# Recent Project Experience
# Mars Reconnaissance Orbiter (MRO)

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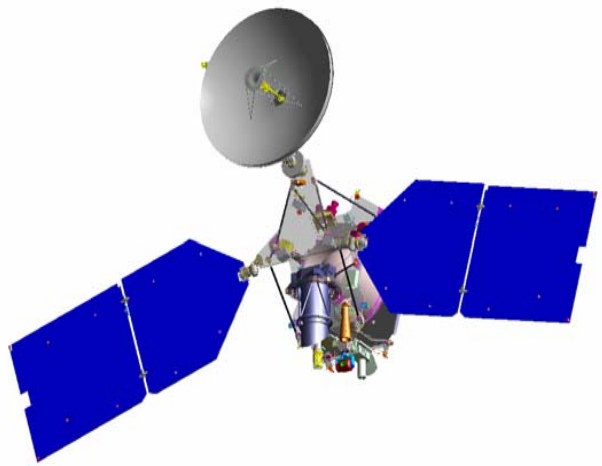
May 3, 2006



# Topics

- MRO Mission Overview
- MRO Data Management & Transport Challenges
- End-to-End Telemetry Data Flow
- High Data Rate & Volume Issues
- CFDP Usage & Issues
  - Product Latency
  - Product Visibility/Accountability

