Mars Network

Mars Network: An Orbital Relay Infrastructure for Mars Exploration

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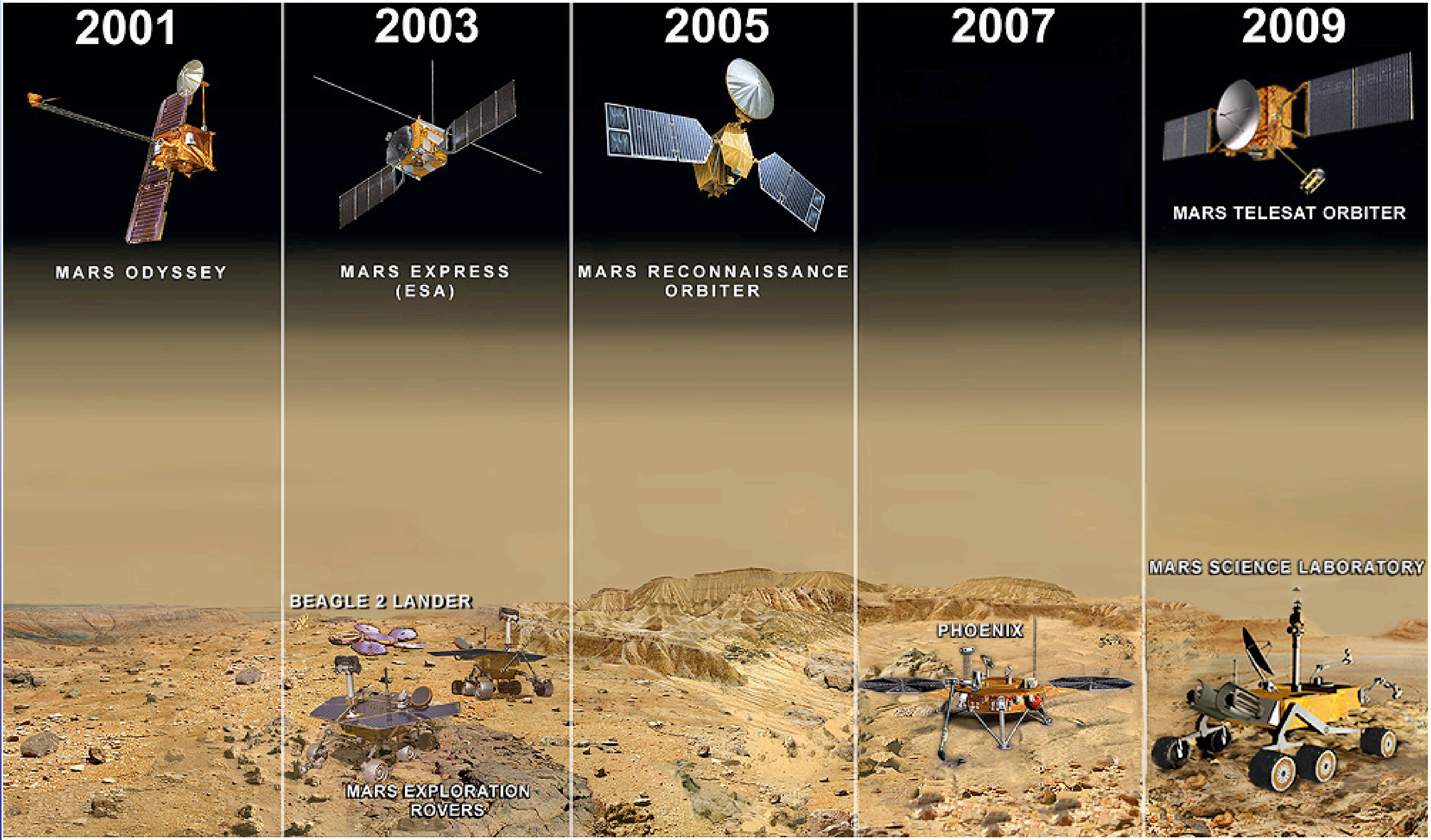
DESCANSO

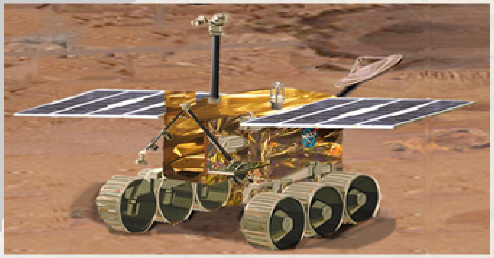
Outline

- **Mars exploration overview - drivers on telecommunications**
- **Program strategies**
  - Improved deep space communications
  - An evolving relay network
    - Science orbiters
    - Dedicated telesats
  - Electra proximity link payload
  - Communications protocols and standards
  - Radio-based *in situ* navigation
- **Case studies**
  - ‘03/’04 UHF relay operations
  - ‘09 Mars Science Loboratory
- **Summary**

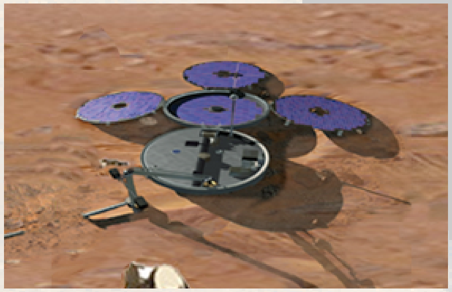
A Decade of Mars Exploration



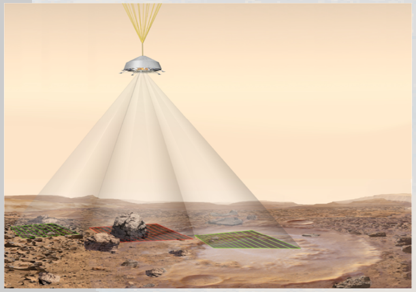
Program Drivers on Telecommunications Infrastructure



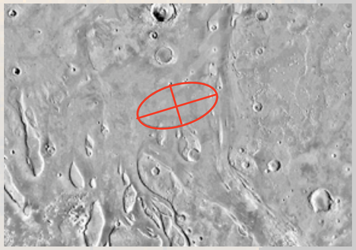
Increased Science Data Return for MSL-Class Landers



