Relay Telecommunications for the Coming Decade of Mars Exploration

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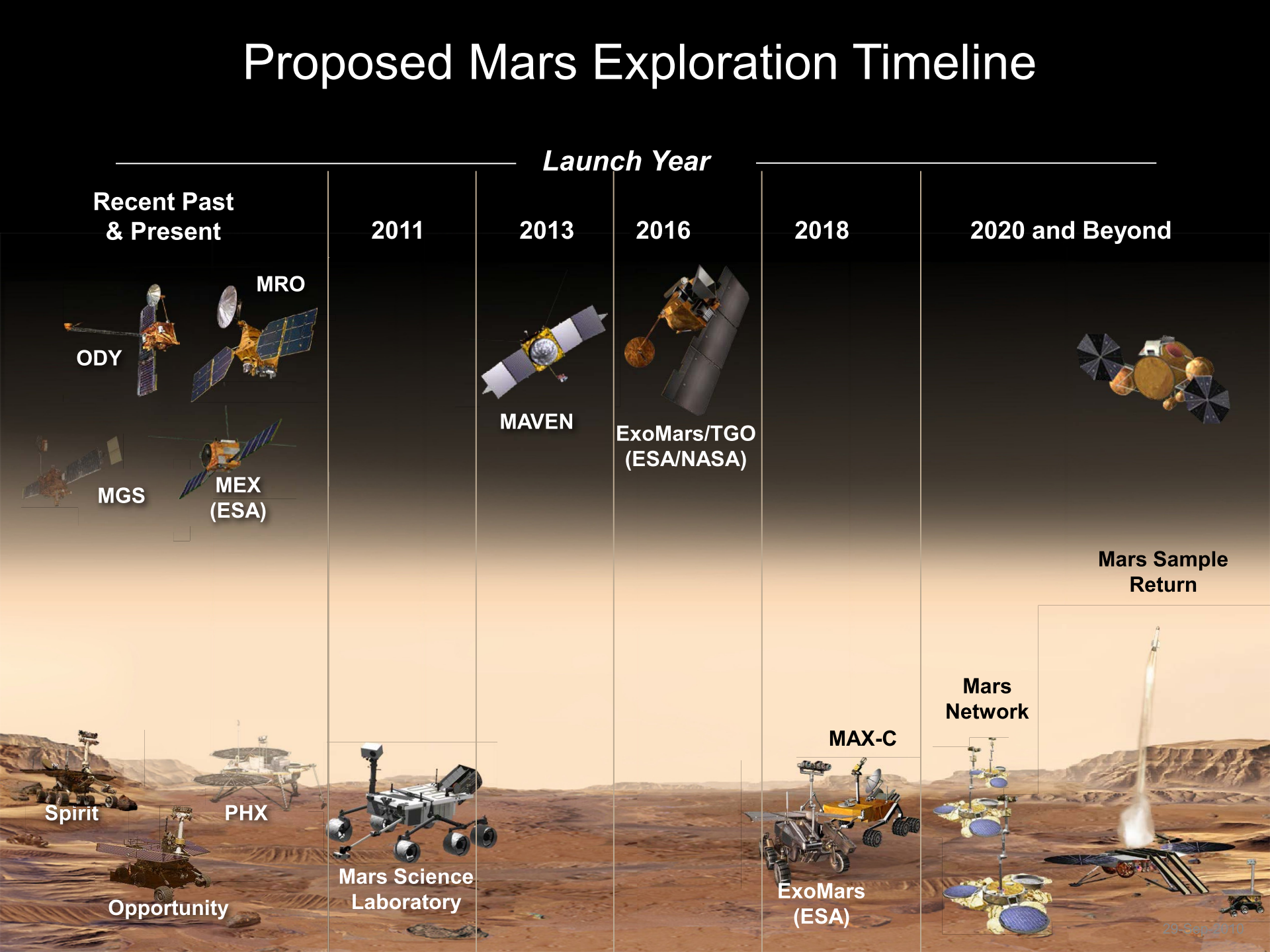
Agenda