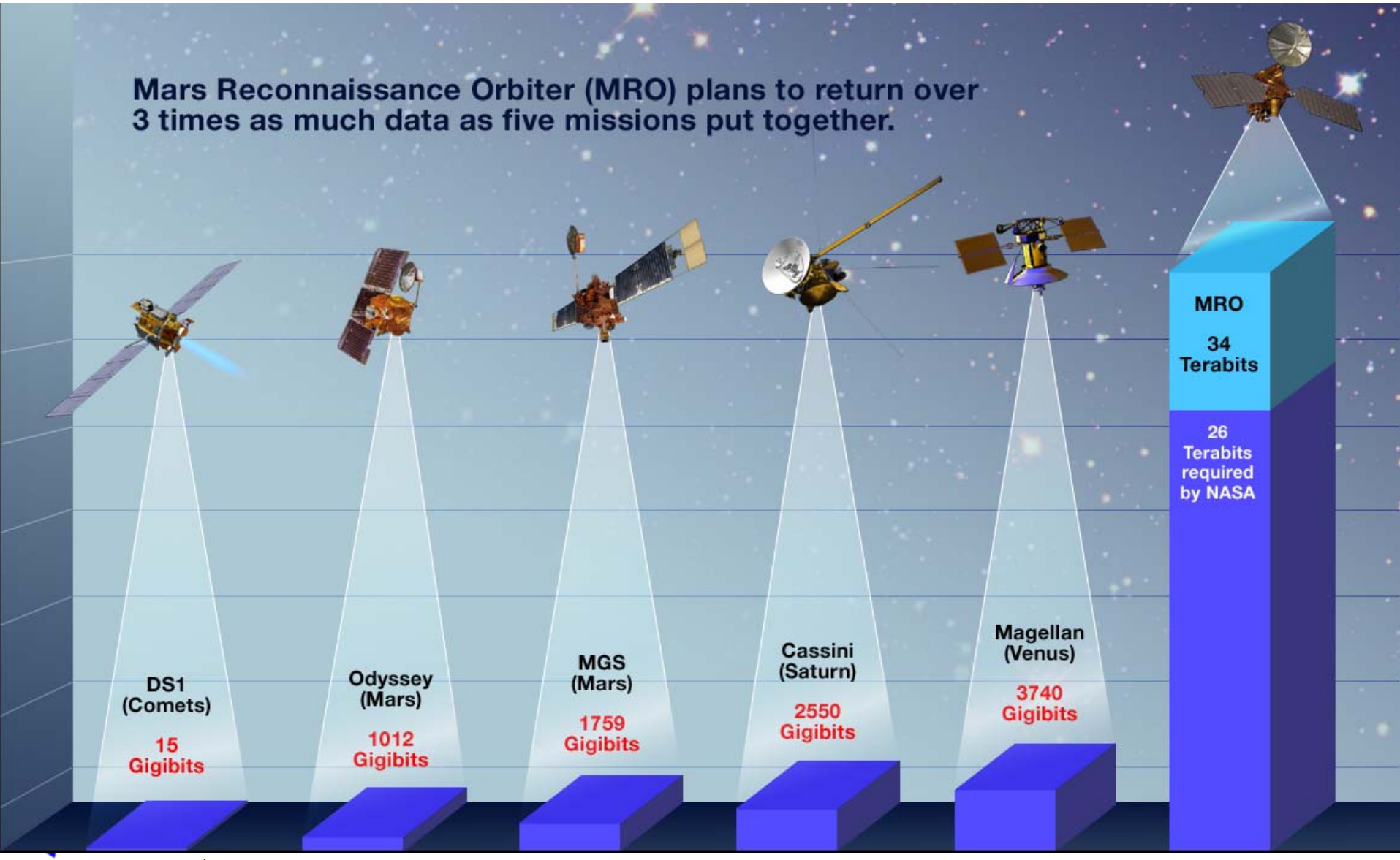
# MRO Mission Overview



- Objectives
  - MRO will characterize the surface, subsurface and atmosphere of Mars
    - Conduct observations in many parts of the electromagnetic spectrum
    - Spatial resolutions substantially better than any preceding Mars orbiter
    - Identify potential landing sites for future missions
  - MRO will provide telecommunications relay capability for follow-on missions
  - MRO will demonstrate optical navigation and Ka-band telemetry in support of future Mars Exploration Program activities
- Timeline
  - Launch 8/2005
  - MOI 3/2006
  - Science 11/2006 - 11/2008 (1 Mars year)
  - Relay 11/2008 - 12/2010 (1 Mars year)

# Data Return Comparison





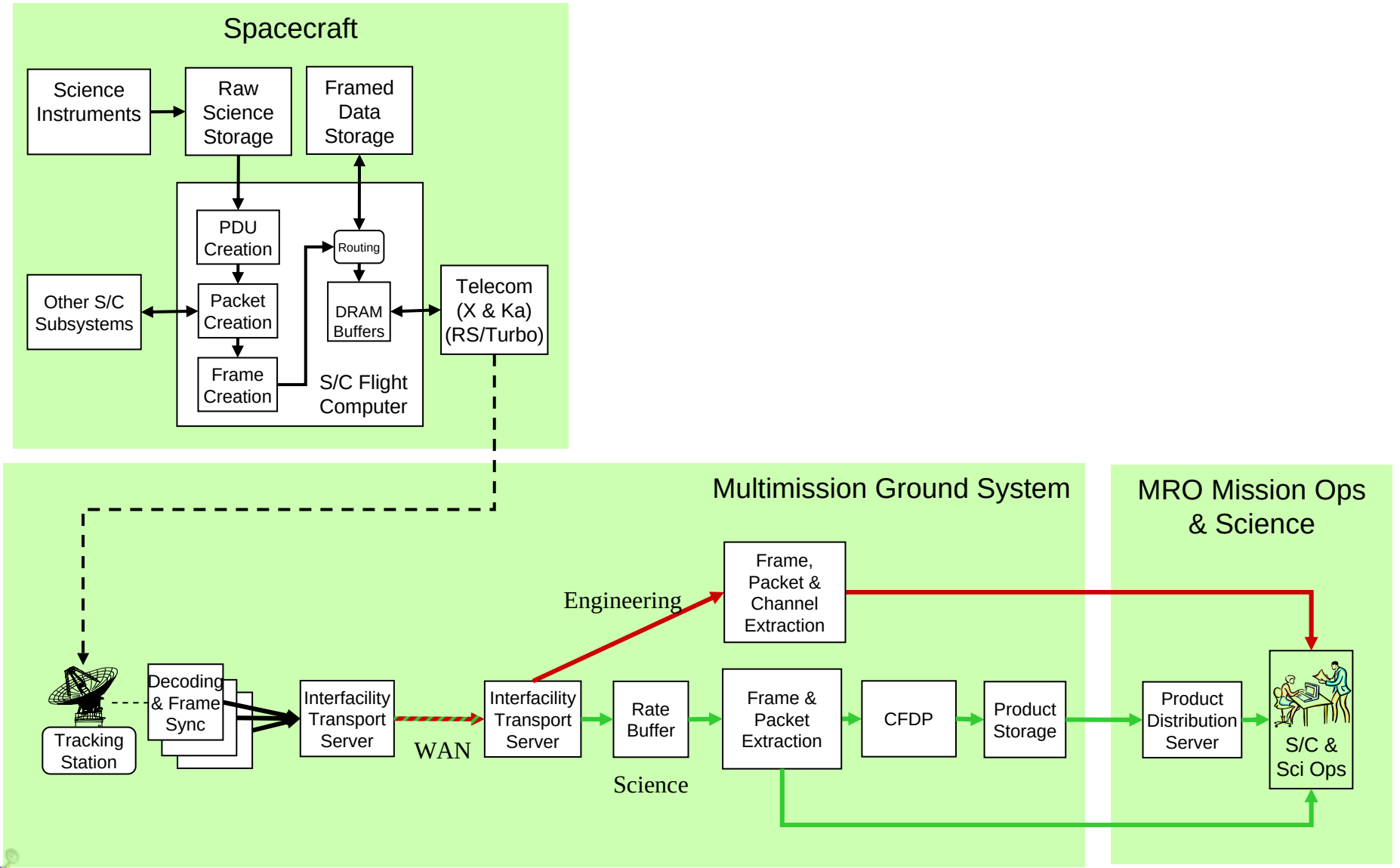
# MRO Data Management & Transport Challenges