Enabling Energy-efficient Relay for Scout-class Missions



Robust Capture of Critical Event Tracking and Telemetry

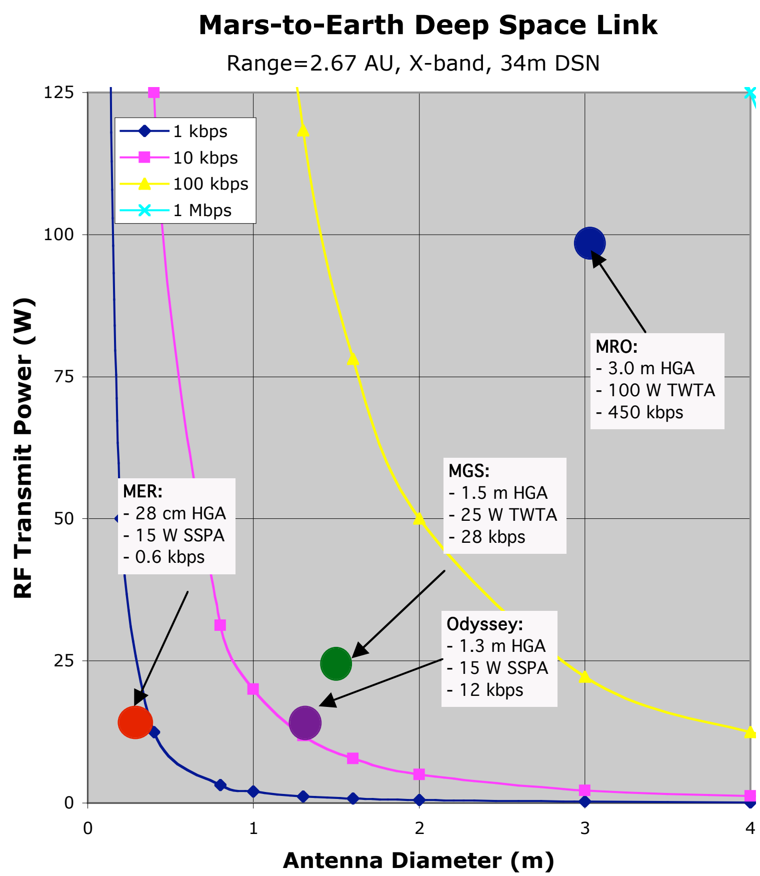


Precision in situ Navigation and Positioning

Public Engagement - Creating a Virtual Presence at Mars

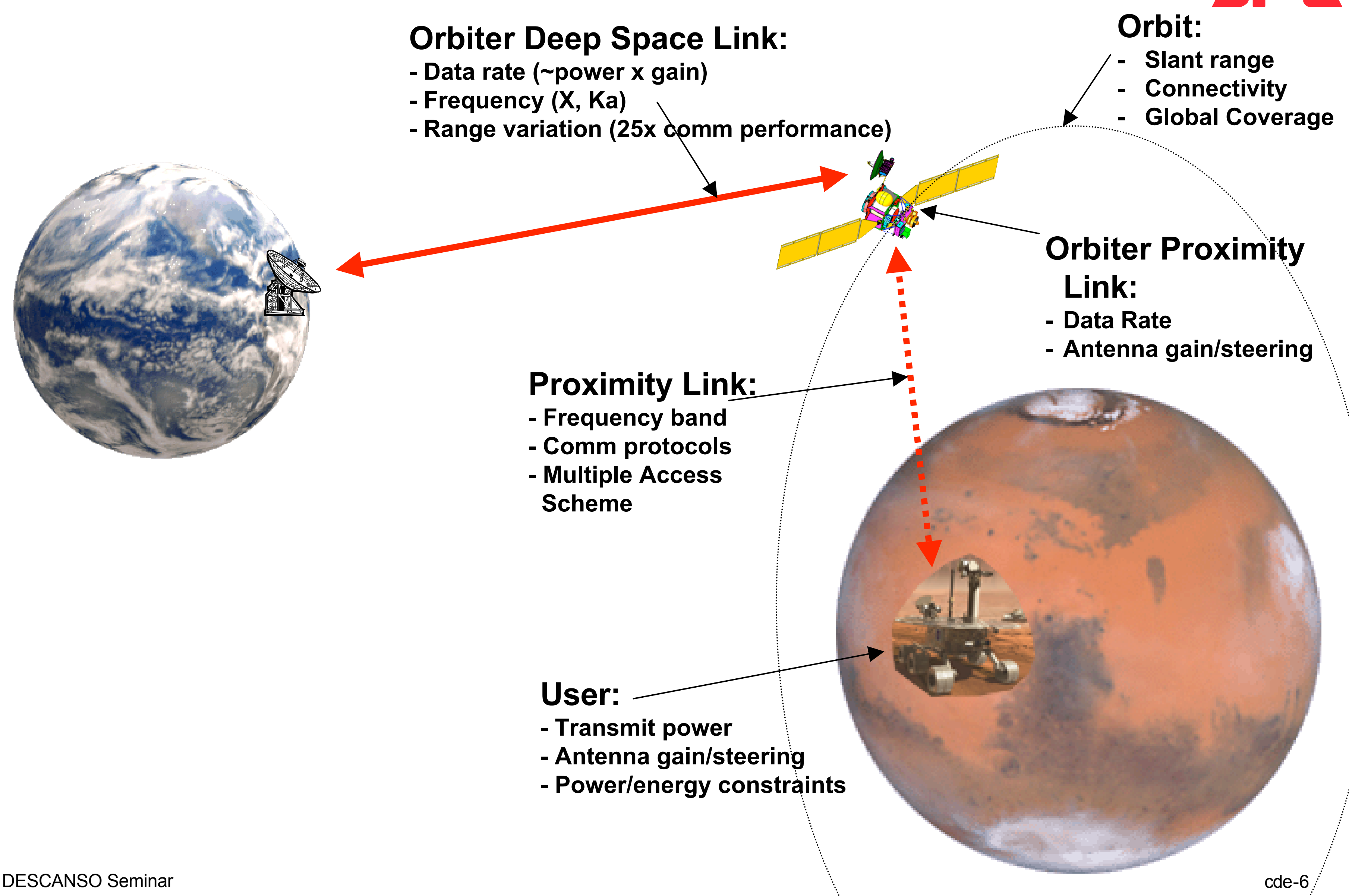
Improved Direct-to-Earth (DTE) Communications

- **Increased X-band EIRP**
  - Larger aperture
    - Large deployable antennas could offer additional improvement
  - Higher power
  - Limited spectrum allocation constrains BW utilization to 4 MHz
- **Transition to Ka-band**
  - ~4x performance improvement over X-band
  - Increased spectral allocation allows higher symbol rates
  - Key enablers:
    - DSN 34m BWG subnet capability
    - 35 W Ka-band TWTA
- **Increased DSN aperture**
  - 70m offers ~4x improvement over 34m (currently X-band only)
  - DSN Large Array could offer significant improvement beyond 70m performance
- **Longer-term Transition to Optical**
  - Further performance increase relative to RF due to highly collimated transmit beam
  - 2009 Mars Telesat Orbiter will include technology demo of 10 Mbps downlink from Mars @ 2.67 AU



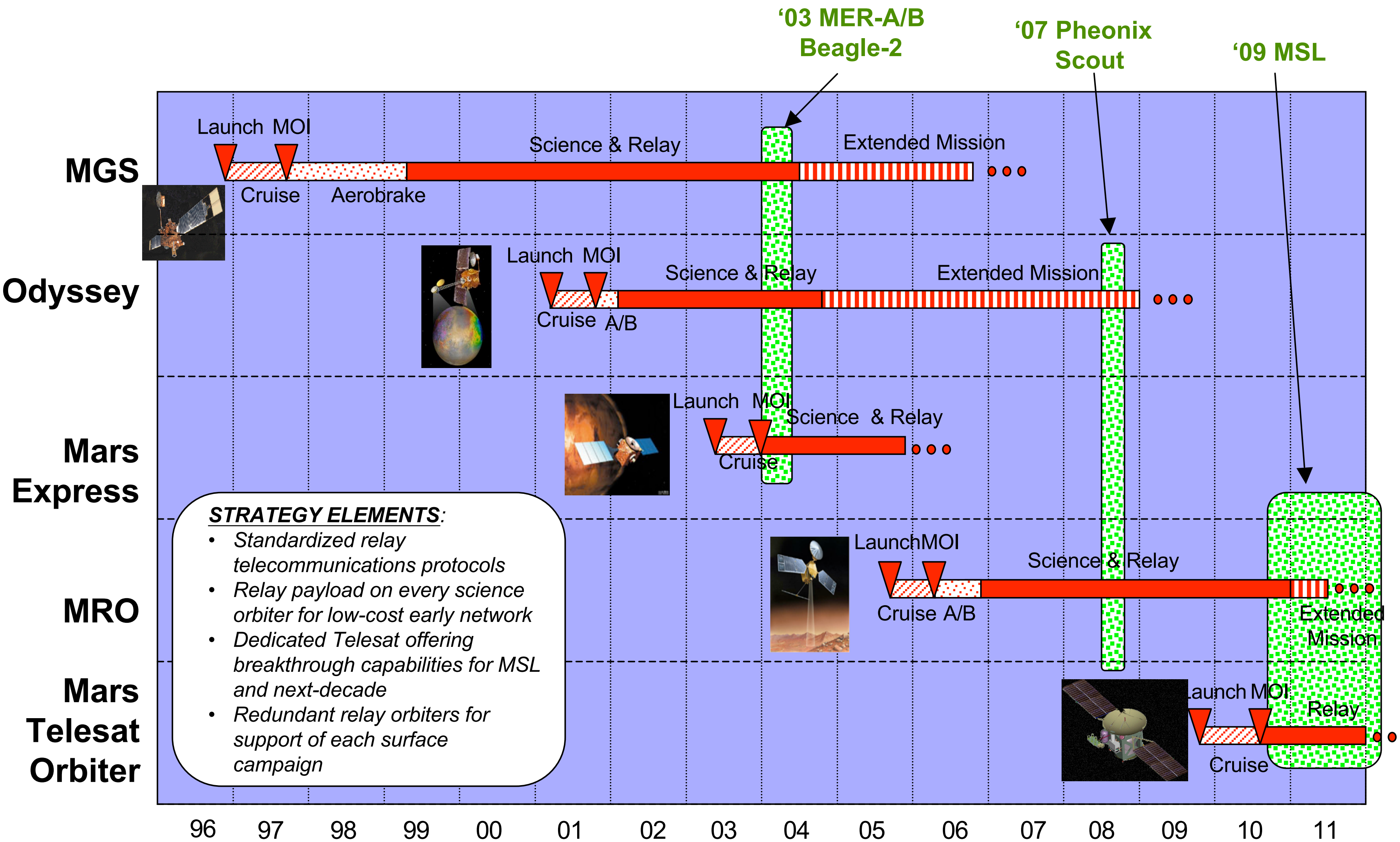
- Mass, power constraints typically limit lander DTE capability to well below orbital DTE capability - one of the primary rationales for relay comm!

