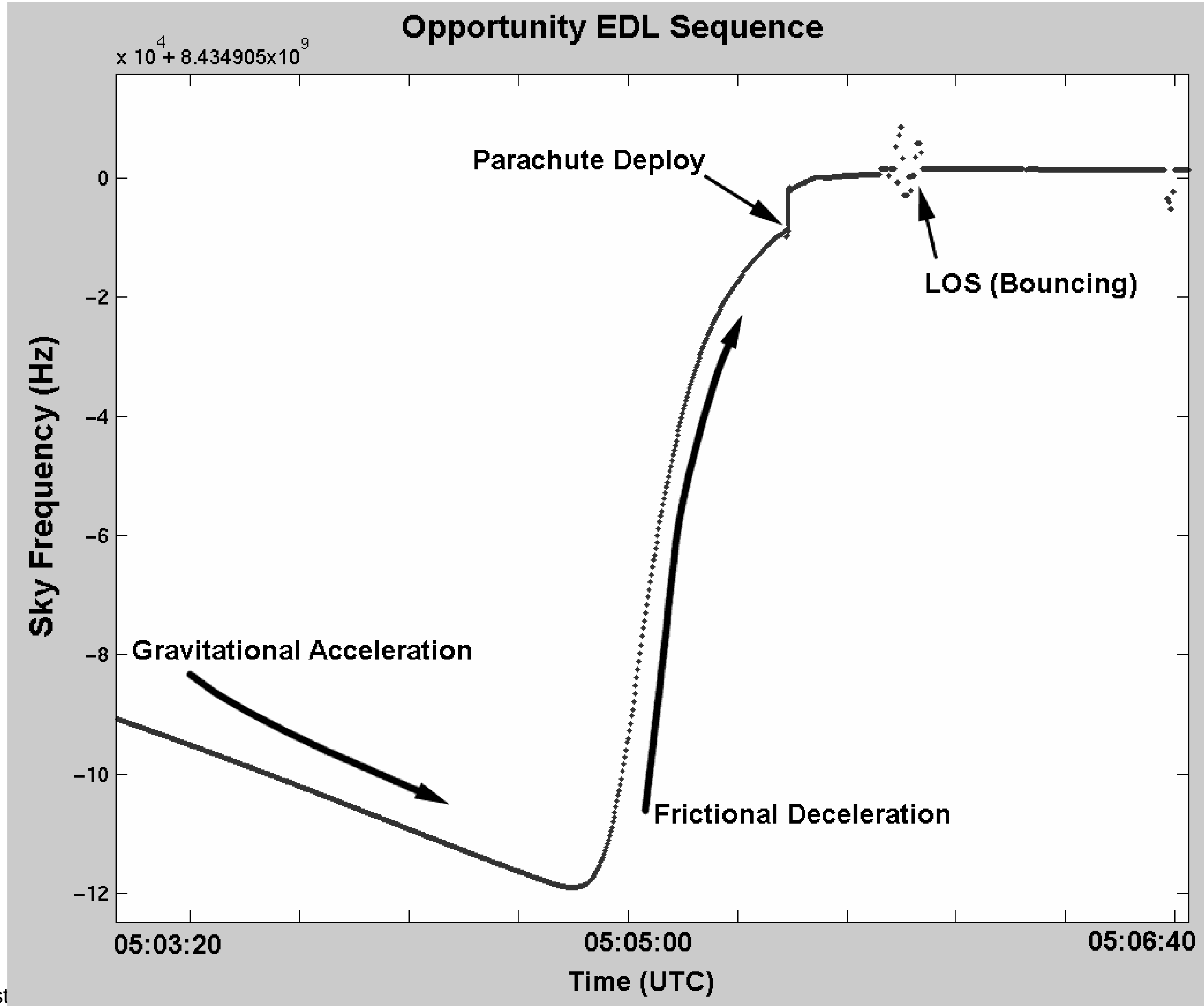
Times are approximate.

