Jet Propulsion Laboratory
California Institute of Technology

Assessment of Potential Mars Relay Network Enhancements

Chad Edwards, Roy Gladden, Charles Lee and Daniel Wenkert
Jet Propulsion Laboratory, California Institute of Technology

IEEE Aerospace Conference
March 6, 2018

The research described in this presentation was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

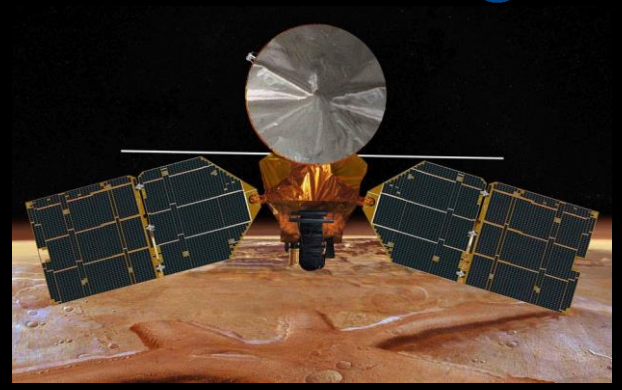
Outline

- Introduction
- Baseline Mars Relay Network Capability
- Anticipated Support Scenarios
- Split-Pass Relay Capability
- MAVEN Extended Mission Orbit
- Low-Density Parity Check Coding
- Summary

Current Mars Relay Network

Odyssey (2001)

MRO (2005)



ESA ExoMars
Trace Gas Orbiter (2016)

Image: ESA

Mars Express (2003)

Image: ESA

MAVEN (2013)

Baseline Mars Relay Network Specifications

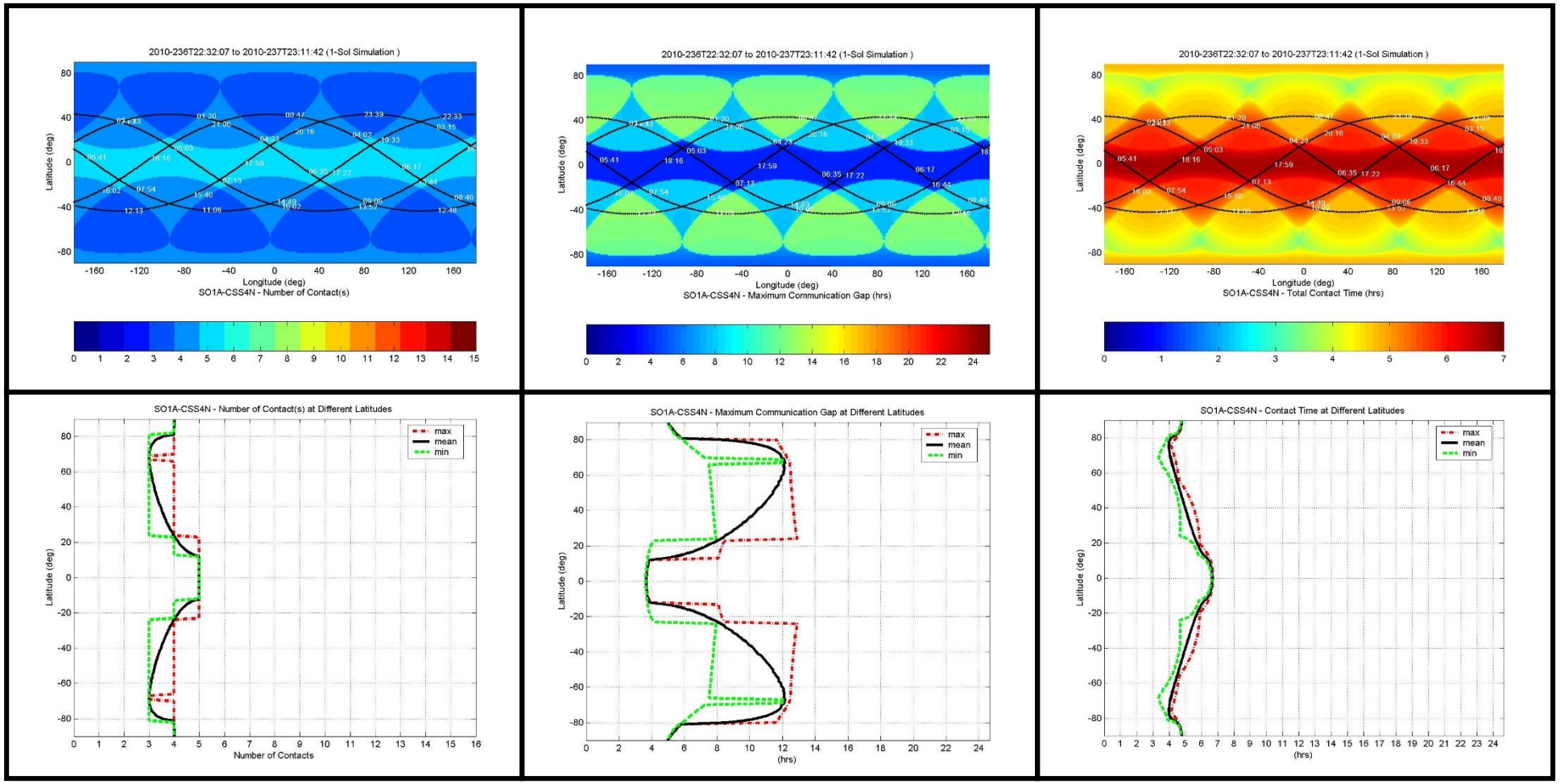
	ODY	MEX	MRO	MAVEN	ExoMars/TGO
Agency	NASA	ESA	NASA	NASA	ESA/RSA
Launch Date	2001	2003	2005	2013	2016
Orbit	400 km 93 deg inclination	298 x 10,100 km 86 deg inclination	255 x 320 km 93 deg inclination	150 x 6200 km 74 deg incilnation	400 km[1] 74 deg inclination
UHF Transceiver	CE-505	Melacom	Electra	Electra	Electra
Antenna	Quadrifilar Helix	Quadrifilar Helix	Quadrifilar Helix	Quadrifilar Helix	Quadrifilar Helix
Max Data Rate	256 kbps	128 kbps	2048 kbps	2048 kbps	2048 kbps
Transmit Power	12 W	8.5 W	5 W	5 W	5 W
Adaptive Data Rate Capable?	N	N	Y	Y	Y