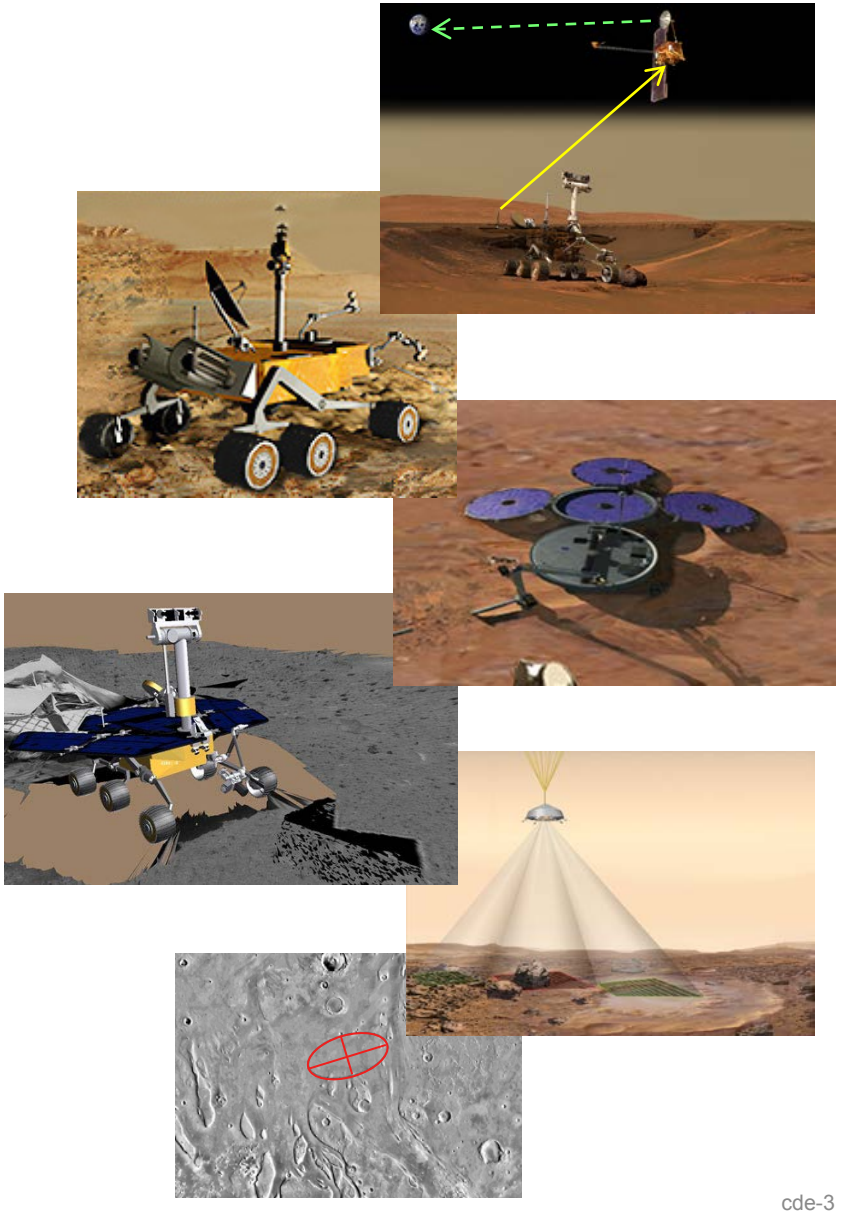
- Mars Exploration Program Overview
- Existing Mars Relay Network
  - Support to Mars Exploration Rovers and Phoenix Lander
- Relay Aspects of Future Missions
  - MSL
  - MAVEN
  - ExoMars/Trace Gas Orbiter
  - MAX-C & ExoMars Rovers
  - Mars Sample Return
- Summary

Proposed Mars Exploration Timeline



Benefits of Mars Relay Orbiters

- Increased data return
  - Significantly increase science return from the Martian surface
- Energy efficiency
  - Enable small, low-cost mission concepts
- Connectivity
  - Support interactive, in situ ops
- Critical event telemetry
  - Capture engineering telemetry during high-risk mission phases
- Radio-based navigation
  - Utilize radio metric observables on comm links for in situ nav



