7.3 Communications & Navigation

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- In this Capability Road Map (CRM) #7, Communications & Navigation is being considered during Aerocapture, Entry, Descent & Landing (AEDL) only in order to precisely position, track and interact with the spacecraft at its destination (moon, Mars & Earth return) arrival.

Benefits of Comm. & Nav.

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The space communication and navigation capability will fully enable AEDL.

- connectivity to exploration vehicles
- spacecraft position
- transferring mission data
- vehicle telemetry
- voice and commands

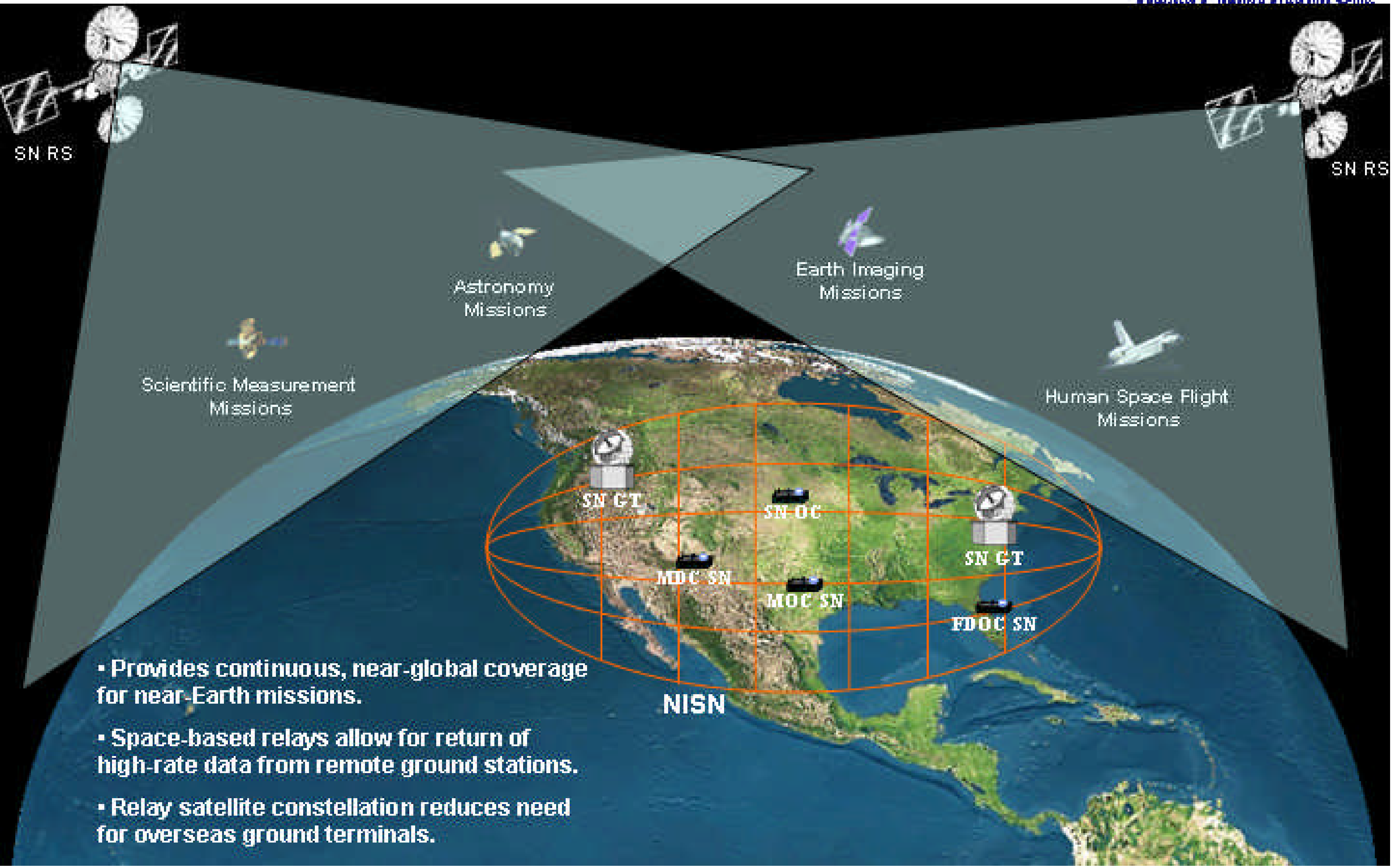
Current State of the Art

- **Today NASA Operates Three Communication Networks**
  - **Space Network (SN): A system of Earth relay satellites covering low Earth orbit**
  - **Deep Space Network (DSN): Three global installations with large aperture antennas for communicating with missions operating in Deep Space**
  - **Ground Network (GN): A network of Earth-based ground communications stations primarily used for communicating with satellites in Earth orbit**
- **SN, DSN, and GN have evolved to support NASA's Current Science and Human Space Flight Mission Model**
- **The Future Exploration and Science Mission Set will Require New Communication Capabilities**