TOAST Capabilities

- TOAST Takes in:
  - Time Epoch and Orbital Elements (NAIF, TLE, Orbital Elements, etc.)
  - Geometric Constraints (mask angle, antenna canting angle, roll steering angle, lander latitude, etc.)
  - Telecom Info. (antenna patterns, trans. power, gains, losses, margins, etc.)
- TOAST Provides:
  - Network Visualization, 2D/3D Animation, and Web-based (future) Capabilities
  - Global Maps (Lon/Lat) and Latitude Maps
  - Contact Metrics
    - Number of Contacts
    - Contacting Time
    - Max Communication Gap
    - …
  - Telecom Metrics (currently UHF Band with Single/Adaptive Rates)
    - Maximum Supportable Data Rate
    - Hours Per Sol That Data Rate Is Above "x" Kbps
    - Cumulative Data Volume Per Sol
    - Largest Data Volume Per Sol with "x" Passes
    - Number Of "x Mb in y Minutes" Passes Per Sol
    - Largest Data Volume in "x" Minutes (Efficiency)
    - Minimum Time Required To Deliver "x" Gb Of Data (Efficiency)

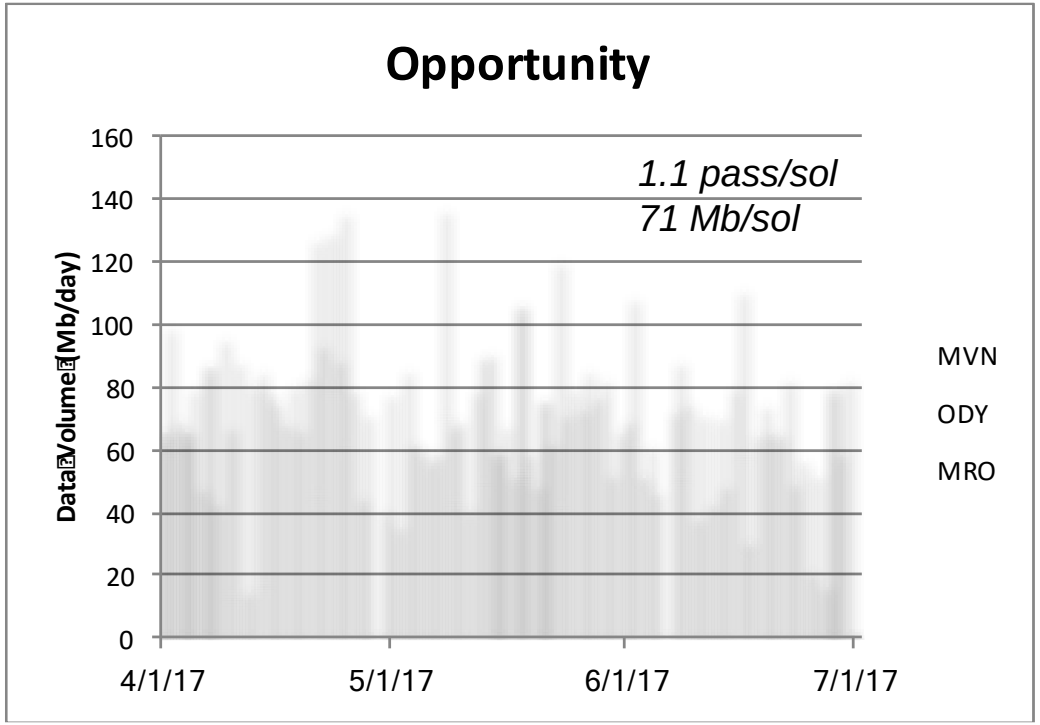
Sample Output of Contact Metrics

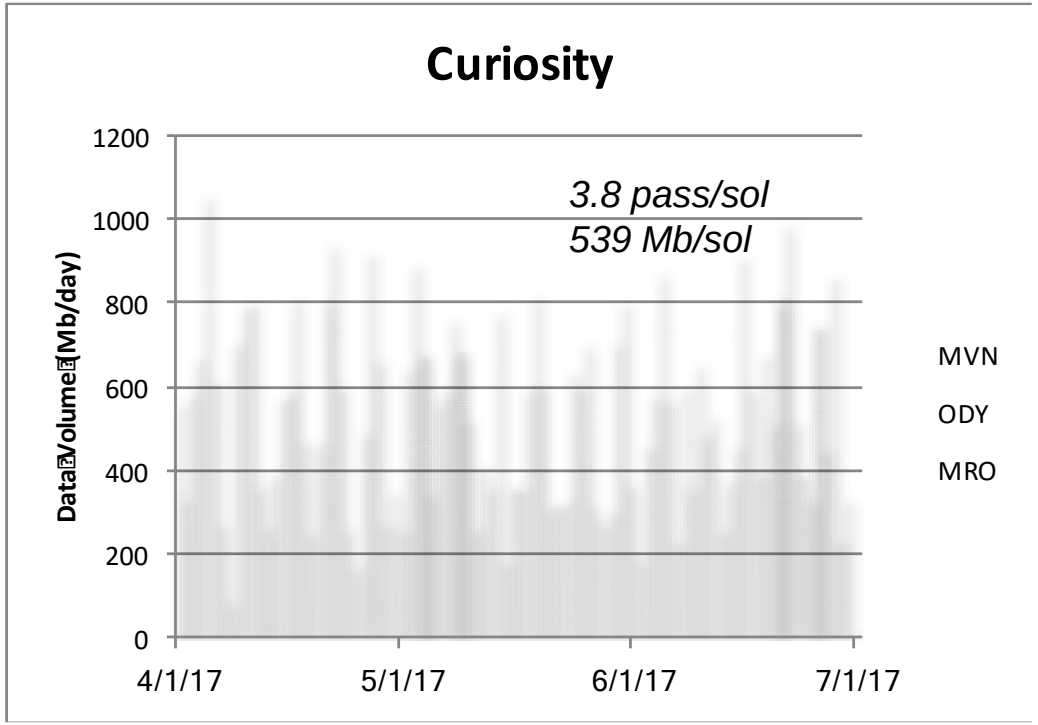
Number of Contacts | Communication Gap | Total Contact Time per Sol



Mars Relay Network Performance

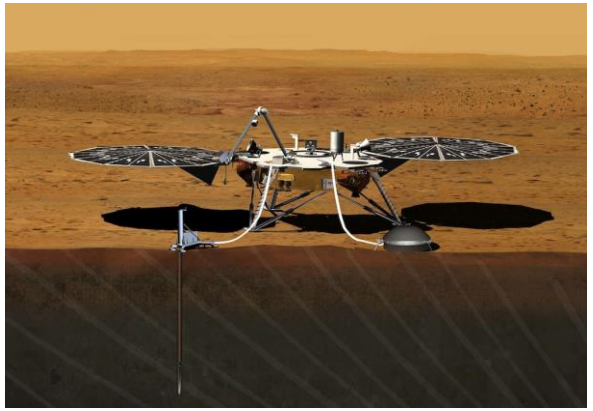
- Currently, MRO and ODY and providing routine support to the Opportunity and Curiosity Rovers
  - MAVEN is just starting to be used on a regular basis after completion of their primary science mission