- High Data Rates & Volumes
  - 6 Mbps telemetry rate
  - 230 Gbits daily volume
  - 51 Tbits total mission downlink (primary mission)
  - These numbers are very high for a planetary mission
  - Volume is greater than all other planetary missions combined
  - Handling of engineering data collected while out-of-contact with Earth
- New Use of CFDP on a Mars Mission
  - Single “product” sizes of up to ~30 Gbits
  - End-to-end latency & completeness
  - End-to-end progress visibility
  - Accountability / Determining cause of partial products
- Bandwidth Constraints & Prioritization Issues
  - Downlink rates much greater than available WAN from tracking sites to JPL
  - Prioritization of science vs engineering data

# End-to-End Telemetry Data Flow

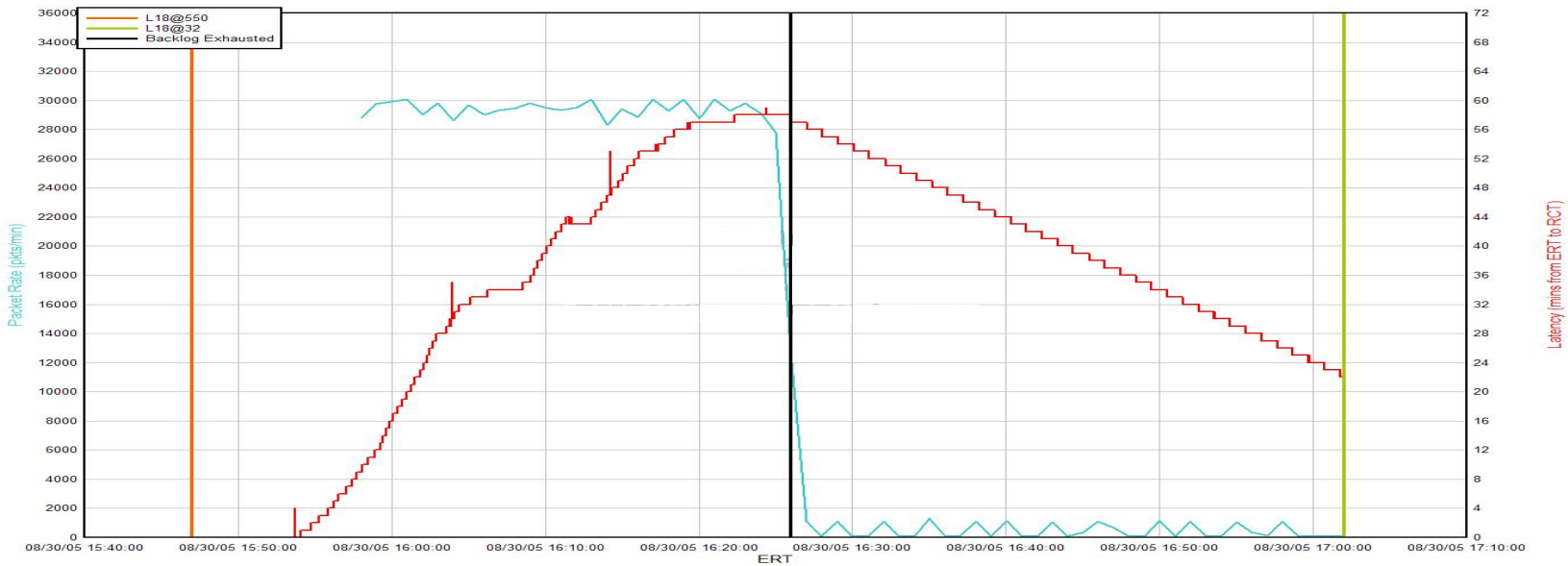




# High Data Rate & Volume Issues

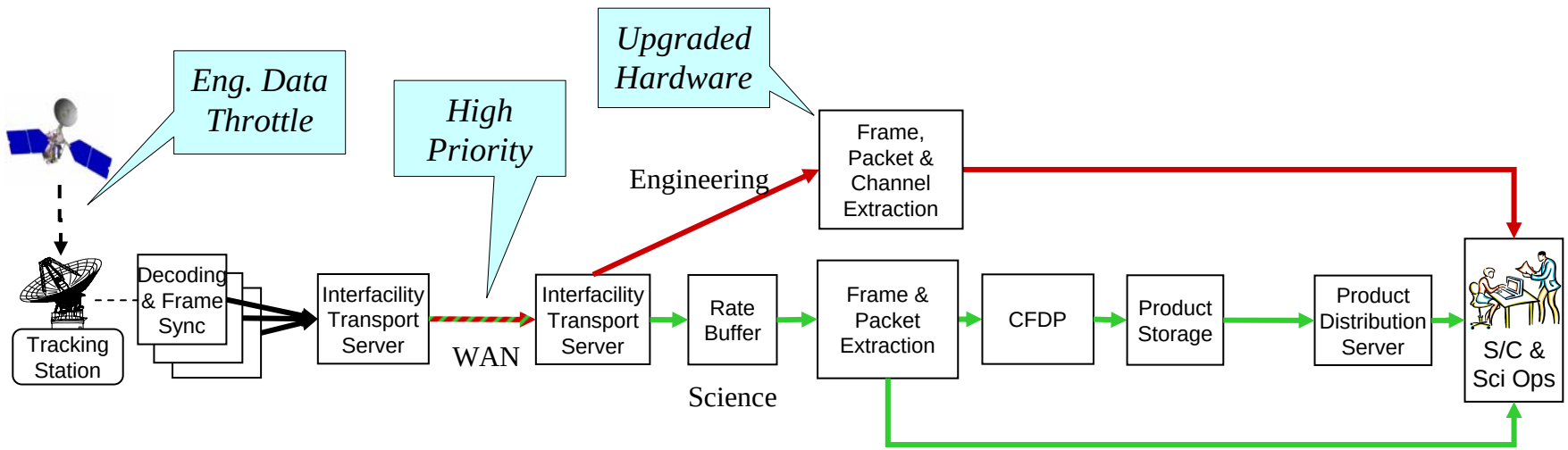


- Unanticipated High Engineering Telemetry Rates & Volumes
