NASA Space Communication and Navigation Program

Deep Space Relay Terminals for Mars Superior Conjunction

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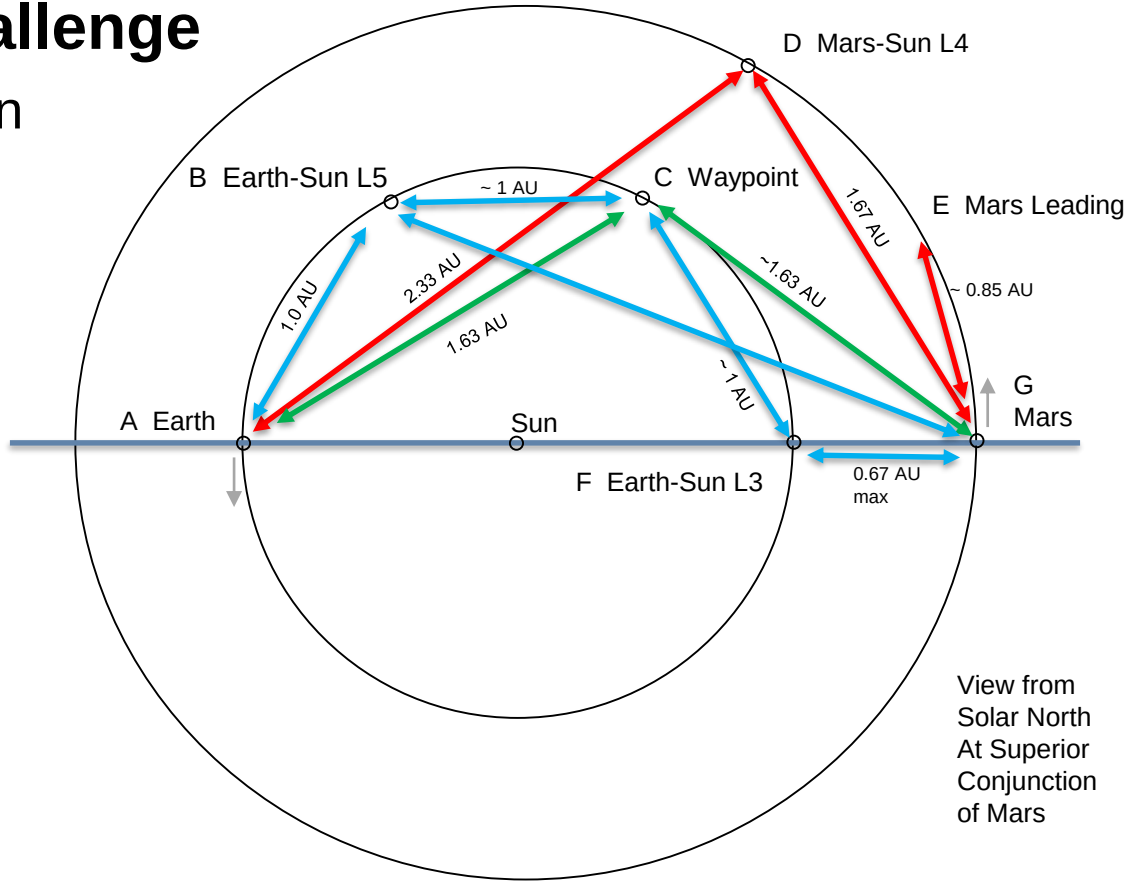
A Communication Challenge

Mars at Superior Conjunction

- Sun periodically obscures Mars
- How provide continuous communication?
  - X-band? Ka-Band?
  - Optical?
  - Which location(s)/route?
  - What size of terminals?



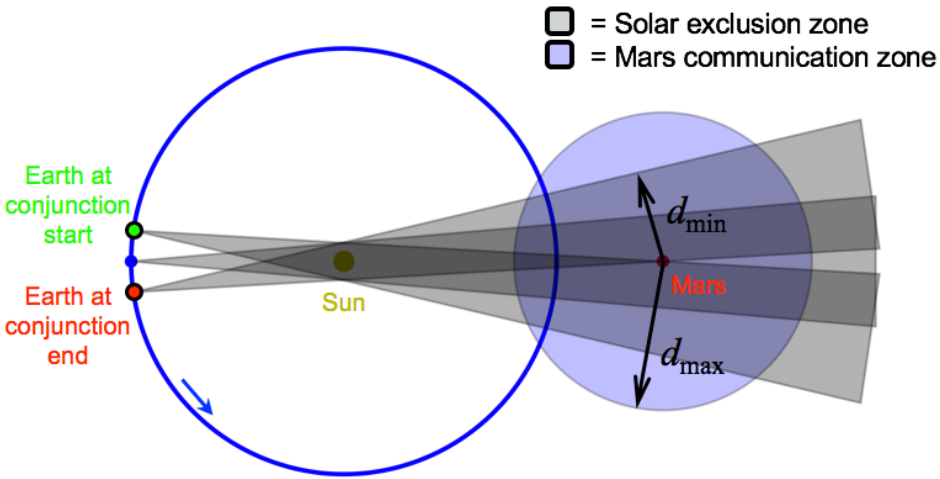
Notional Communication Terminal Characteristics