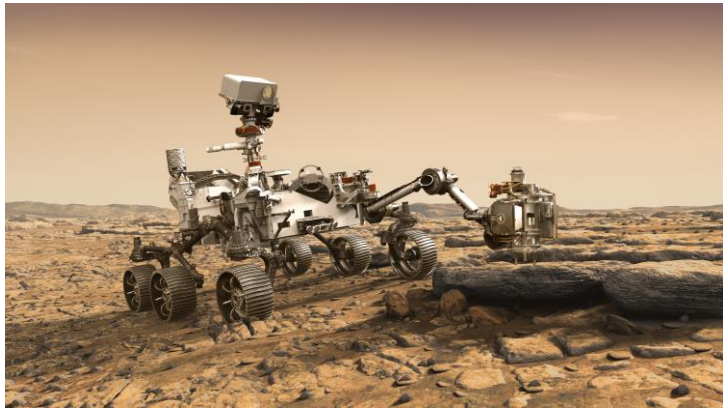
Anticipated Relay Support Scenarios

2018
InSight Lander
(NASA)



- *Science Goals: Subsurface science (seismology, heat flux, geodesy)*
- *Launch Period Open: 5-May-2018*
- *Landing: 26-Nov-2018*
- *X-band DTE (MGA only) + UHF*
- *Landing site close to MSL*
- *During instrument deployment, need afternoon relay passes to support overnight planning*

2020
Mars 2020 Rover
(NASA)

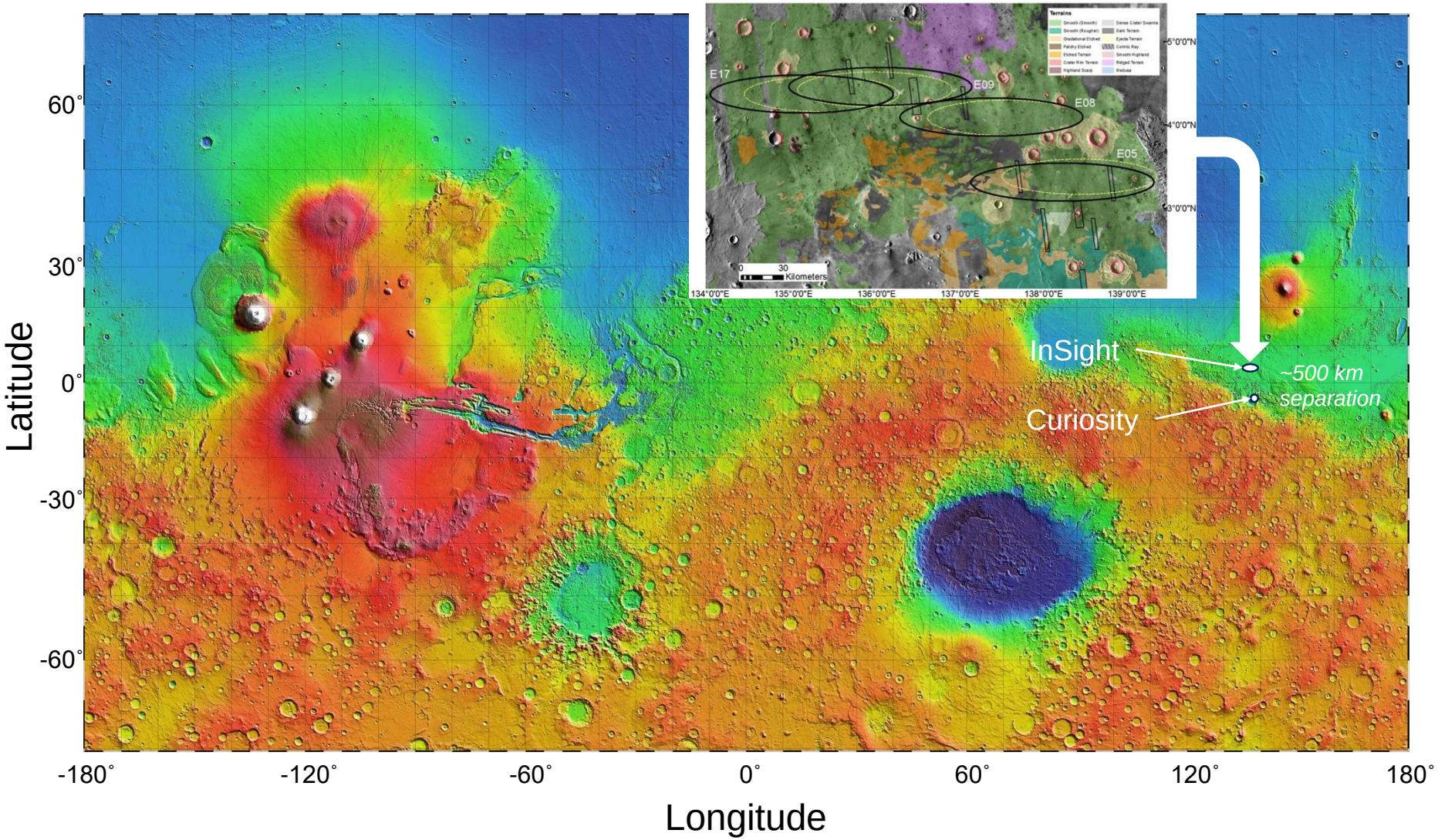


- *Science Goals: Search for ancient life, cache samples for potential return, prepare for human exploration*
- *Launch Period Open: 17-Jul-2020*
- *Landing: 18-Feb-2021*
- *High heritage to MSL/Curiosity*
- *X-band DTE (LGA/HGA) + UHF Relay*
- *1150 Mb/sol data return & 250 Mb/sol decisional data for overnight planning*