  - Background
    - MRO flight software normally produces spacecraft health & safety (engineering) data at relatively low rate (~10 kbps), and downlinks it continuously when in contact with Earth
    - When the spacecraft is out of contact with Earth, this data is nominally put into an area of storage designated for non-real-time downlink (along with Science data)
    - However, there are periods where we are “briefly” out-of-contact, and want to “buffer” the engineering data so that it begins where it left off, and quickly catches up to real-time
  - Problem
    - During cruise, a spacecraft anomaly caused an excessive buildup of engineering data, that was subsequently downlinked at high rate, resulting in unexpected latencies and loss of real-time visibility for the operations teams



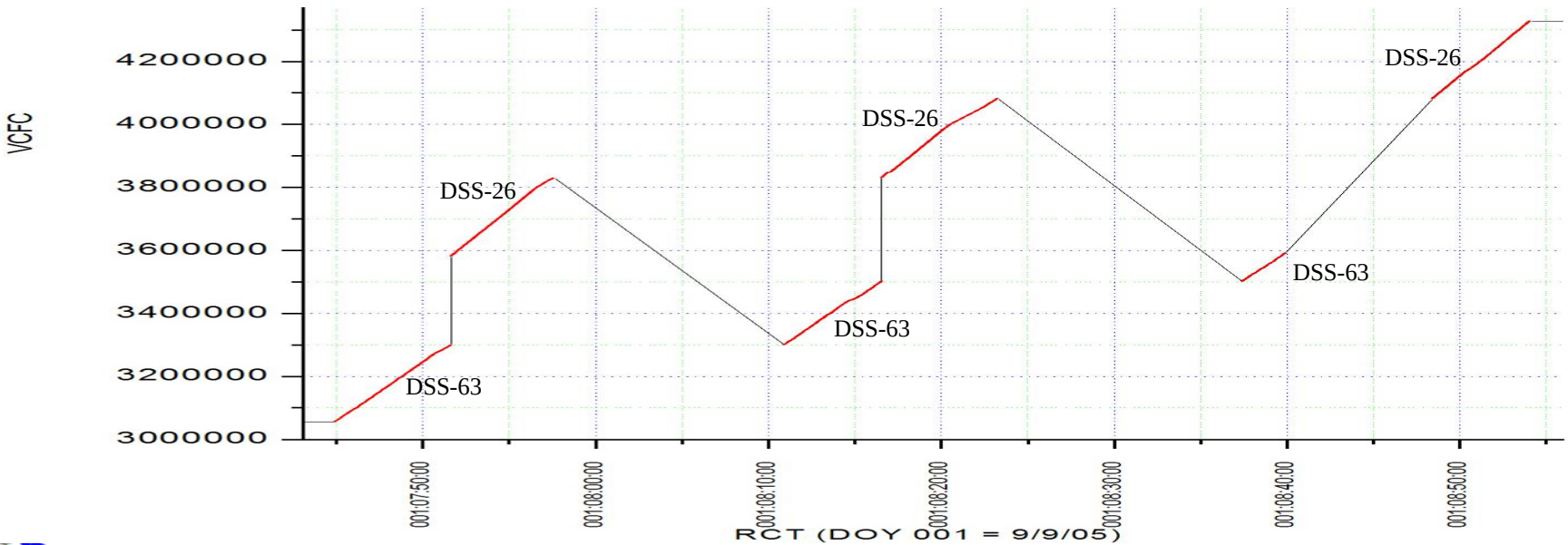
# High Data Rate & Volume Issues (cont.)