- At Mars
  - Areostationary Orbiter
  - Ka-band, 940 W 32 GHz Transmitter, 6-meter dish
  - Optical, 1550 nm 3x15 W Lasers, 50 cm aperture
- Deep Space Relay Terminal
  - Ka-band, 34.3 GHz 94 W Transmitter, 75 cm dish
  - Optical, 1064 nm 15 W Laser, 50 cm aperture, Avalanche Photo Diode or Superconducting Nanowire array detector (with cryocooler)
- Earth Terminal
  - 8-meter RF-optical hybrid within 34-meter Antenna, 15 kW 1064 nm transmitter, multi-beam

Pre-Decisional Information -- For Planning and Discussion Purposes Only

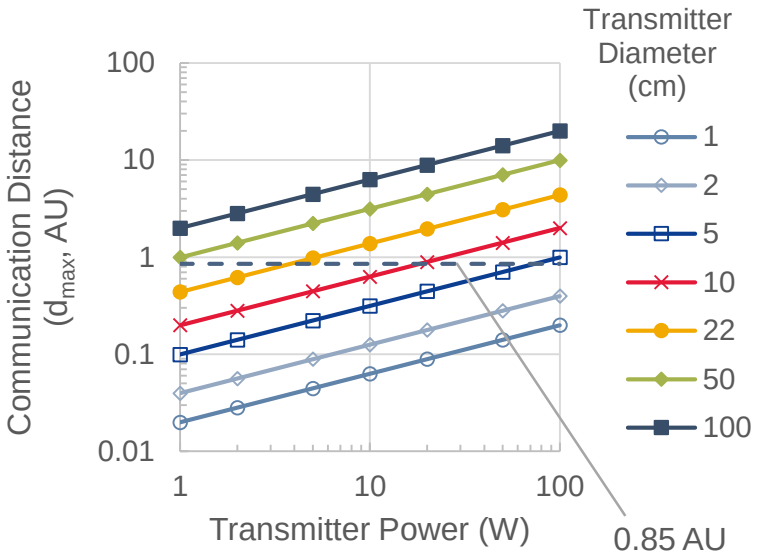
Communication Constraints

- Potential Relay Positions
  - Sun-Earth Lagrange Points
  - Temporary Waypoints
  - Sun-Mars Lagrange Points
  - Mars Leading/Trailing Orbits
  - …and many others, total of 38 families
  - Excluded Multi-Hop Solutions (may still be useful in long run)
- Solar Exclusion Zone
  - For optical, need ~10 degrees Sun-Earth-Probe angle
    - For entire duration of conjunction: d_{min} = 0.85 AU
  - For RF, need ~1.2 degrees at Ka-band



Communication Constraints (cont'd)

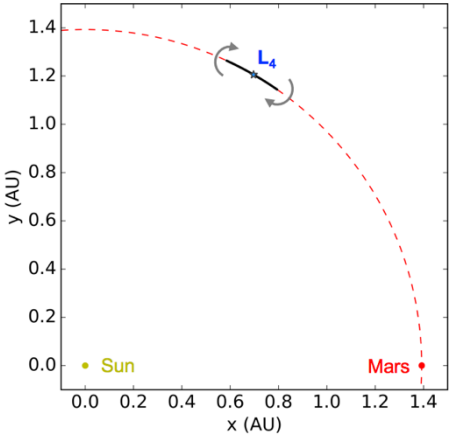
- Beacon Illumination Intensity
  - Beacon assists terminals with acquisition, and spacecraft attitude disturbances
  - Current architecture needs ~4 picowatt / m^2
  - Sets maximum distance for a given aperture and power
    - Greater than 22 cm/10W needed for 0.85 AU