Current Mars Relay Network

Odyssey

Launched 2001

Orbit:
- 400 km sun-synch
- 93º inclination
- ~4 AM asc node

Deep Space Link:
- X-band
- 1.3 m HGA
- 15 W SSPA

Relay Link:
- CE-505 UHF Txcvr
- 8, 32, 128, 256 kbps
- CCSDS Prox-1 Protocol

Mars Express

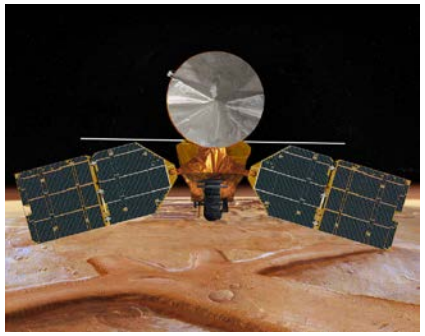
Launched 2003

Orbit:
- 250 x 10,142 elliptical
- 86º inclination
- Non-sun-synch

Deep Space Link:
- X-band
- 1.65 m HGA
- 65W TWTA

Relay Link:
- Melacom UHF Txcvr
- 2, 4, …, 128 kbps
- CCSDS Prox-1 Protocol

MRO



Launched 2005

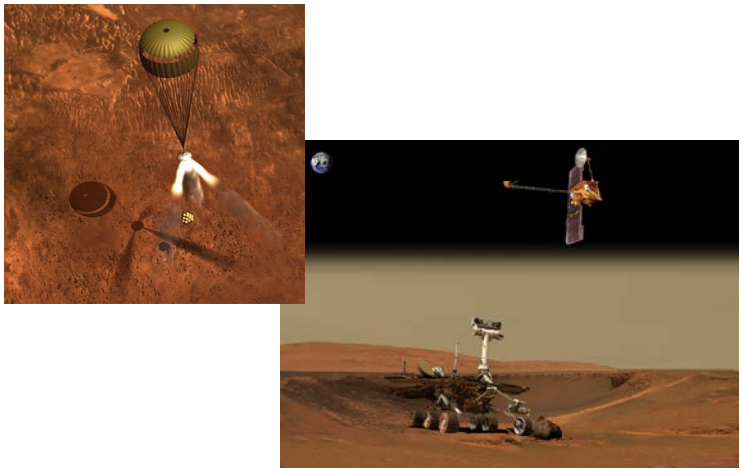
Orbit:
- 255 x 320 km sun-synch
- 93º inclination
- ~3 PM asc node

Deep Space Link:
- X-band
- 3 m HGA
- 100 W TWTA

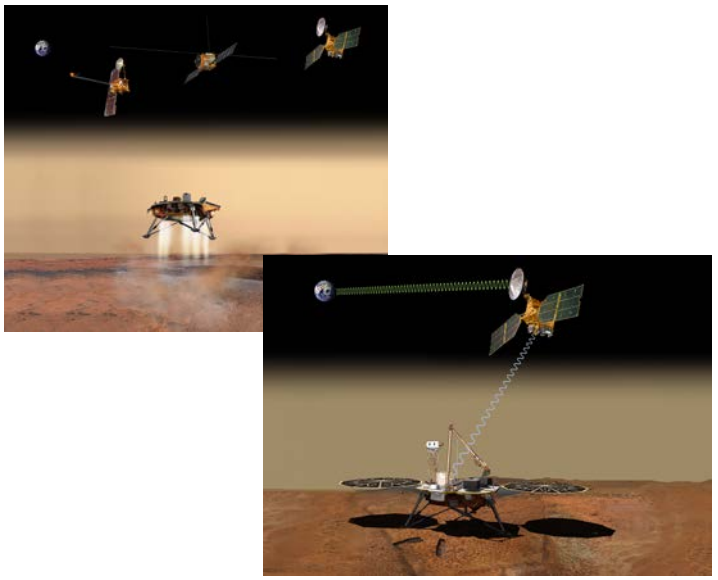
Relay Link:
- Electra UHF Txcvr
- 1, 2, 4, …, 1024 kbps
- CCSDS Prox-1 Protocol

Prior Support to MER and PHX

- Mars Exploration Rovers (Spirit and Opportunity)
  - 98% of all data obtained from Spirit and Opportunity has been returned via UHF relays (ODY, MGS, MRO, MEX)
  - 8 kbps UHF link to MGS during EDL (after parachute deployment)



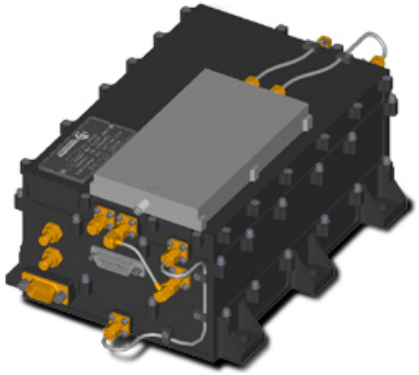
- Phoenix Lander
  - UHF-only, based on MER relay success
  - Saved mass, power, and cost for resource-constrained Scout mission
  - UHF links to MRO, ODY, and MEX (up to 32 kbps) during entire EDL trajectory
  - 861 supported relay passes over 151-sol surface mission, averaging over 250 Mb/sol