- Unanticipated High Engineering Telemetry Rates & Volumes (cont.)
  - Analysis & Solutions
    - Although an anomaly caused the very large backlog, analysis showed that large backlogs would occur in real flight situations (such as during aerobraking)
    - A multi-part solution was designed and implemented
      - 1. Update WAN forwarding to provide high priority for MRO engineering data; Also, throttled max downlink rate so as not to starve out other WAN users
      - 2. Upgraded the JPL telemetry processing hardware sufficient to process the maximum allowed engineering data downlink in real-time



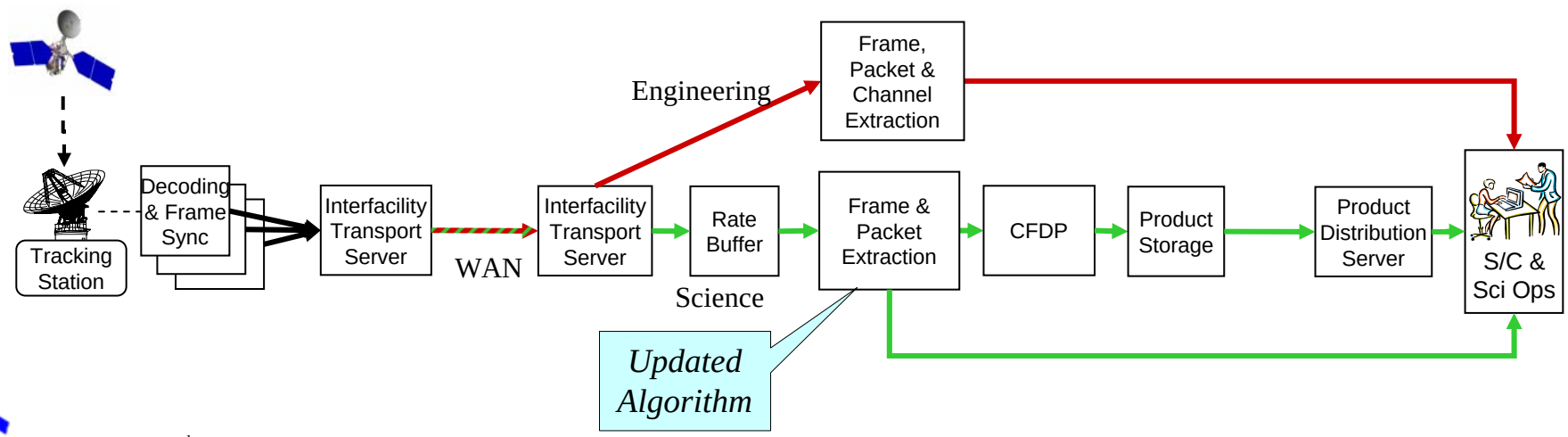
# High Data Rate & Volume Issues (cont.)

- High Rates => Large DSN Backlogs => Large Time Overlaps between Stations
  - Background
    - Given high MRO rates, and limited WAN bandwidth, many hours of backlog will develop
    - When we handoff downlink to another station, this new station will initially be delivering data in near-real-time in parallel with the many hours old data from the first station
  - Problem
    - During Cruise, there were unexplained gaps produced in many CFDP products during periods when we had solid downlink



# High Data Rate & Volume Issues (cont.)

- High Rates => Large DSN Backlogs => Large Time Overlaps between Stations (cont)
  - Analysis & Solutions
    - An accountability analysis revealed that there we no missing frames corresponding to the product gaps, however, there were missing packets
    - The ground system handles overlapping sets of frames from multiple stations fine, but we discovered an issue with handling packets related to the fact that MRO packets are made up of many frames
    - Prior, lower-rate missions did not often exhibit this behavior, so limitations in the ability of the ground to handle overlapping (out of order) data from multple sites was not exposed
    - The solution was to update our telemetry processing software to handle overlapping sequences of frames from multiple stations



# CFDP Usage & Issues



- Product Latency
  - End-to-end latency when using CFDP differs from packet stream latency in substantial ways
    - With a packet stream, the end user/application can receive data more or less in real-time as it is being produced (ignoring OWLT and ground processing architecture limitations)
    - With products, generally speaking, files are fully created, transferred as a stream, and reassembled before being passed on to the end user/application
    - Various ground throughput limitations (e.g. WAN bandwidth), can add up to 24 hours of additional latency
  - MRO latency requirement for ground processing is 24 hrs from ERT to product delivery
    - Allows for up to 18 hours of station backlog / WAN latency
    - Assumes that CFDP "Timers" will be used if necessary in the case of very large products
    - The ground system can comfortably meet this latency requirement
  - MRO latency requirement for ground processing and delivery of Relay products is 30 minutes
    - Represented a challenge for the baseline ground architecture, requiring some special handling for relay data
    - Fortunately, Relay data is down-linked using it's own virtual stream, facilitating special treatment on the ground
  - Other notes concerning latency
    - Trying to unambiguously specify latency requirements can be quite difficult considering the many variables involved, including highly variable product sizes (resulting in highly variable times for downlink), assumptions about using special "quick-look" product delivery options, and assumptions about what to do when products are missing pieces...
    - JPL's CFDP implementation supports a variety of timers and product release options to allow some customization of how latency is handled for different types of products