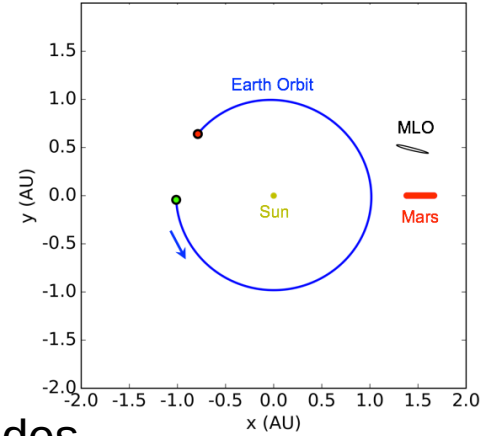
- Data rate balance
  - Data rate in/out of relay must balance in the long run, implies 2x optical system, 2x radio system

Relay Orbit Selection

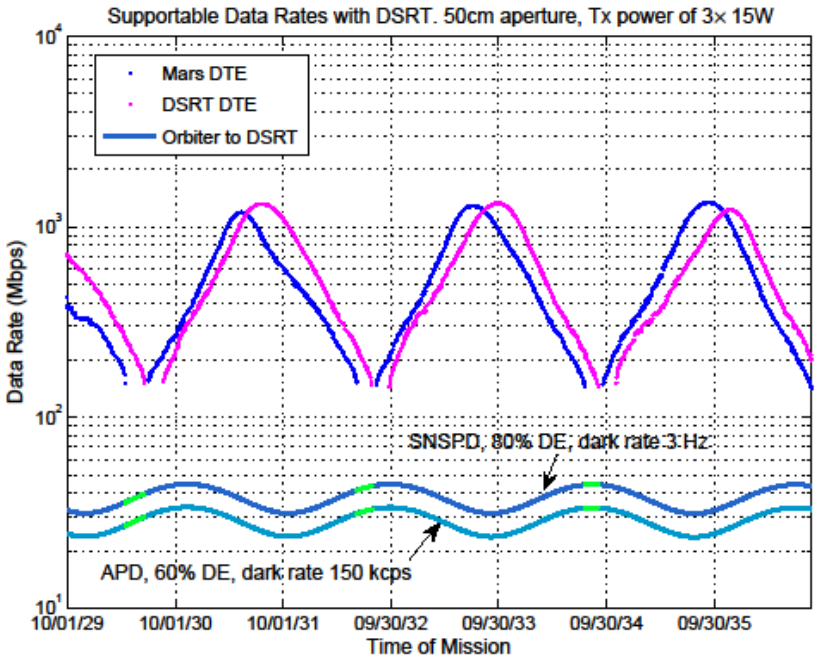
- Orbit should:
  - Extend beyond solar exclusion zone
  - Enter visible zone
  - Remain visible for extended period
  - Either remain in visible zone permanently, or re-enter synodically
    - Placement of multiple relay spacecraft over time could provide a long-term solution if this constraint was not met
- Only the Mars-Sun L4 “Mars Leading Orbit (MLO)” and L5 long-period “Mars Trailing Orbit (MTO)” (Trojan) orbits satisfied all constraints
  - Remain within the visible communication zone for decades