Electra Proximity Link Payload

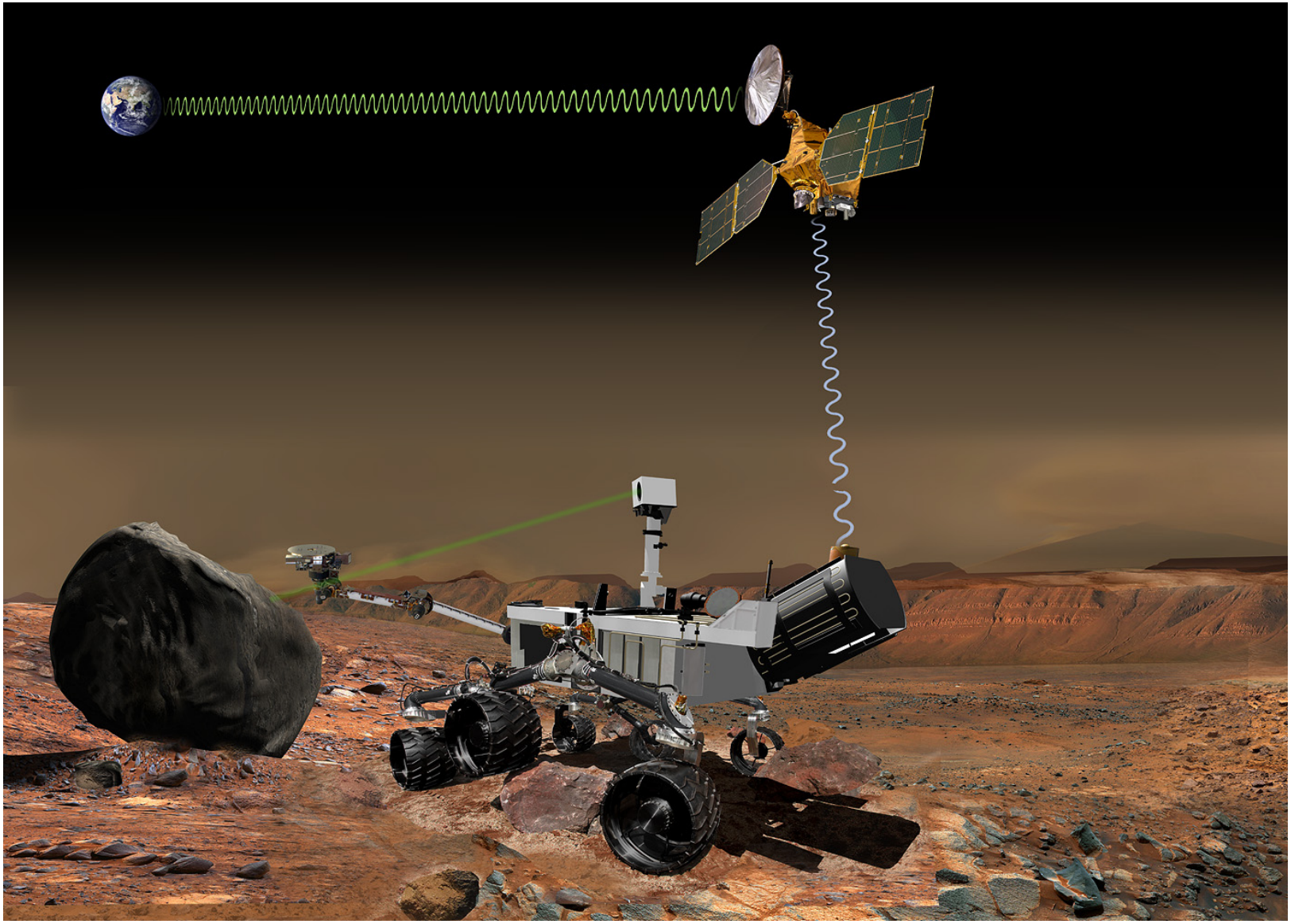
- Electra software-defined radio provides flexible platform for evolving relay capabilities
  - Electra payload onboard Mars Reconnaissance Orbiter
  - Electra-Lite payload in development for Mars Science Laboratory (40% mass/volume reduction for lander applications)
- Key Electra features
  - CCSDS Proximity-1 Link protocol for interoperability and reliable data transfer
  - Frequency-agile operation across UHF band (390-450 MHz)
  - Fully reprogrammable software/firmware functionality
  - Integrated Doppler navigation and timing services