Key Aspects of Relay Communications



Planned Program Telecom Infrastructure

Mars Network

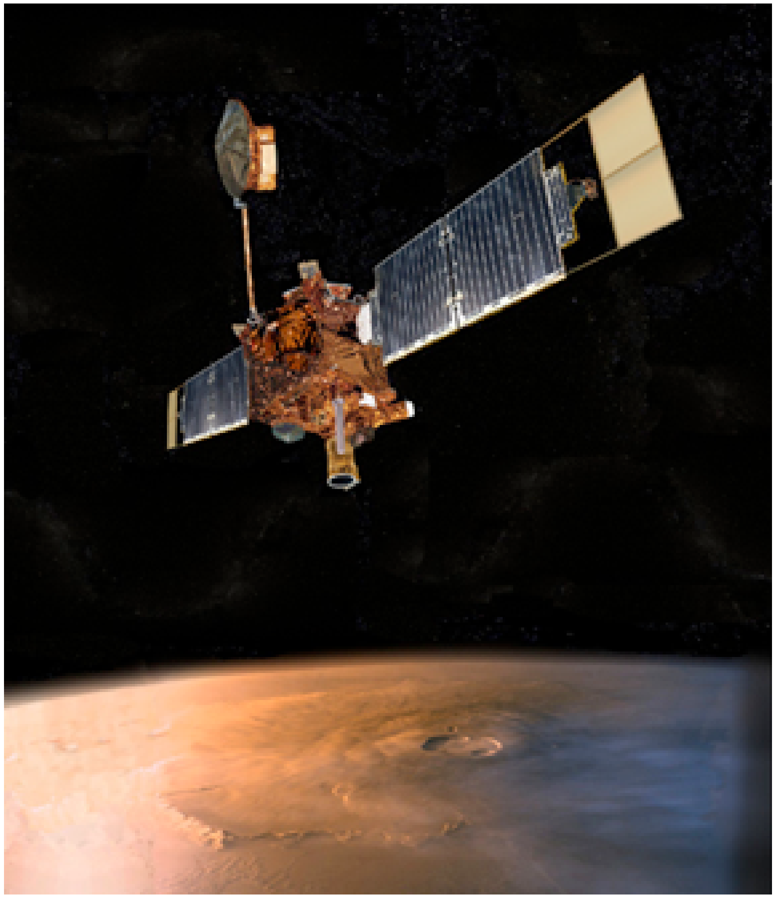


STRATEGY ELEMENTS:

- *Standardized relay telecommunications protocols*
- *Relay payload on every science orbiter for low-cost early network*
- *Dedicated Telesat offering breakthrough capabilities for MSL and next-decade*
- *Redundant relay orbiters for support of each surface campaign*

Mars Network Evolution: Mars Global Surveyor

- **Launched in 1996**
- **Low altitude science orbiter**
- **Mars Balloon Relay UHF radio**
  - Return-link only (no command link)
  - Unreliable bitstream communications
  - Limited data rates (8, 128 kbps)
  - Fixed frequency operation
- **Relay data flow through Mars Orbiter Camera**
  - Malin Space Science Systems



Mars Network Evolution: Mars Odyssey

- **Launched in 2001**
- **Low altitude science orbiter**
- **CE505 UHF Transceiver**
  - First implementation of CCSDS Proximity-1 Link protocol
  - Hailing procedure & link directives
  - Forward and return link (TLM & CMD); fixed frequencies
  - Framed data, ARQ retransmission for reliable data transfer
  - Add'l data rates: 8, 32, 128, and 256 kbps
- **Open-loop sampling (1 bit/sample)**

Mars Network Evolution: Mars Express (ESA)

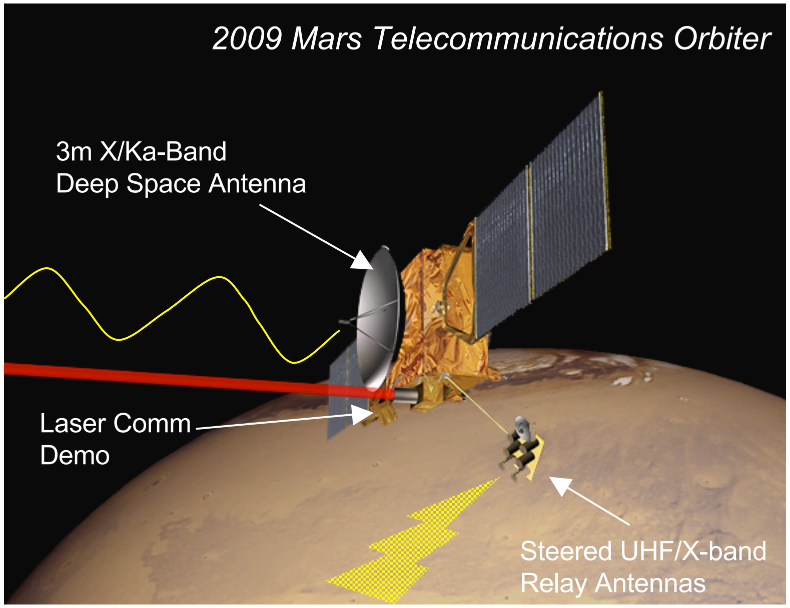
- **Launched in 2003**
- **Highly elliptical orbit (258 x 11,560 km, 7.5 hr period)**
  - Irregular coverage
  - Long proximity link communications slant range
  - Low data volume return
- **Will deploy Beagle 2 lander prior to Mars orbit insertion**
- **CCSDS Prox-1 compliant relay radio**
  - Built by QinetiQ
  - Interoperable with Odyssey, MER
- **Nominal mission lifetime through Apr'08**

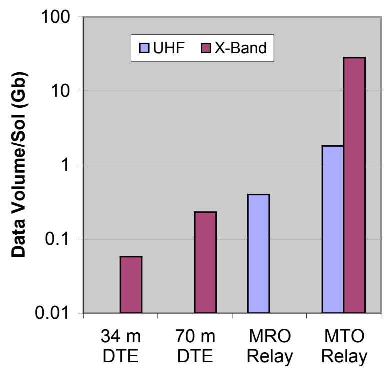
Mars Network Evolution: Mars Reconnaissance Orbiter