2020
ExoMars Rover & Surface Platform
(ESA/RSA)

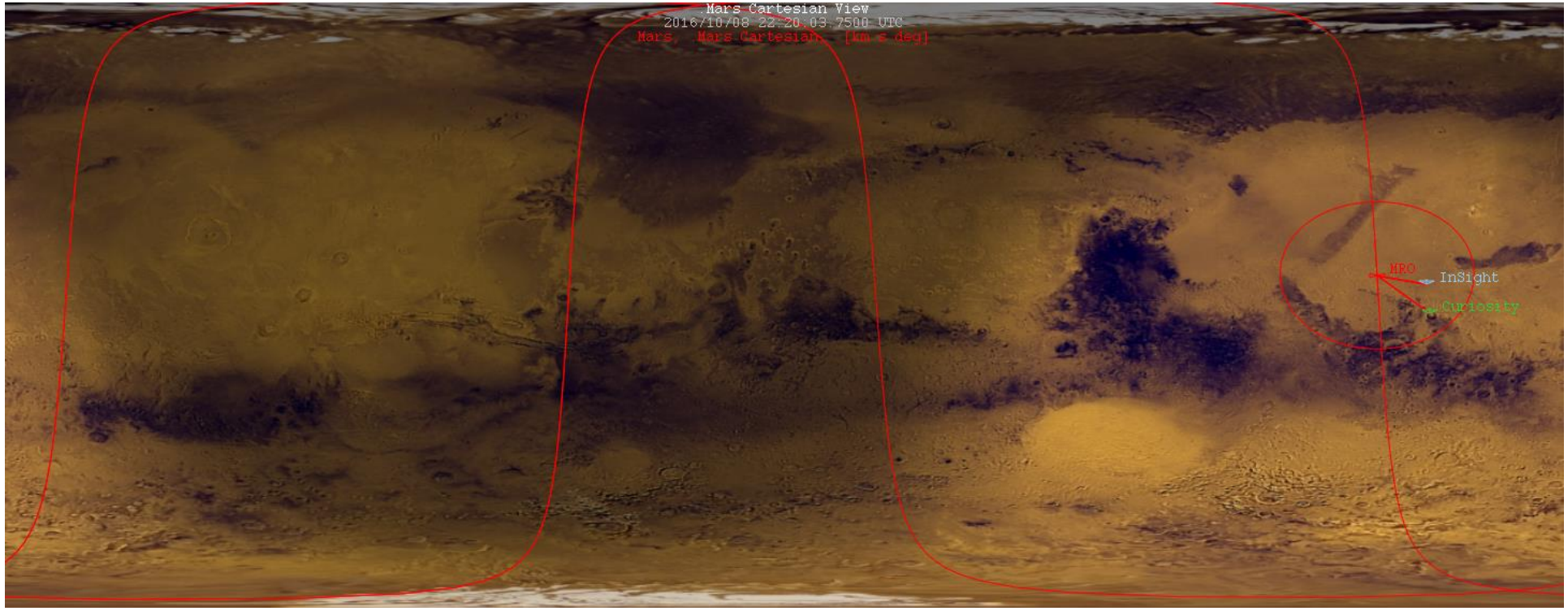
- *Science Goals: Astrobiology w/ 2m subsurface drill*
- *Separate Rover and Surface Platform*
- *Launch Period Open: 25-Jul-2020*
- *Landing: 19-Mar-2021*
- *UHF Relay (No DTE capability on surface)*
- *400 Mb/sol aggregate lander/rover data return*
- *AM pass for commands, PM pass for telemetry to support overnight planning*