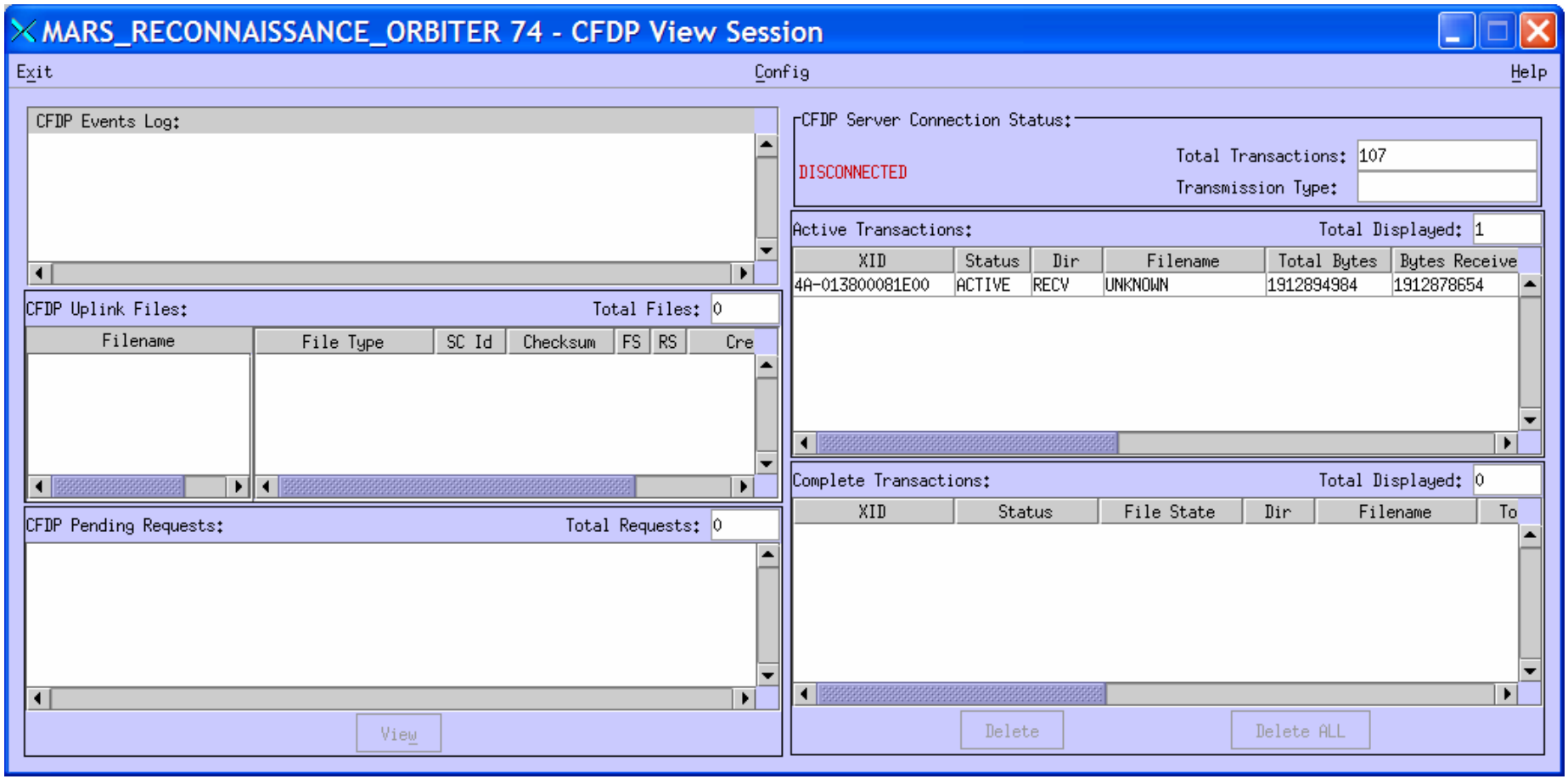
# CFDP Usage & Issues



- Product Visibility
  - Giving the complexities of both on-board and ground processing of products, predicting and monitoring status of particular products can be very complex
  - Our ground CFDP implementation includes a GUI (FDM Viewer) that provides visibility into products that are being assembled, or have recently been released
  - To provide more end-to-end visibility, MRO has a tool (TRUST), with the following features
    - Receives predicted product info. (name, size, time) from the uplink planning process
    - Receives status from ground file repositories as products are moved in and out
    - Receives spacecraft engineering data and extracts on-board processing status
    - Incorporates all this information into a database, and provides a web-based user interface