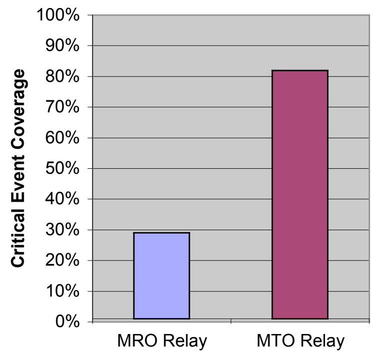
- **Launch in 2005**
- **Low altitude science orbiter**
- **Electra UHF Transceiver**
  - Standardized CCSDS Prox-1 Protocol
  - Add'l data rates (1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048 kbps)
  - Tunable frequency (390-450 MHz)
  - 2 dB coding improvement
  - Improved open-loop sampling (8 bits/sample)
  - Flight-reprogrammable s/w radio
  - USO for precision timing/nav
- **High-performance DTE link**
  - X-band prime; Ka-band demo
- **Initial use of CCSDS File Delivery Protocol (CFDP) for end-to-end data accountability**

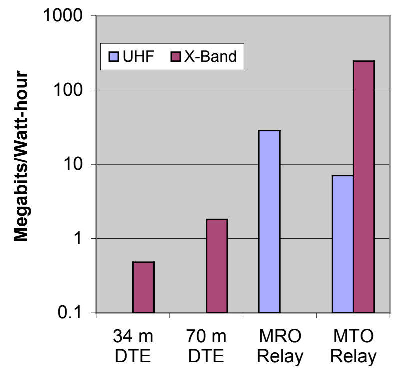
Mars Network Evolution: Mars Telecommunciations Orbiter

- **High-altitude telesat orbit (4450 km)**
  - Increased contact time (~4 hrs/sol at all latitudes; greatly improved coverage of critical events)
- **Electra UHF/X Transceiver**
  - Addition of X-band (8.4 GHz) receive capability for very high-rate directional links
  - 12 dBi steered UHF antenna; 50 cm steered X-band MGA
- **RF and Optical *in situ* tracking/nav**
- **High-performance DTE link**
  - X/Ka-band prime
  - Optical comm demo
- **File-based relay ops**
- **Immediate payoff for MSL, w/ feed-forward capabilities for next decade exploration**



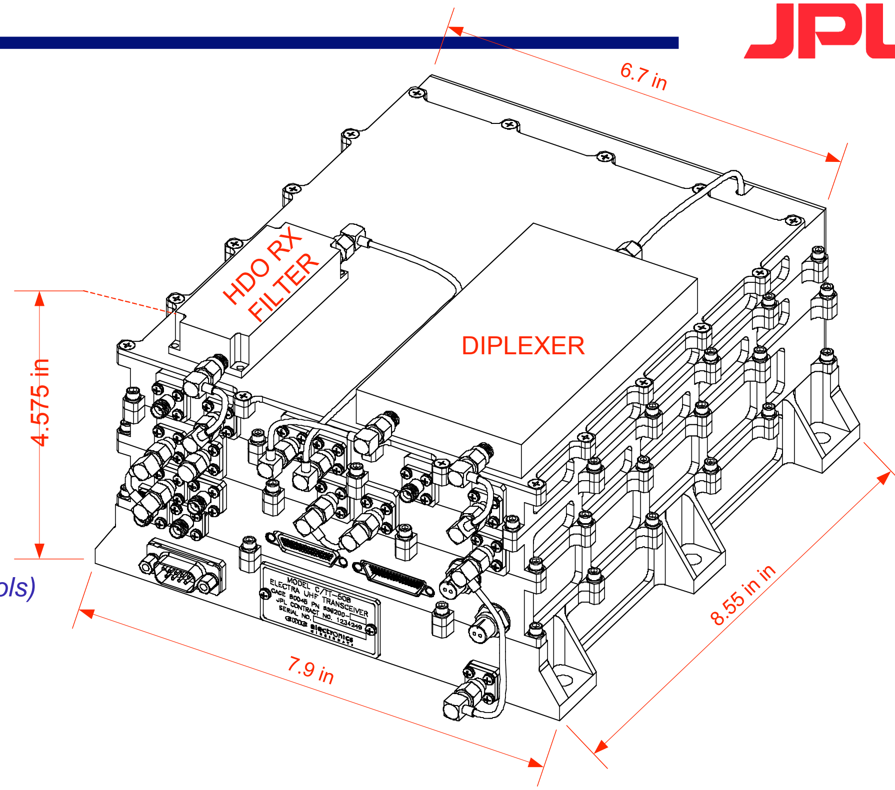






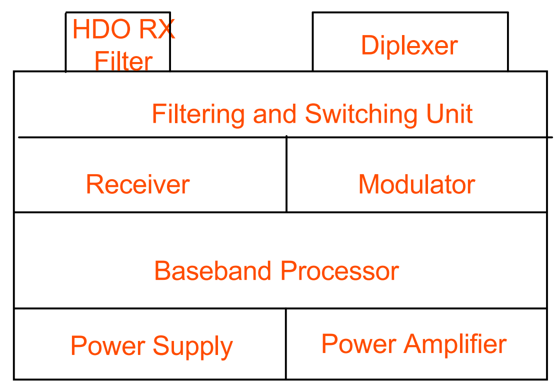
Electra Proximity Link Payload

- **Standardized proximity link radio for Mars**
  - Reprogrammable software radio architecture
  - First flight on 2005 Mars Reconnaissance Orbiter
  - Subsequent flight on 2009 Mars Telesat and all future Mars orbiters