InSight-Curiosity Collocation



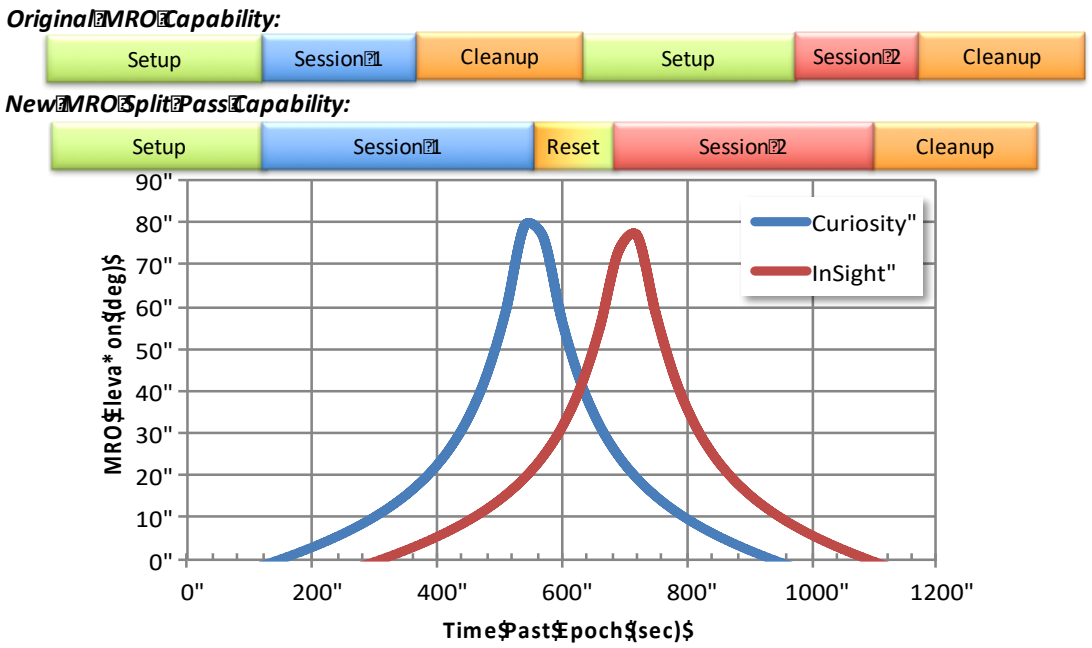
Relay Contention

- Orbiter footprint is large compared with InSight-Curiosity separation
  - View periods will largely overlap for most orbiter overflights
- ODY/MRO/MAVEN relay payloads can only support one instantaneous proximity link
- As a result, the two landers will be in contention for nearly all relay overflights



Split-Pass Relay Capability

- Nominal MRO Electra relay capability required ~10 min to reconfigure between passes, due to constrained S/C 1553 bus bandwidth
  - Precluded splitting a single oversight between the two landers
- MRO implemented new, streamlined relay configuration block to enable efficient pass splitting, reducing the re-configuration time to ~2 min
  - Allows providing afternoon (~3 pm) relay coverage to both InSight and MSL, key for overnight planning to support 1-sol rover/lander operations



MAVEN Extended Orbit Options

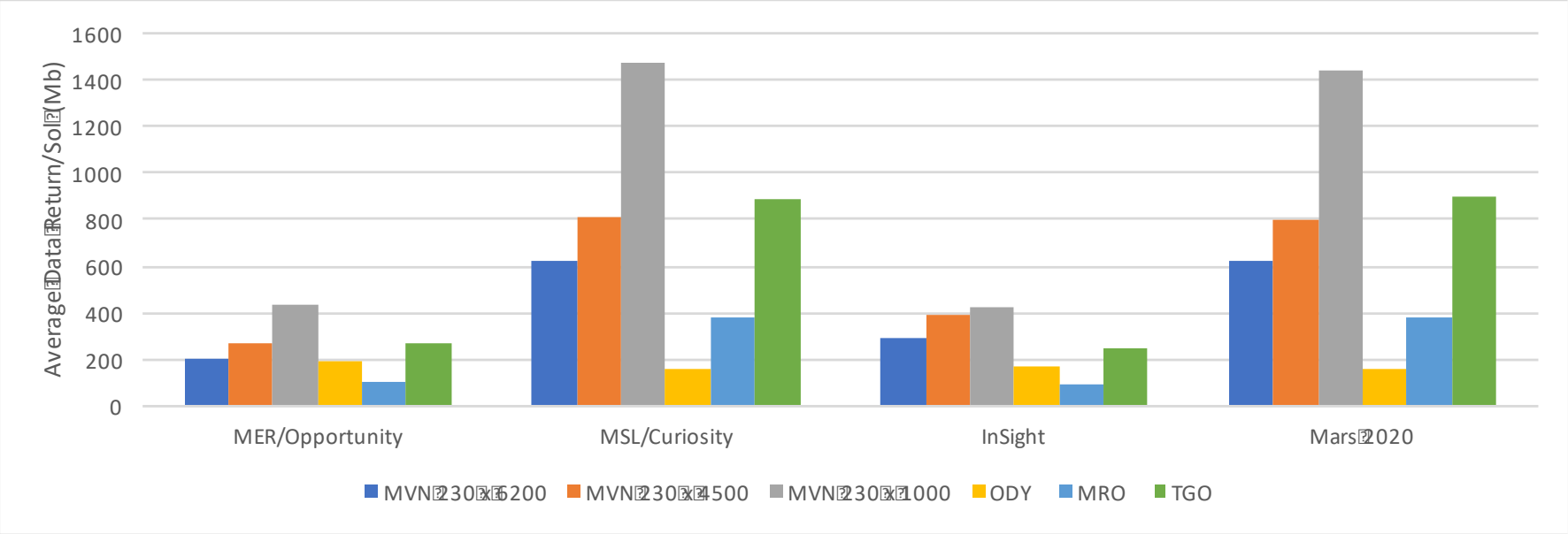
- MAVEN currently operates in a 6200 x 150 km science orbit
- Baseline mission plan calls for small periapsis raise (to 6200 x 230 km) to reduce atmospheric drag and extend relay orbital lifetime
- Mars Exploration Program also considering apoapsis reduction to improve relay performance
  - Lower slant range increases prox link data rate
  - Insufficient propellant to reduce apoapsis with impulsive burn
  - However, a conservative aerobraking strategy can achieve apoapsis reduction
- Considered three primary MAVEN orbit options
  - 6200 x 230 km (extended science baseline)
  - 4500 x 230 km
  - 1000 x 230 km