Electra UHF Transceiver



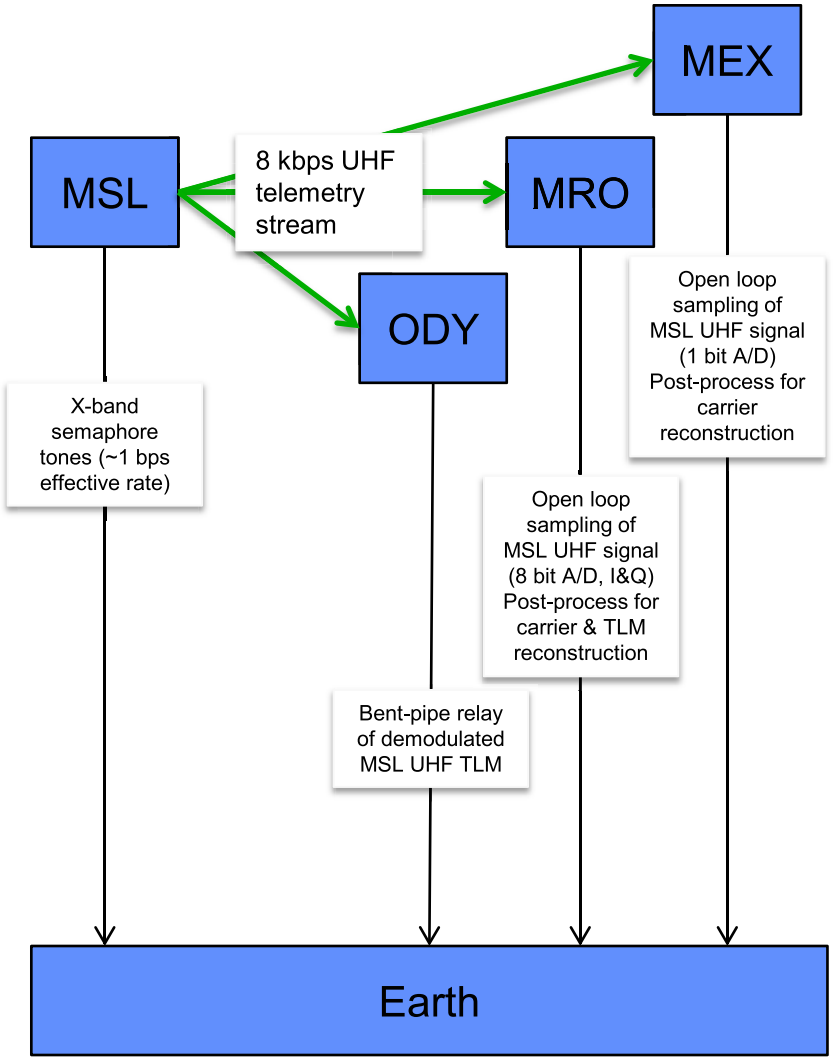
Electra-Lite UHF Transceiver

Mars Science Laboratory 2011



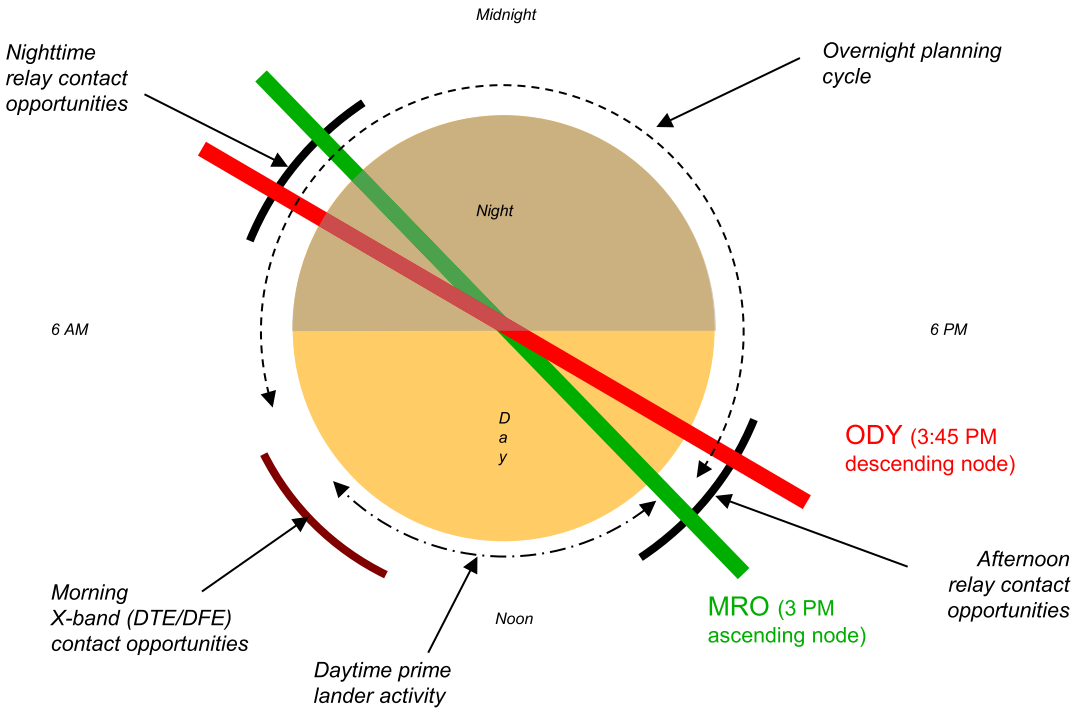
MSL: Critical Event Communications During Entry, Descent, and Landing