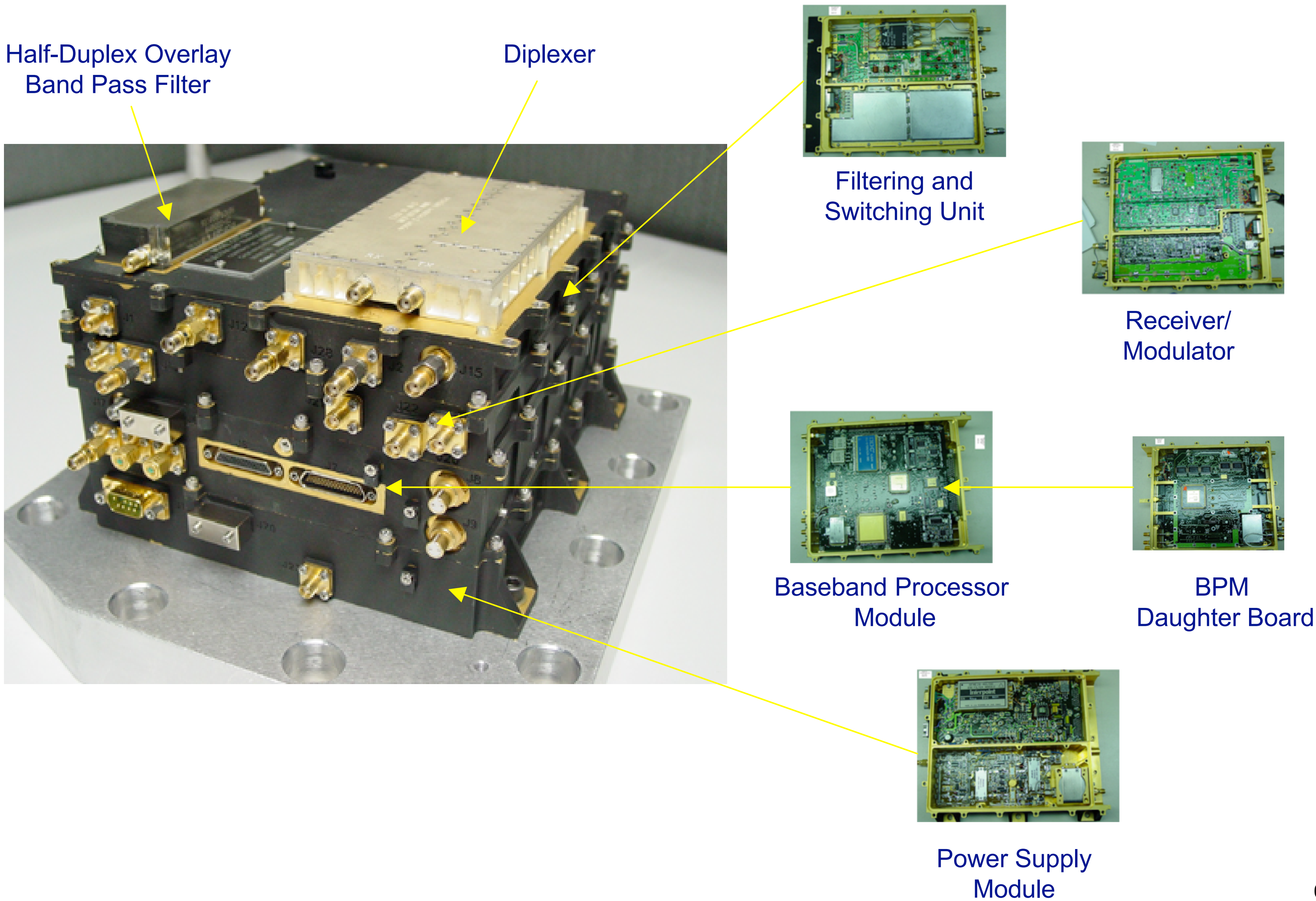


Specifications:

•CCSDS Proximity-1 Protocol (Reliable and Expedited Link Layer Protocols)
•Software radio architecture:
  •Sparc V.7 rad-hard payload controller
  •Xilinx XQVR 1000 rad-tolerant flight-reprogrammable FPGA
•Mass: 5.0 kg
•Full-duplex/Half-duplex operations modes
•Transmit Power: 5W Full-duplex, 7W Half-duplex
•Noise Figure: 4.9 dB Full-duplex, 3.9 dB Half-duplex
•Radiation Total Dose: 20 Krad 100 mil Al
•DC Power: 71 W (Full-duplex)
•Frequency Bands: 390-405 MHz; 435-450 MHz
•Suppressed and Residual Carrier Modes
•Symbol Rates: 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048 ksps
•Demodulation: Within 2.0 dB of theory at all rates
•Coding: K=7, 1/2 convolutional, [255,239] RS, [204,188] RS
•Interfaces: 1553B for Monitor & Control; LVDS for High-Speed Data
•Option to add X-band (8.4 GHz) downconverter slice
•Radio Metrics: Carrier phase/Doppler observables w/ 60 ns time tag accuracy
•In-flight self-test capability



Electra UHF Transceiver



Future Proximity Link Developments

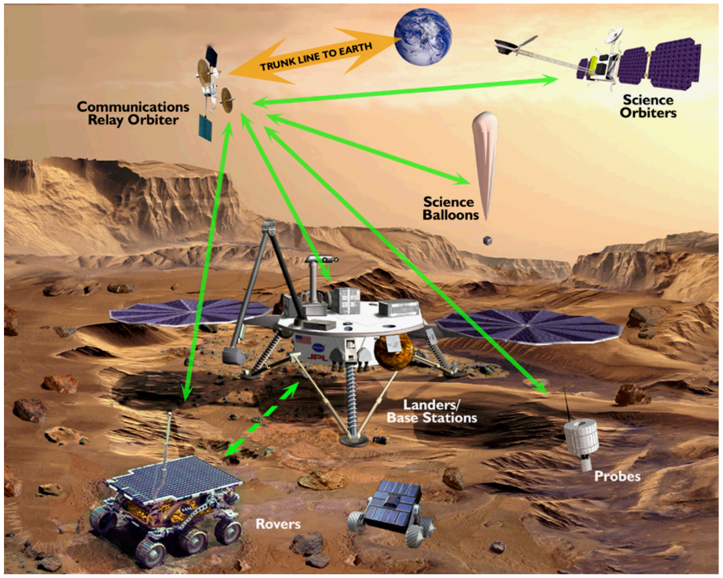
- **Addition of X-band slice for MTO**
  - Enables high-rate X-band directional link from surface to orbit
    - Addition of QPSK and increase in symbol rate to enable up to 8 Mbps data rate (uncoded)
- **Electra Lite**
  - Tailoring of orbiter design (targeted descopes) to achieve lower mass/volume/power more appropriate for lander payload
    - Current baseline for MSL

Parameter	*Electra*	*Electra-Lite*
Mass	5.0 kg	2.1-2.9 kg
Volume	5080 cc	2120-2940 cc
Power	71.0 W	55-58 W

- **Adaptive Data Rates**
  - MTP-funded effort to develop and demonstrate adaptive data rate profiling during pass
    - Allows link operation near capacity of actual (not predicted) communications channel - increased performance and increased robustness
- **Increased proximity link antenna gain for MTO**
  - MTP-funded effort to develop 12-15 dBic steered UHF antenna for MTO
    - Compensates for longer slant ranges in high-altitude Telesat orbit

Communications Protocols

- **CCSDS Proximity-1 Space Link Protocol**
  - Provides international standards for the physical and data link layers for Mars proximity communications
  - First implemented on Mars Odyssey followed by Beagle2, Mars Express, MER A/B; will be used by MRO, Phoenix, MTO, and MSL
  - Key for achieving interoperability among multiple Mars landers and orbiters
- **CCSDS File Delivery Protocol (CFDP)**
  - Provides reliable and complete end-to-end file delivery
  - Addresses unique aspects of deep space communications
    - Long RTLT
    - Intermittent connectivity
    - High BER links
    - Multi-hop store-and-forward relays
    - Custody transfer to minimize onboard storage rqmts



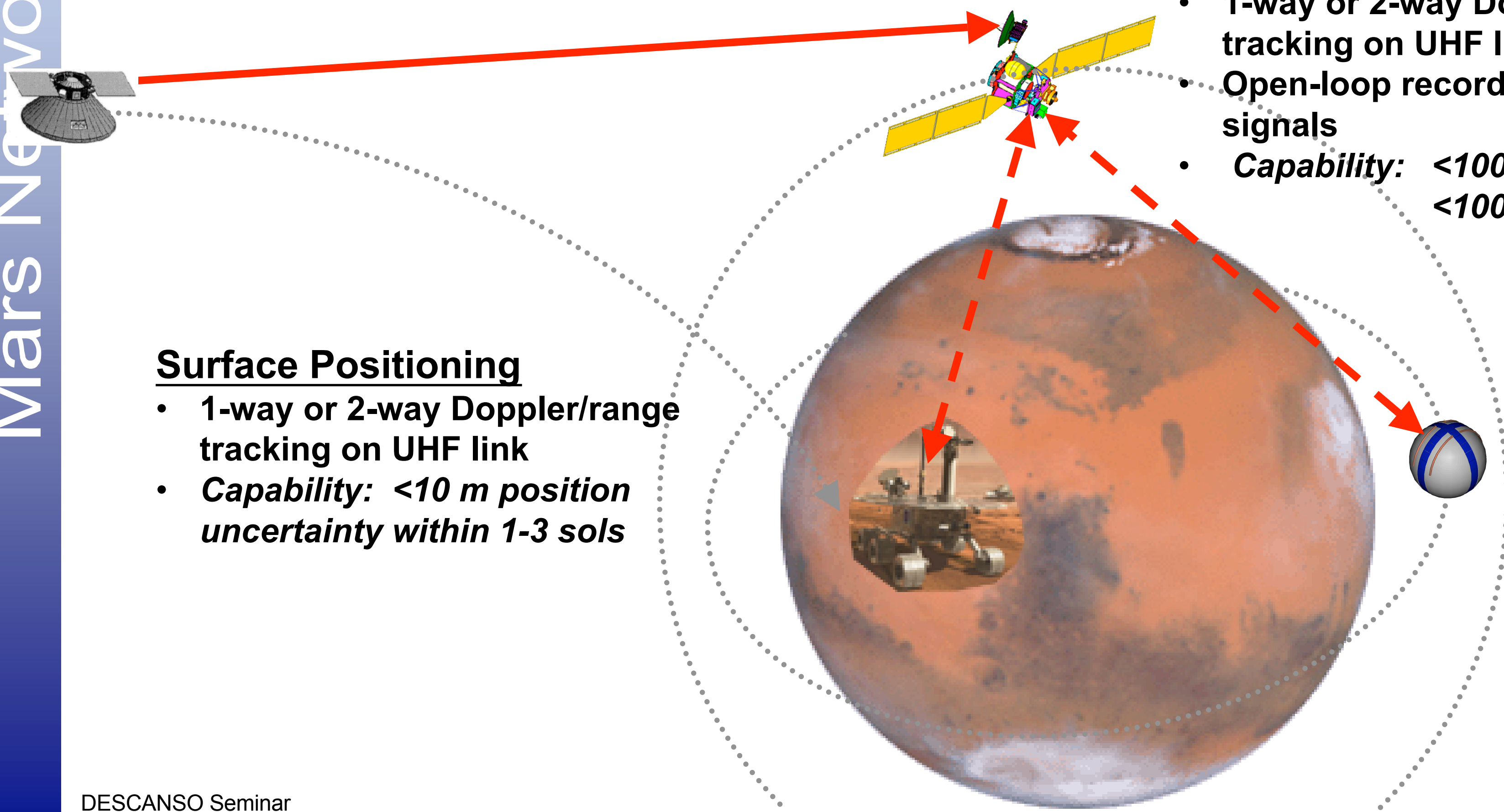
- **Full documentation at http://www.ccsds.org**