Key Features of Current and Future Mars Landers impacting Relay Performance

	MER-B	MSL	InSight	Mars 2020	ExoMars/RSP
Landing Site (LAT, ELONG)	Meridiani Planum (-2.1, 353.8)	Gale Crater (-4.6, 137.4)	Elysium Planitia (4.4 deg, 136.8)	Jezero Crater (18.9, 77.5)	Oxia Planum (18.3, 335.4)
UHF Transceiver	CE-505	Electra-Lite	CE-505	Electra-Lite	QineteiQ
Antenna	Monopole	Quadrifilar Helix	Quadrifilar Helix	Quadrifilar Helix	Quadrifilar Helix
Max Data Rate	256 kbps	2048 kbps	256 kbps	2048 kbps	1024 kbps
Transmit Power	12 W	8.5 W	12 W	8.5 W	5 W
Adaptive Data Rate Capable?	N	Y	N	Y	Y

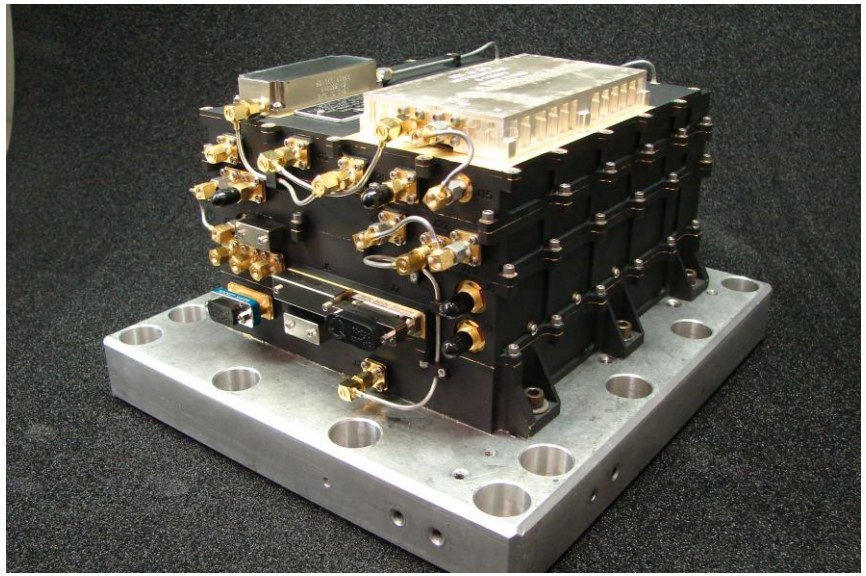
MAVEN Relay Performance Comparison

- Aerobraking MAVEN to a lower apoapsis can significantly improve relay performance
- For Mars 2020:
  - Reduction to 1000 km: 120% data return increase (relative to 6200x230 km)
  - Reduction to 4500 km: 30 % data return increase