Sample L4 long-period orbit in sun-Mars rotating frame



Optical Communication Performance



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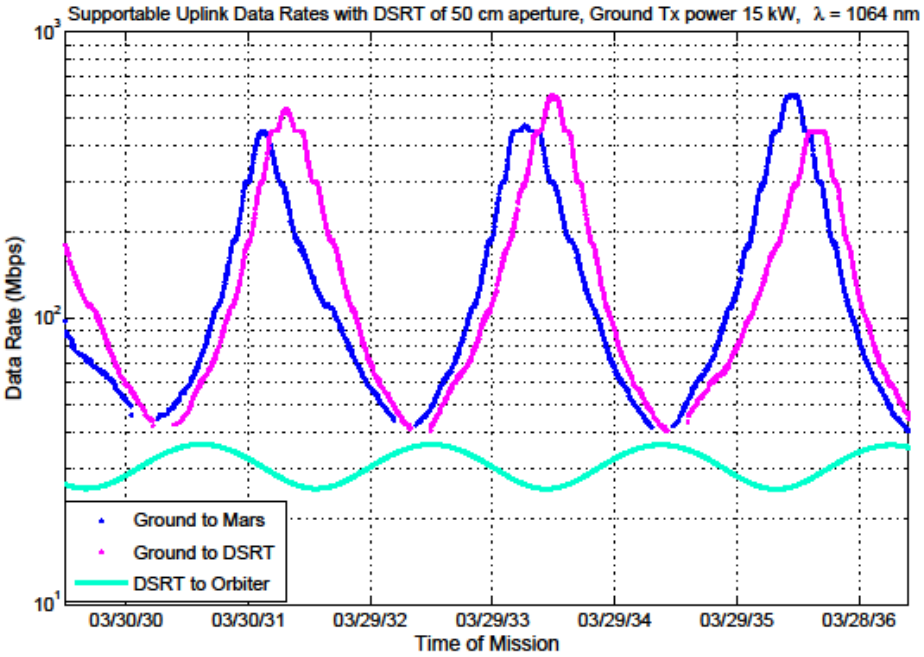
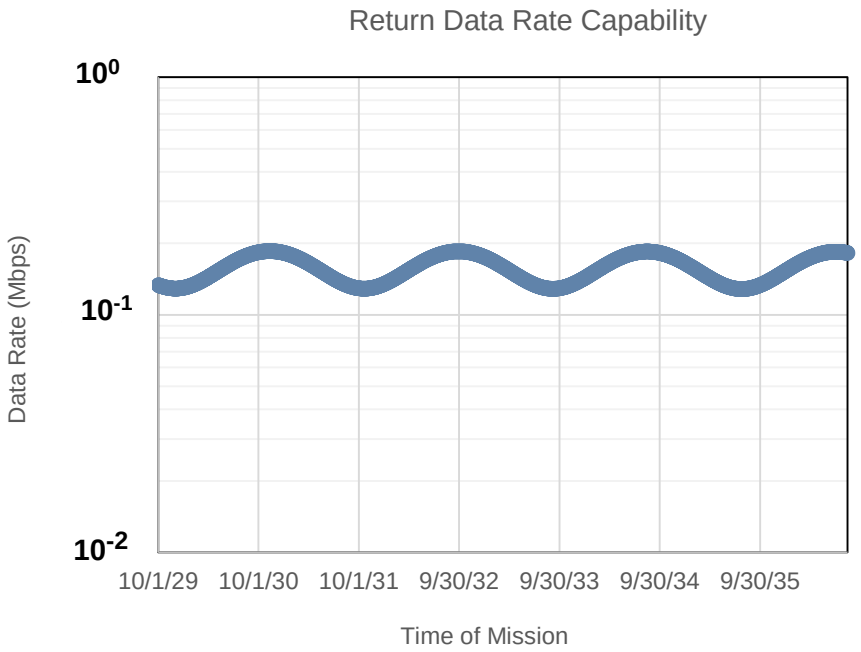


Forward

Ka-Band Communication Performance



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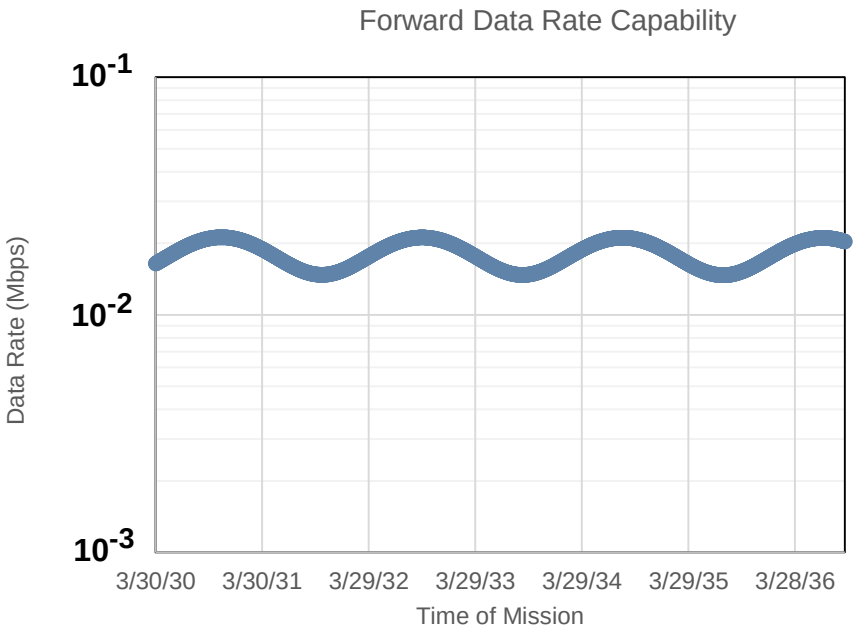

Forward

Summary

- A deep space relay terminal placed in an appropriate MLO or MTO, with
  - Two 50 cm optical telescopes, lasers, transceivers
  - Two 75 cm Ka-band dish antennas, transceivers
- Can support Mars superior conjunctions with
  - Optical data rate: 28 to 44 Mbps return, 30-36 Mbps forward
  - Ka-band data rate: 127 to 185 kbps return, 14 to 21 kbps forward
- The optical relay would need efficient, low-noise optical detectors, e.g. appropriately cooled Avalanche Photo Diode or Superconducting Nanowire Single Photon Detectors

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