Mars Network

In Situ Navigation Using Proximity Link Radio Metrics

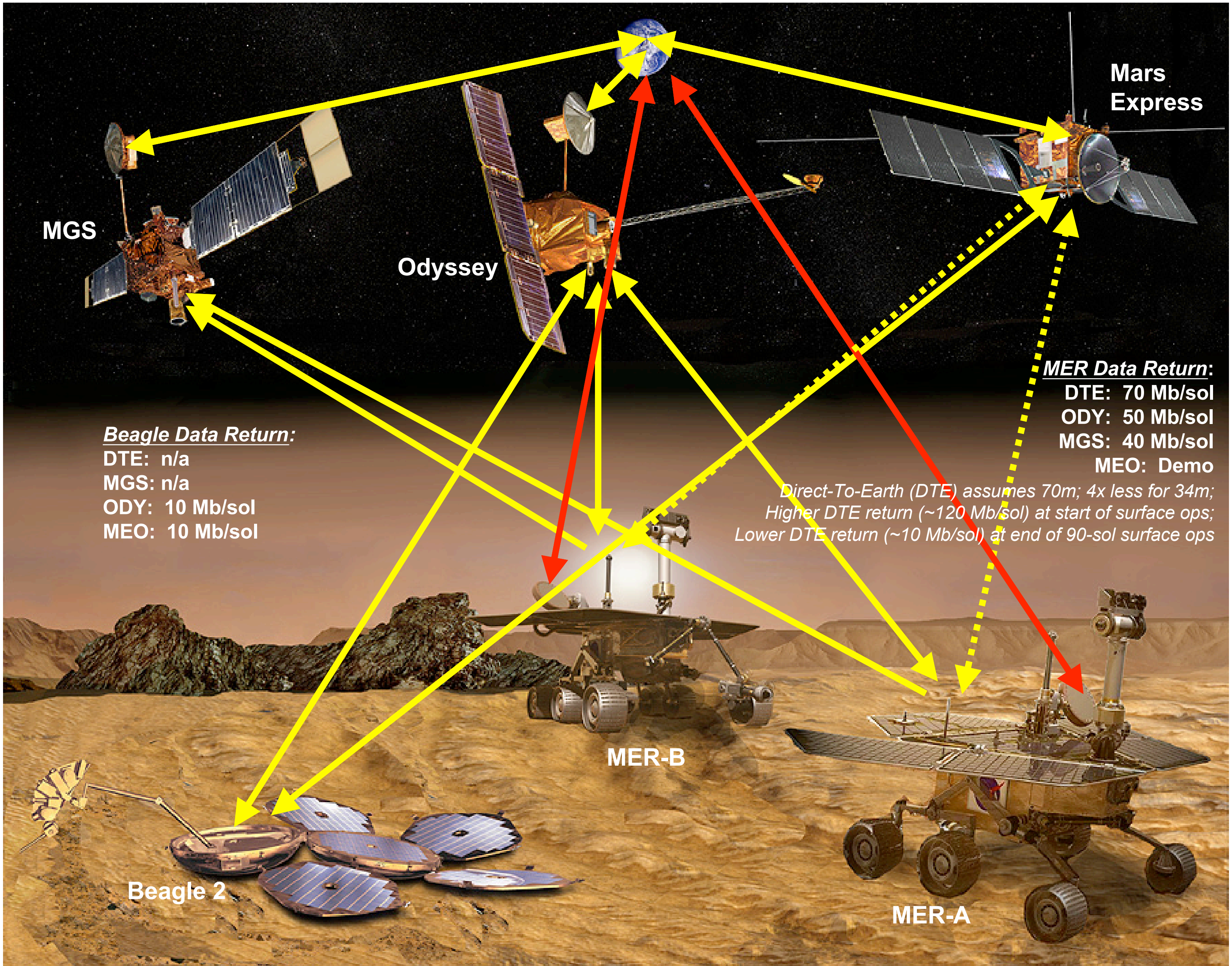
Precision Approach Navigation
- **X-band Doppler on HGA link between approach s/c and orbiter**
- ***Capability: < 1 km B-plane error @ E-1 day***

Orbiting Sample Canister Tracking
- **1-way or 2-way Doppler tracking on UHF link**
- **Open-loop recording for weak signals**
- ***Capability: <100 km 1-way***
  <100 m 2-way



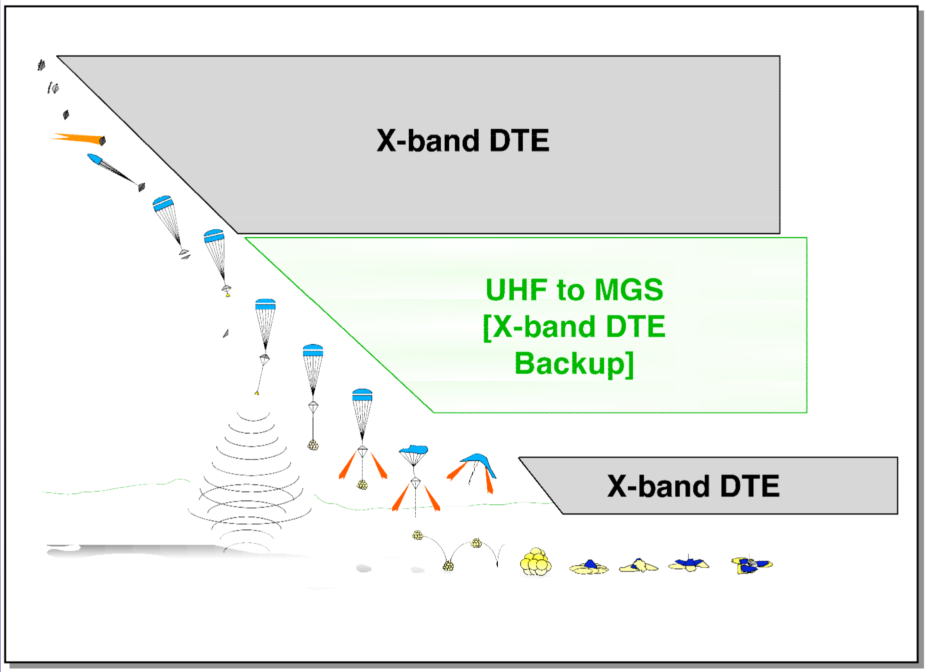
Surface Positioning
- **1-way or 2-way Doppler/range tracking on UHF link**
- ***Capability: <10 m position uncertainty within 1-3 sols***