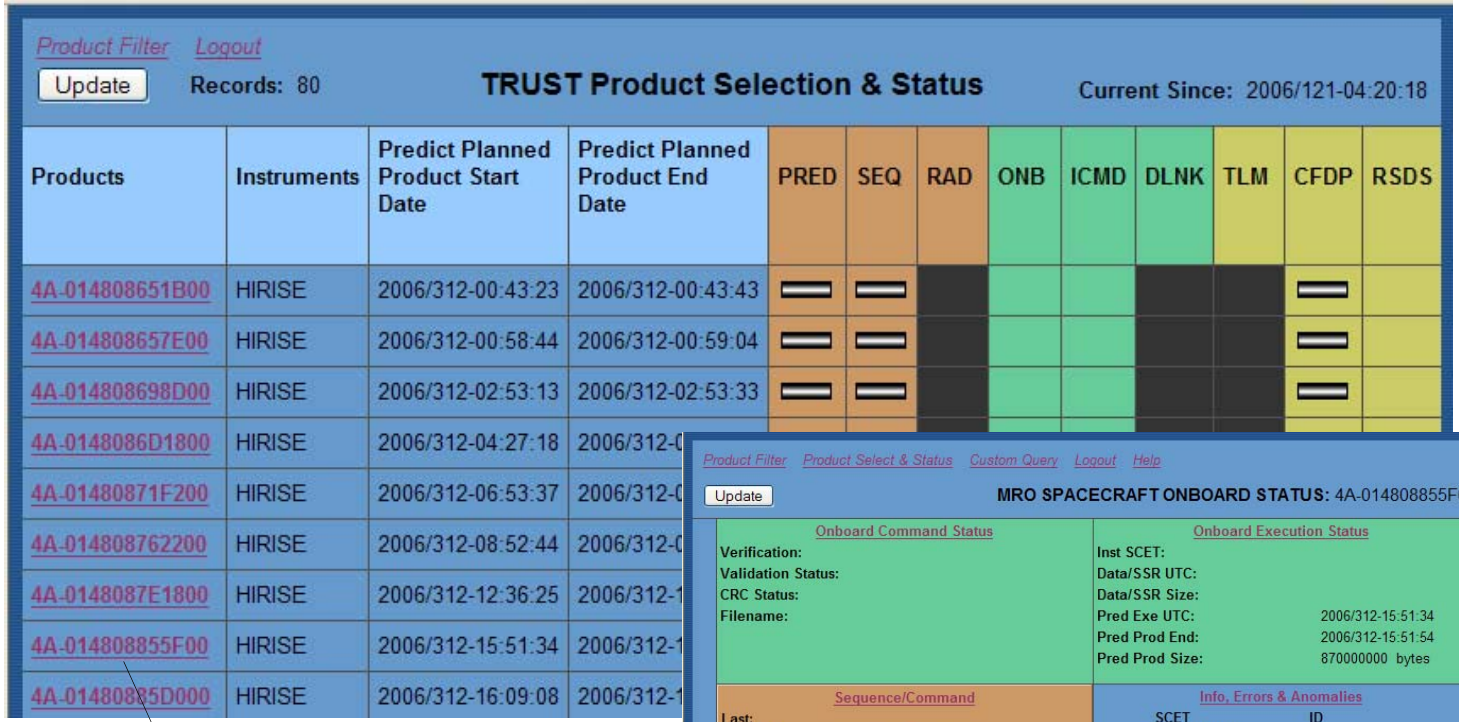
# FDM Viewer User Interface





# TRUST User Interface





Product Filter Logout

Update Records: 80

**TRUST Product Selection & Status**

Current Since: 2006/121-04:20:18

| Products | Instruments | Predict Planned Product Start Date | Predict Planned Product End Date | PRED | SEQ | RAD | ONB | ICMD | DLNK | TLM | CFDP | RSDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4A-014808651B00 | HIRISE | 2006/312-00:43:23 | 2006/312-00:43:43 | | | | | | | | | |
| 4A-014808657E00 | HIRISE | 2006/312-00:58:44 | 2006/312-00:59:04 | | | | | | | | | |
| 4A-014808698D00 | HIRISE | 2006/312-02:53:13 | 2006/312-02:53:33 | | | | | | | | | |
| 4A-0148086D1800 | HIRISE | 2006/312-04:27:18 | 2006/312-0 | | | | | | | | | |
| 4A-01480871F200 | HIRISE | 2006/312-06:53:37 | 2006/312-0 | | | | | | | | | |
| 4A-014808762200 | HIRISE | 2006/312-08:52:44 | 2006/312-0 | | | | | | | | | |
| 4A-0148087E1800 | HIRISE | 2006/312-12:36:25 | 2006/312-1 | | | | | | | | | |
| 4A-014808855F00 | HIRISE | 2006/312-15:51:34 | 2006/312-1 | | | | | | | | | |
| 4A-01480885D000 | HIRISE | 2006/312-16:09:08 | 2006/312-1 | | | | | | | | | |

Product Filter Product Select & Status Custom Query Logout Help

Update

**MRO SPACECRAFT ONBOARD STATUS:** 4A-014808855F00

Current Since: 2006/121-04:23:06

FORWARD LINK

RETURN LINK

**Onboard Command Status**

Verification:
Validation Status:
CRC Status:
Filename:

**Onboard Execution Status**

Inst SCET:
Data/SSR UTC:
Data/SSR Size:
Pred Exe UTC: 2006/312-15:51:34
Pred Prod End: 2006/312-15:51:54
Pred Prod Size: 870000000 bytes

**Onboard Downlink Status**

Pred Dlink UTC: 2006/322-23:28:35
CFDP Dlink Start Time: null
CFDP Dlink End Time: null