- NASA's Mars Exploration Program requires capture of engineering telemetry during critical events sufficient to reconstruct a potential anomaly
- Multiple links available
  - Direct-to-Earth: X-band semaphore tones (MFSK modulation) w/ effective info rate of ~ 1bps
  - UHF: 8 kbps MSL telemetry rate
    - ODY *(low-latency carrier & TLM info)*
    - MRO *(robust signal capture for post-processing to recover carrier & TLM info)*
    - MEX *(post-process to recover carrier info)*
    - UHF signal may experience plasma-induced attenuation during hypersonic phase of EDL
  - Detailed coverage geometry not fully known until final site selection and launch day



MSL: Relay Support During Surface Operations

- MSL will significantly advance Mars relay capabilities
  - MSL-MRO link will fully exploit Electra capabilities
    - Data rates up to 1 Mbps
    - 250 Mb/sol data return spec (5x the MER-ODY spec) is well-matched to high-rate MSL science instrument suite (e.g., equivalent to 30 sec of MastCam HD video)
    - Adaptive Data Rate algorithm provides autonomous control of return link data rate based on actual channel characteristics during each pass
  - X-band pass each Mars AM to deliver commands for that sol
  - Afternoon UHF pass via MRO for bulk sci/eng telemetry return to support next-sol planning
  - Additional ODY and MRO passes to augment science return



Mars Atmosphere and Volatile Evolution (MAVEN) Scout Orbiter

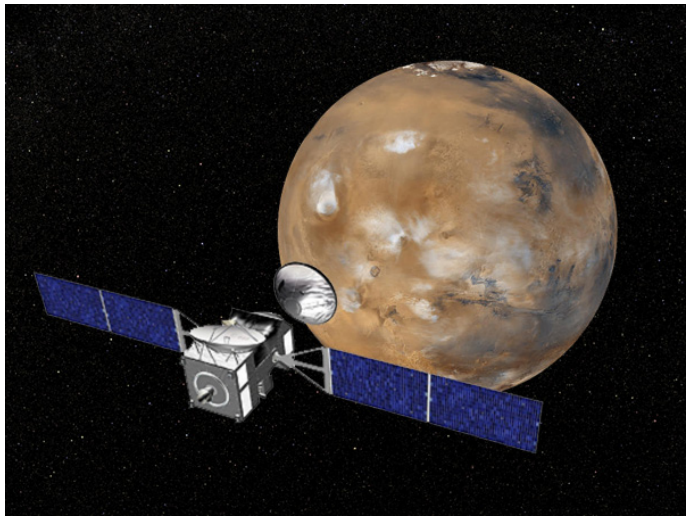
- Second Mars Scout Mission
  - Mars aeronomy orbiter – fulfills a high-priority National Academy of Science objective
  - Aeronomy science objectives drive orbit selection
    - 6200 x 150 km elliptical orbit
    - 4.5 hr period
    - Results in highly variable relay contact statistics
- Will carry an Electra UHF relay payload
  - Provided by Mars Program (outside of Scout cost-cap)
  - Single-string Electra UHF Transceiver
  - Flight Spare MSL UHF Antenna
- Mission overview
  - Launch: Nov 18 – Dec 7, 2013
  - MOI: Sep 16 – Sep 24, 2014
  - Primary Science Mission: 1 Earth year
  - Extended mission: Preliminary propellant lifetime analysis indicates potential for extended science and relay operations through 2023
- Relay operations
  - Body fixed HGA and science attitude strategy implies link to Earth is not typically available
  - Will need to schedule DSN contacts immediately before and after a relay pass to support end-to-end flow of forward and return link products
  - During the relay pass, MAVEN will roll to point the UHF antenna boresight towards the relay user asset