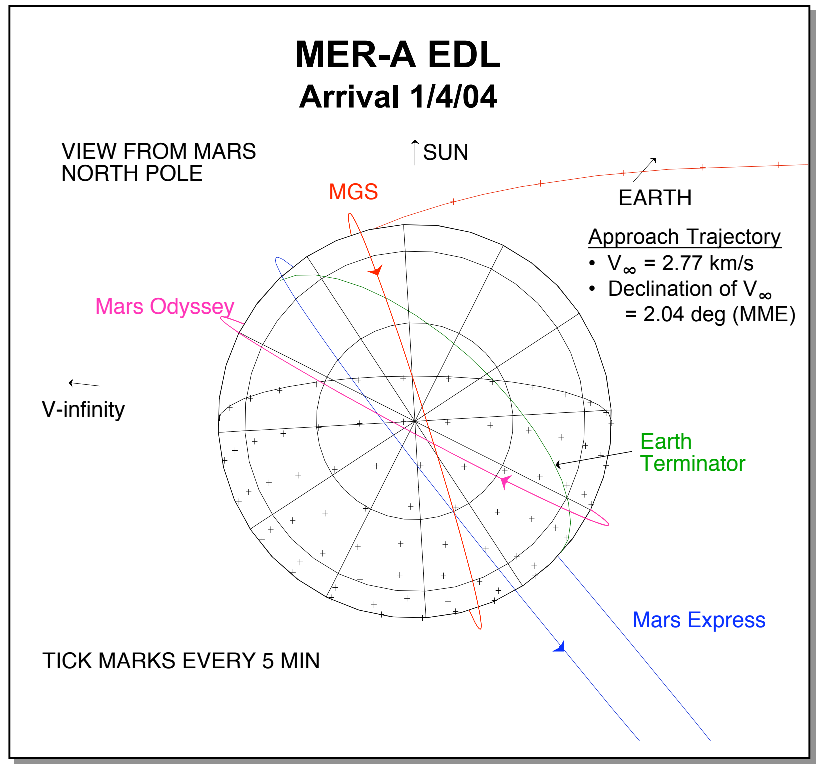
Case Study: '03/'04 UHF Relay Ops



Case Study: '03/'04 UHF Relay Ops (cont'd)

- **Critical Event Communications for MER Entry/Descent/Landing**
  - X-band MFSK tones ("semaphores") on DTE link
    - ~1 bps effective data rate
  - UHF telemetry to MGS after lander separates from backshell
    - 8 kbps engineering telemetry





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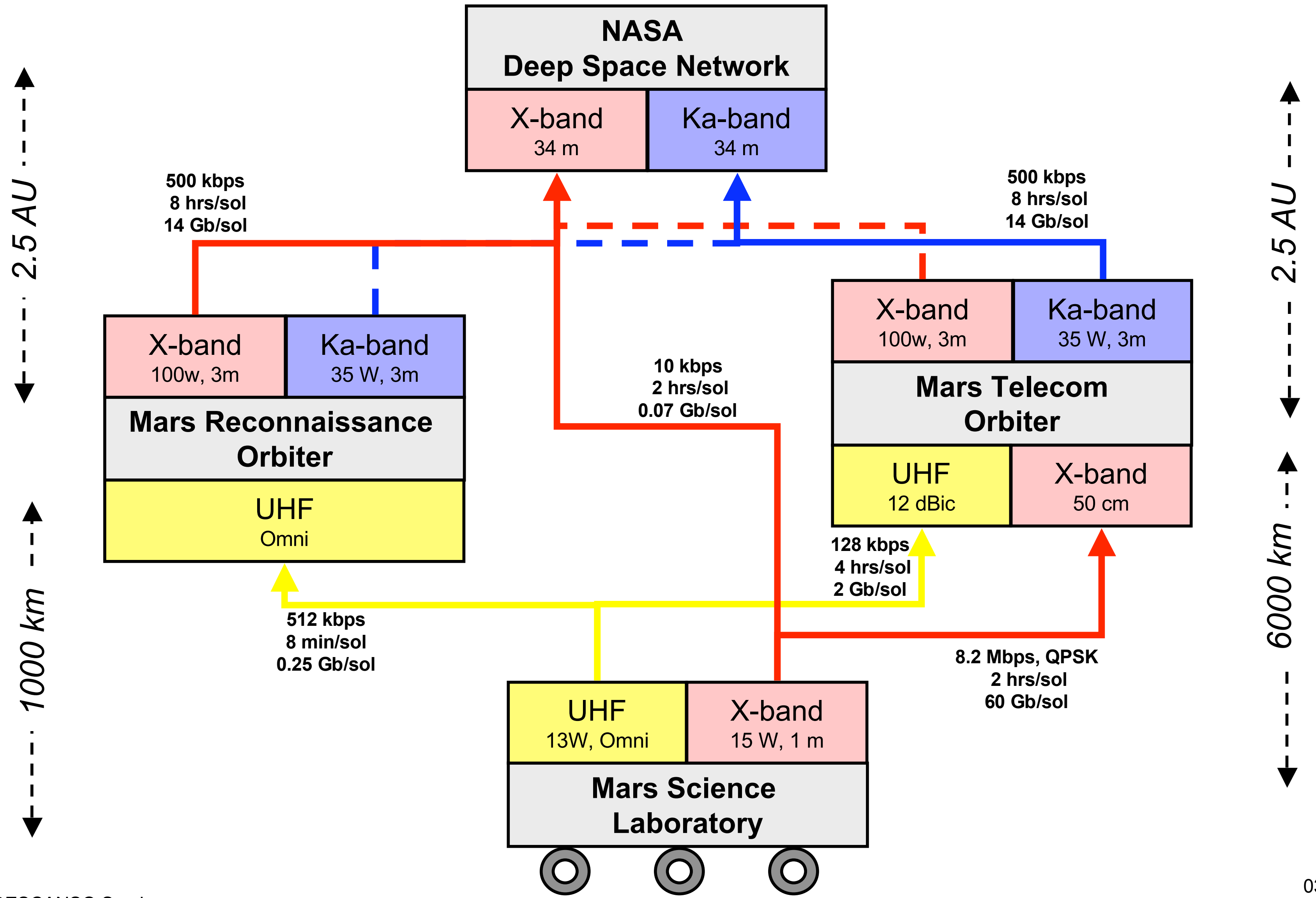
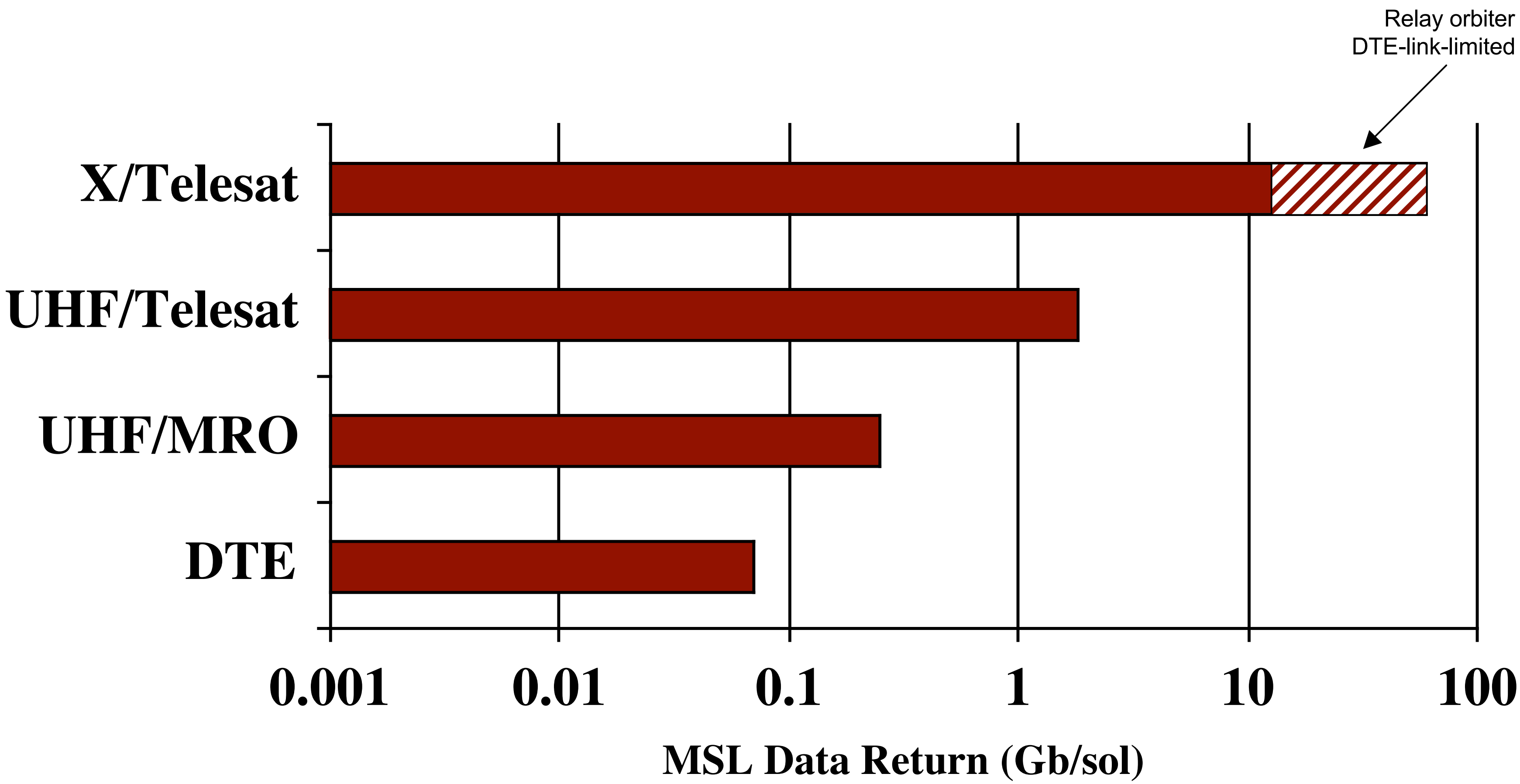
Case Study: '03/'04 UHF Relay Ops (cont'd)