Low-Density Parity Check Codes

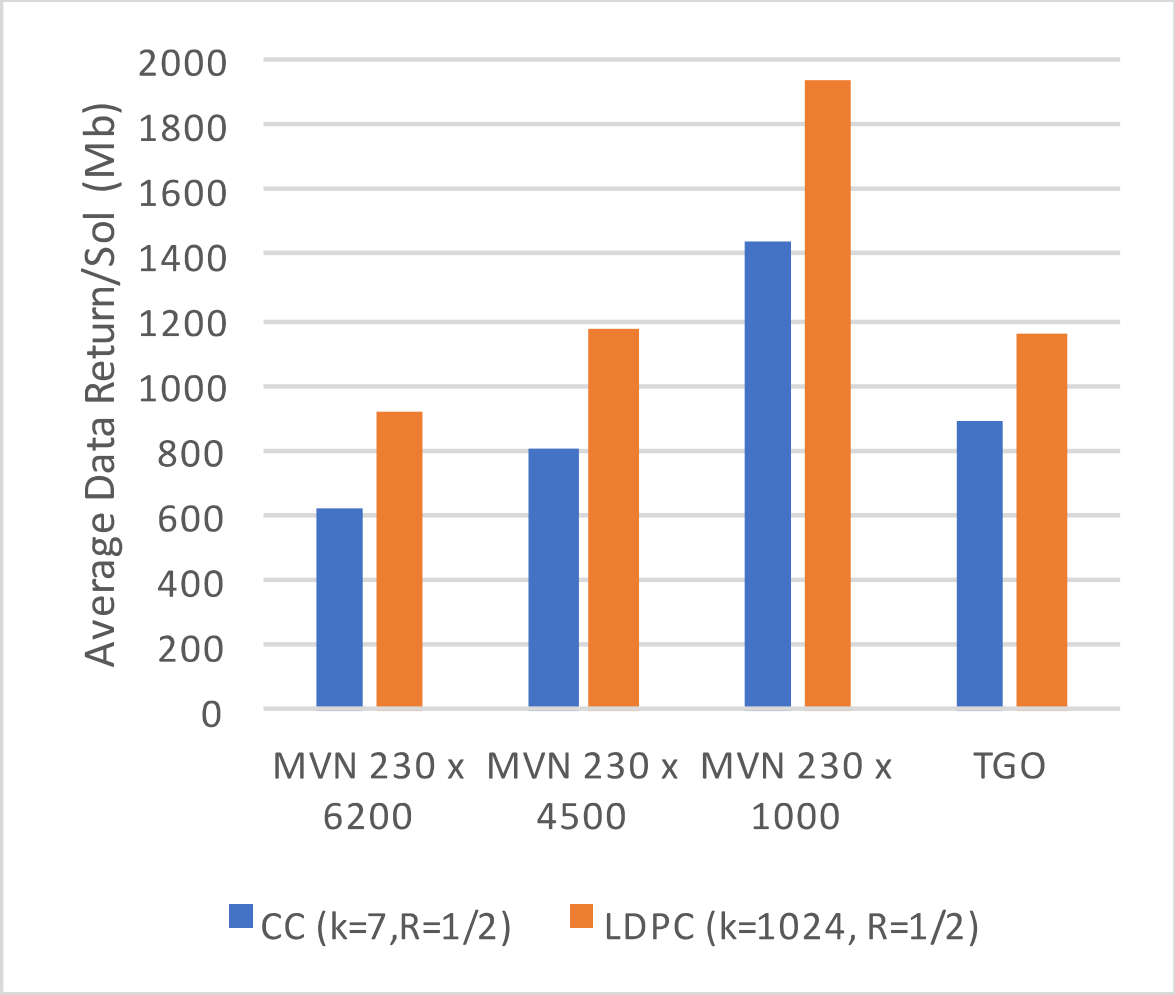
- The Electra payloads on MAVEN and TGO implement a new CCSDS Low-Density Parity Check (LDPC) forward error correcting code
  - Offers ~ 3 dB advantage over baseline (7,½) Convolutional Code
- However, Electra's Adaptive Data Rate algorithm is not yet tuned to operate with LDPC code
  - ADR directs lander data rate changes based on observed return link Symbol Signal-to-Noise Ratio
  - LDPC needs new version of ADR to account for capability to operate at ~3-dB lower Symbol SNR
  - Requires Electra software/firmware update



MAVEN Electra UHF Transceiver

LDPC Performance Benefit

- Link analysis shows that LDPC offers data volume improvements of 30-45% over the baseline (7, ½) convolutional code
- Given the potential benefit to Mars 2020, MEP is planning to move forward with LDPC/ADR implementation on MAVEN and TGO



Summary

- A number of potential improvements in the capabilities of the Mars Relay Network have been described, offering new capabilities and enhanced performance to meet the challenges of future landed missions in the coming years
  - Split-pass relay capability will enable MRO afternoon support to both InSight and Curiosity, and subsequently to ExoMars Rover and Surface Platform
  - MAVEN aerobraking can offer significant improvement in relay performance for all supported landers/rovers
  - Completion of the LDPC/ADR implementations on MAVEN and TGO will provide additional relay performance improvements for M2020

Jet Propulsion Laboratory
California Institute of Technology