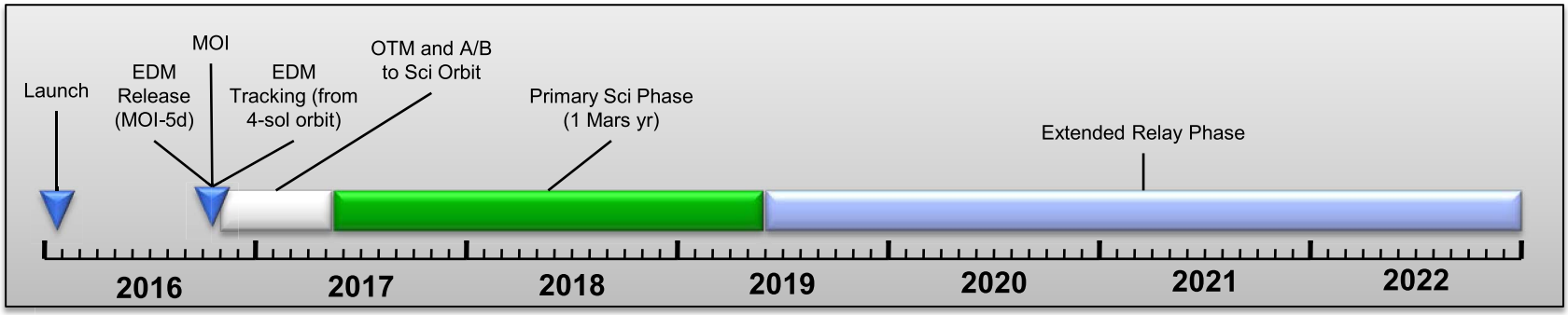
Key Orbit Parameters	
Apoapsis Altitude	6200 km
Periapsis Altitude*	150 km
Eccentricity	0.46
Inclination	75 deg
Orbit Period (hrs)	4.5 hrs

**Periapsis altitude is controlled to fly at a fixed atmopsheric density; five "deep dip" campaigns are planned during the primary science phase, lowering periapsis to roughly 125 km; periapsis altitude would be raised sometime during the extended mission phase to achieve long propellant lifetime*

ExoMars/Trace Gas Orbiter

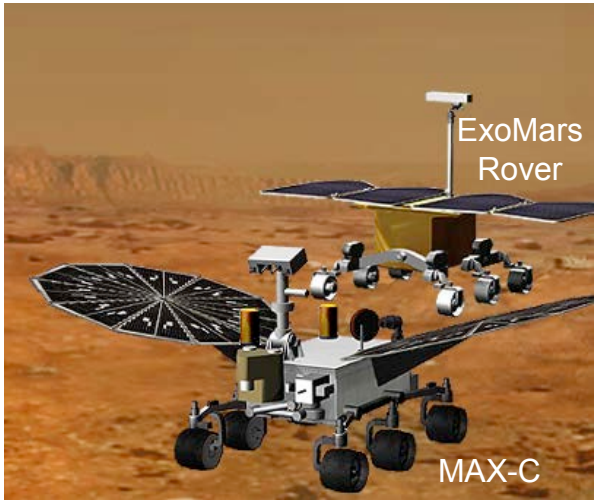
- Mission Overview
  - Joint ESA-NASA mission
  - Science orbiter focused on measurement of trace gases in Martian atmopshere
  - Key ESA contributions:
    - Orbiter bus
    - EDL Demonstrator Module
    - Science instrument (1)
  - Key NASA contributions
    - Launch vehicle
    - Science instruments (4)
    - Electra UHF Relay Payload (dual-string redundant)
  - Science Orbit
    - 400 km circular orbit (non-sun-sync)
    - 74 deg inclination