- **Transceiver idiosyncrasies**
  - Lack of reprogrammability prevents correction of firmware bugs - even some found pre-launch
- **Large multipath effects**
  - Wide-beamwidth, long-wavelength UHF links
- **Relay coordination process**
  - Multi-agency interaction to identify/resolve RFI scenarios
- **Contingency planning**
  - Need prompt visibility into link performance and end-to-end data flow, as well as rapid turn-around relay plan updates, particularly during first few sols of surface ops
- **Orbiter-driven operations concept**
  - Need to examine potential advantages of alternative lander-driven relay ops concept

Case Study: 2009 Mars Science Laboratory



Case Study: 2009 Mars Science Laboratory (cont'd)



Summary

- **Mars exploration is significantly enhanced - and in some cases enabled - by establishing an orbital telecommunications infrastructure**
  - Increased data return and contact time
  - Robust critical event coverage
  - Energy-efficient relay
  - In situ navigation
- **Key strategies**
  - Improved DTE performance
  - Relay capability on every Mars science orbiter
  - Dedicated Telesat to provide breakthrough capability
  - Reprogrammable “network node” - Electra
  - Standardized comm protocols for interoperability and reliable end-to-end file transfer between Mars and Earth

Backup

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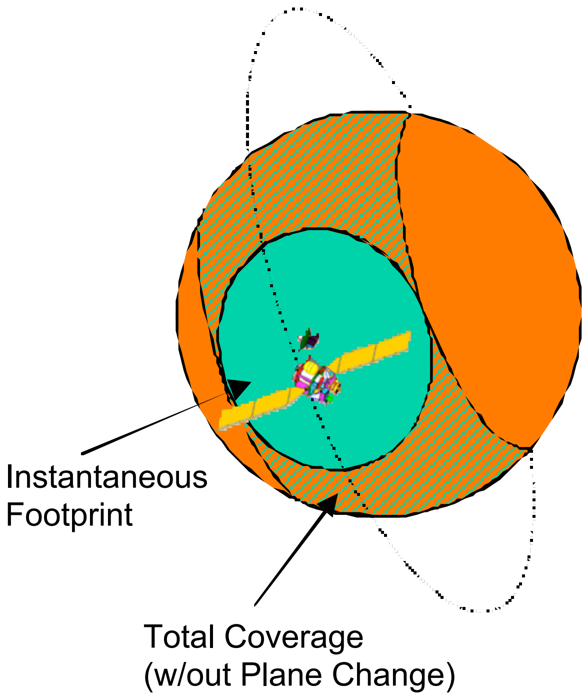
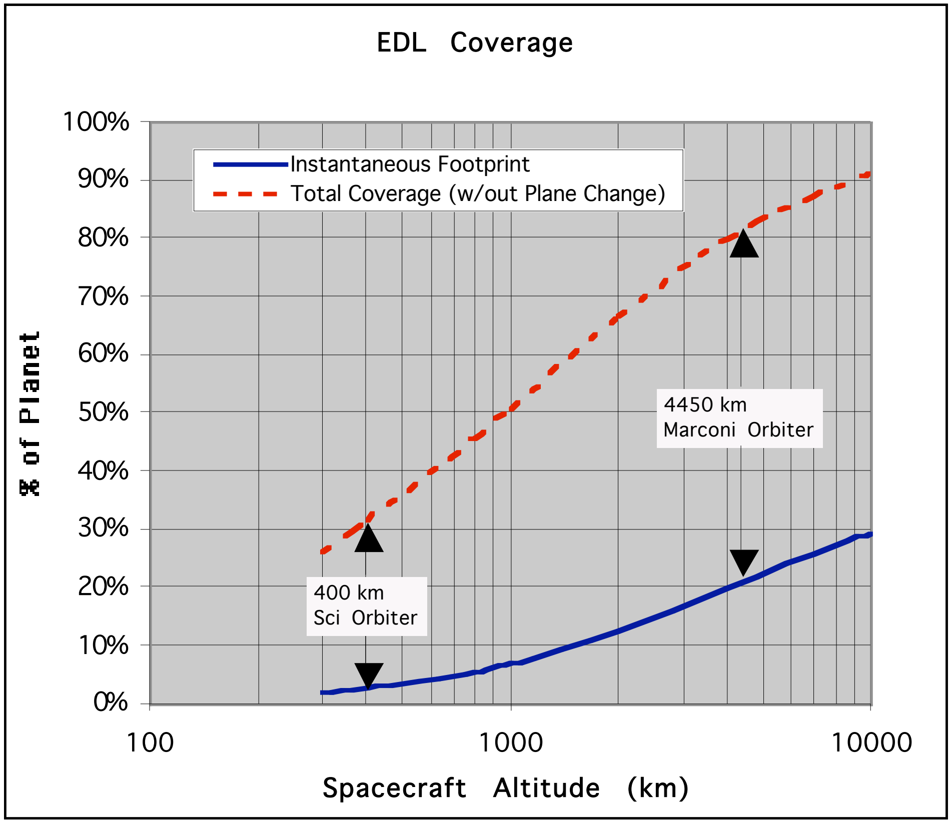
Critical Event Communications

- Higher-altitude telesat orbit provides much greater coverage for critical events (e.g., EDL) than low-altitude science orbiters





EEIS and Operability Issues