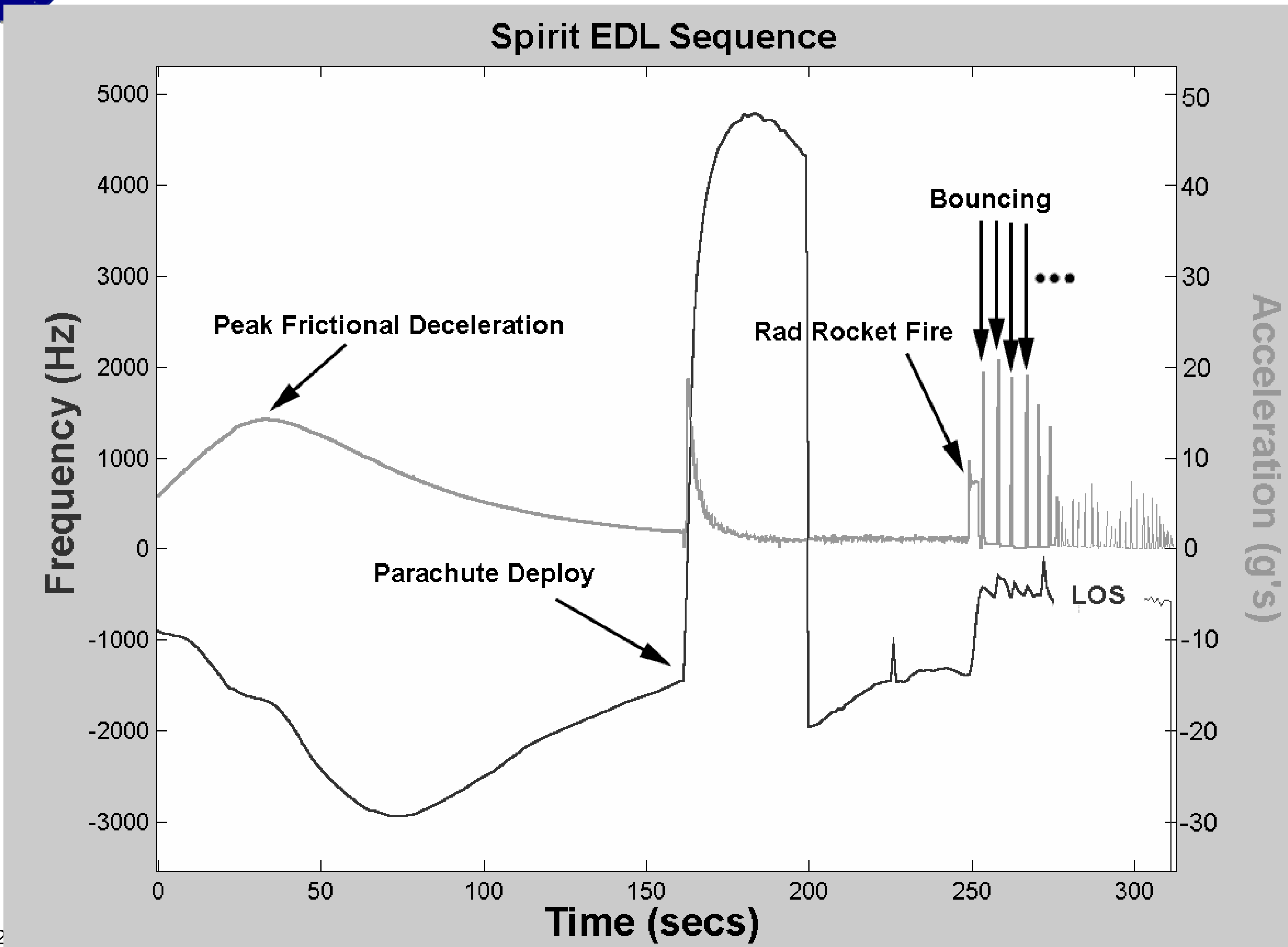
Approach Phase | EDL Phase

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).

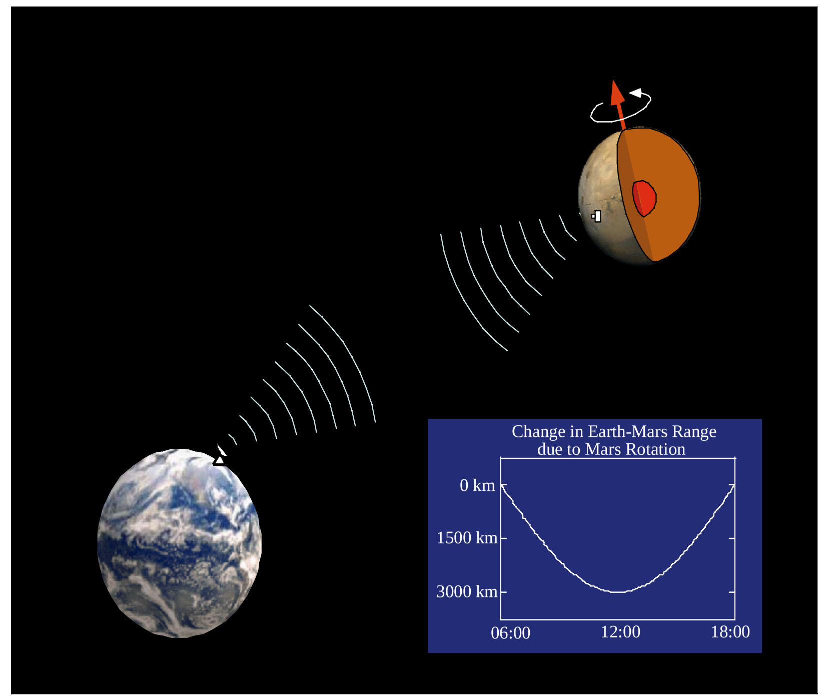
    Radar solution (20 no sol./12 sol.)
  - Priority 3: Fault Tones
  - Priority 4: Deceleration tones
  - Priority 5: Calibration tones
- After the lander descent on the bridle (@ L-75s), no tone reception is certain because the lander sways.


Opportunity EDL Sequence
x 10^4 + 8.434905x10^9
Sky Frequency (Hz)
0
−2
−4
−6
−8
−10
−12
Gravitational Acceleration
Parachute Deploy
LOS (Bouncing)
Frictional Deceleration
05:03:20
05:05:00
05:06:40
Time (UTC)


Spirit EDL Sequence
Frequency (Hz)
Acceleration (g's)
Time (secs)
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
50
40
30
20
10
0
-10
-20
-30
0
50
100
150
200
250
300
Peak Frictional Deceleration
Parachute Deploy
Rad Rocket Fire
Bouncing
LOS

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

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