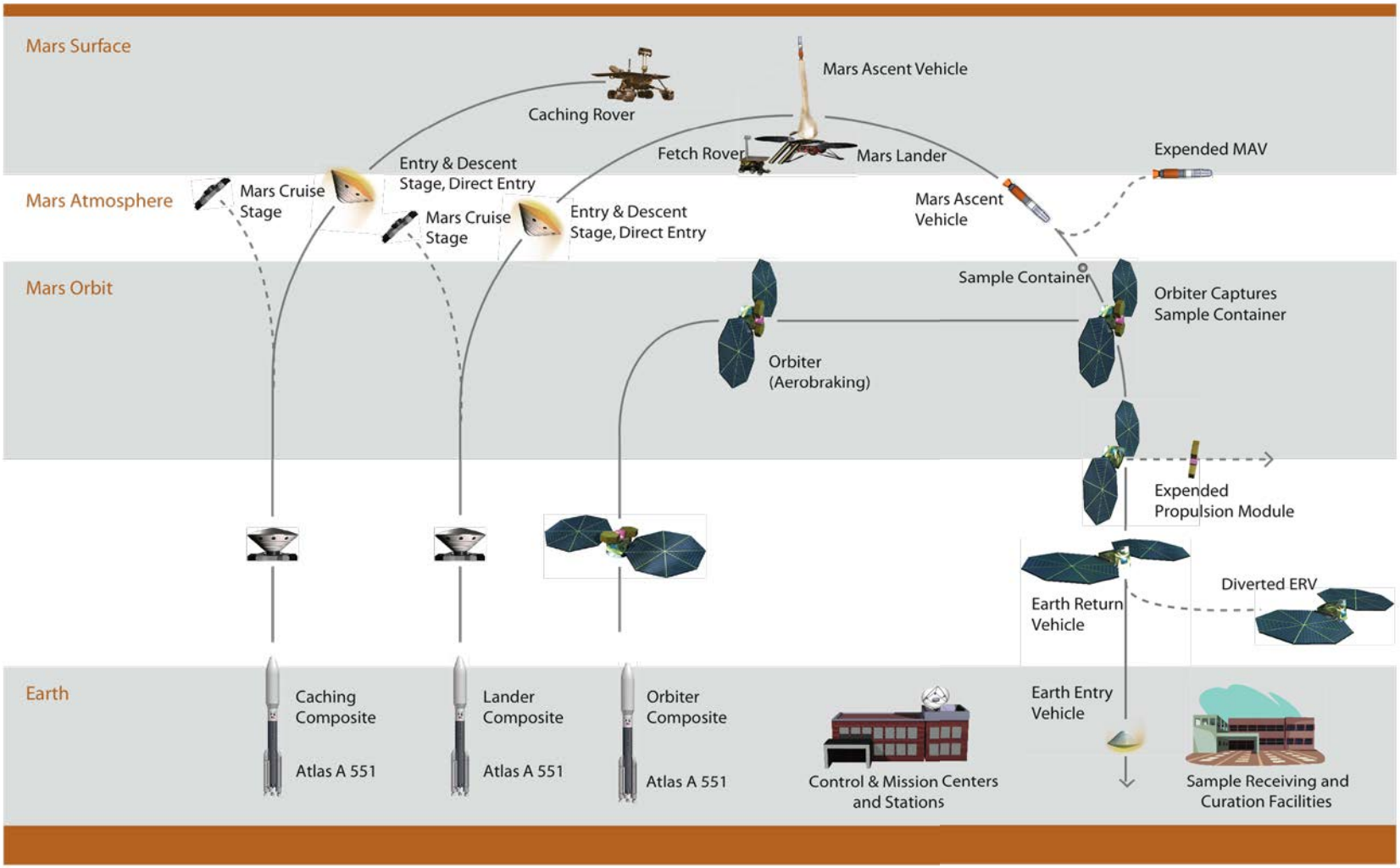
MAX-C/ExoMars Rovers

- Mission Overview
  - Joint NASA-ESA mission
  - MSL-heritage “skycrane” EDL system with two rovers in Aeroshell
    - NASA Mars Astrobiology Explorer – Cacher (MAX-C)
    - ESA ExoMars Rover
- Mission Timeline
  - Launch: May 2018
  - EDL: Jan 2019
- Collocated rovers introduce new relay scenarios
  - Multiple access options to allow both rovers to receive relay service during a single overflight
    - TDMA (baseline)
    - FDMA
    - CDMA
  - Rover-to-rover UHF link?
    - Could allow ESA to deliver EXM commands on X-band link to MAX-C, which would then relay them to EXM via UHF cross-link
    - Could support collaborative rover science activiies



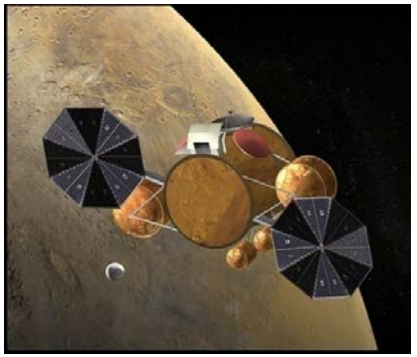
	MAX-C	EXM
Primary surface mission duration	1 Earth year	180 sols
Communications Capability	X-band DTE UHF Relay	UHF Relay
Returned Data Volume Requirement	250 Mb/sol	150 Mb/sol

Mars Sample Return Mission Overview



Mars Sample Return
Communication and Tracking Aspects

- EDL critical event communications
- Relay support for surface operations
  - Lander
  - Fetch rover
  - Mars Ascent Vehicle (MAV) on lander
  - Caching rover (potentially still operational)
- MAV launch
  - Critical event telemetry
  - Doppler tracking for trajectory reconstruction
- Orbiting Sample Canister (OSC) detection
  - RF detection being considered as option in addition to passive optical detection



Backup

Mars Relay Timeline