**Sequence/Command**

Last:
Onbrd File: d:/seq/fsw_diag.mod

**Info, Errors & Anomalies**

SCET ID
Description

**CFDP Processing**

File: 4A-014808855F00-2006-116T16.21.19.dtl
Last UTC: 2006/116-16:21:19
Last Size: 187913740 bytes
Cmplt: 100 %
File State: COMPLETE
Fill: 0
Trans State: FINISHED
Timer State: CANCELLED_BY_APP
Gap Count: 0

**Product Prediction**

Latest UTC: 2006/118-22:26:13
Coortl ID: TEAM-IO-WX
Compression: ENABLE
Obs Type: Small Off-Nadir High Stability
Latitude: -4.430
Longitude: 297.690
Orbit Number: 545a
Request Pri: 13
RF Band: X

**RSDS Processing**

Latest from DOM: 2006/116-16:24:08
Latest to Users: 2006/116-16:32:37

Frame Gap Summary Frame Gap Report

# CFDP Usage & Issues



- Product Accountability
  - Accountability of products from the standpoint of how far along they are in the end-to-end process is facilitated by the tools described in the previous section
  - However, a different accountability goal is to be able to determine the cause of incomplete (partial) products, which in turn helps us ensure that our end-to-end system is working properly
    - This goal is important during development, test, and operations phases
  - The existing legacy ground processing system is essentially a pipeline architecture, with little accountability information captured along the way
    - In particular, there is no direct traceability from transfer frames, to packets, to products
    - When an incomplete (partial) product is produced, it is extremely difficult to trace back to the root cause
  - There are two activities underway to help address this issue
    - The first is a light-weight MRO-specific tool (VERIFI) that shadows the operational frame to packet to product processing system, but also produces metadata that provides full traceability between specific frames, packets, and products; An early prototype is in use
    - The second is a more comprehensive, multi-mission effort to capture various meta-information throughout the ground system, and make it available to various applications including ones that will address accountability issues; More on this in Mike Levesque's presentation later today

# VARIFI Product Detail Display



EEDAT DETAILED FRAME ACCOUNTABILITY TOOL

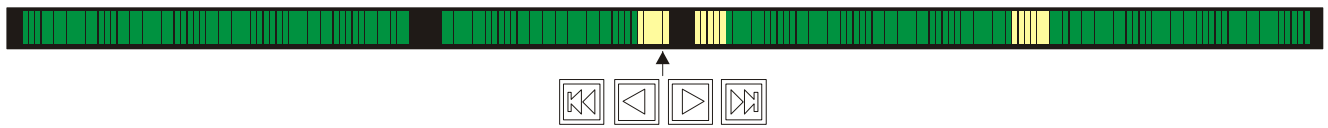
**PRODUCT VIEW**

Product: CAF3productId

PDU Number

0000 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 | 8000 | 9000

X



```
frame
   ERT: 2006/11/13:05:44:33:000002
   VC_CNT: 1,336,584
   SCID: 74
   RSN: 234542
   RETRANS: yes
pkt
   APID: 06
   SEQ: 2234
cfdp
   ID: (cfdp id)
   OFFSET: 1024
```

FRAME META DATA

```
00000:  44 52 F8 F0 F8 22 32 CC FA CE 00 FF 0B 6C 0B 79
00016:  0B 45 0B 6C 0B 4A 0B 64 0B 6A 0B 69 0B 83 0B 65
00032:  0B 4E 0B 57 0B 5B 0B 67 0B 6C 0B 4A 0B 67 0B 6C
00048:  0B 41 0B 73 0B 53 0B 6C 0B 3A 0B 66 0B 61 0B 5F
00064:  0B 54 0B 55 0B 3E 0B 61 0B 47 0B 63 0B 62 0B 68
00080:  0B 75 0B 4B 0B 5D 0B 5B 0B 68 0B 79 0B 62 0B 6A
00096:  0B 56 0B 57 0B 59 0B 55 0B 61 0B 89 0B 53 0B 67
00112:  0B 58 0B 5C 0B 5F 0B 65 0B 5A 0B 73 0B 50 0B 65
00128:  0B 5F 0B 69 0B 73 0B 4A 0B 5C 0B 52 0B 5A 0B 6E
00144:  0B 55 0B 4E 0B 5C 0B 5F 0B 52 0B 70 0B 57 0B 79
00160:  0B 46 0B 5A 0B 4A 0B 60 0B 63 0B 49 0B 51 0B 80
00176:  0B 59 0B 5E 0B 54 0B 5A 0B 77 0B 50 0B 4C 0B 60
00192:  0B 4E 0B 6A 0B 5E 0B 58 0B 5D 0B 6B 0B 4B 0B 69
00208:  0B 5E 0B 80 0B 30 0B 5B 0B 5C 0B 69 0B 5D 0B 6F
00224:  0B 57 0B 5C 0B 4C 0B 4D 0B 5B 0B 57 0B 76 0B 4D
```

PRODUCT PDU DATA