Deep Space Network Today

- Supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe.
- Supports selected Earth-orbiting missions (e.g., high Earth orbiting satellites).
- Provides emergency support

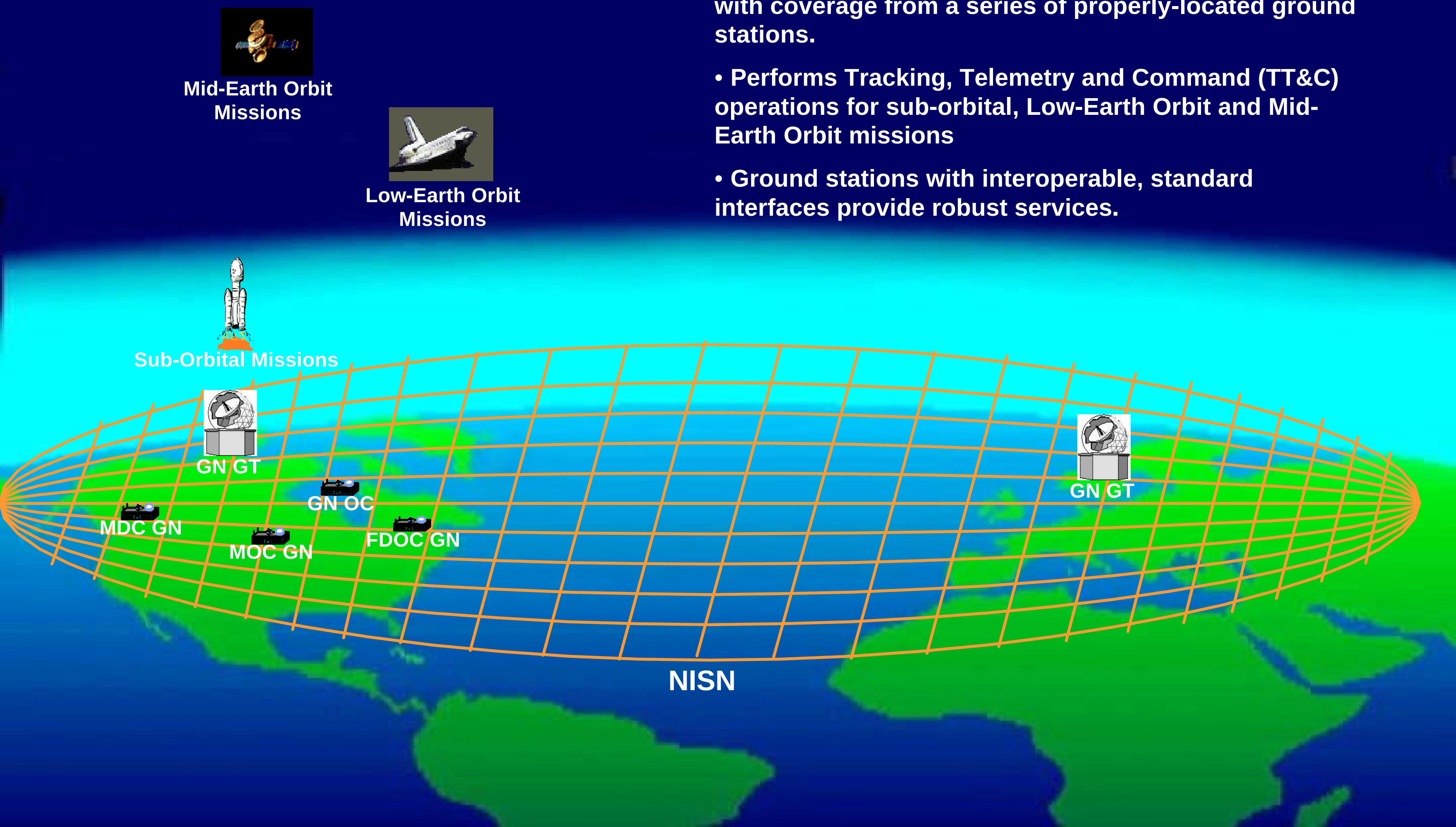
Space Network Today



- Provides continuous, near-global coverage for near-Earth missions.
- Space-based relays allow for return of high-rate data from remote ground stations.
- Relay satellite constellation reduces need for overseas ground terminals.

Ground Network Today

- Supports Launch and Early Orbit (L&EO) operations with coverage from a series of properly-located ground stations.
- Performs Tracking, Telemetry and Command (TT&C) operations for sub-orbital, Low-Earth Orbit and Mid-Earth Orbit missions
- Ground stations with interoperable, standard interfaces provide robust services.



Current State-of-the-Art for Communication Capability

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- **Current Earth-based Network:**
  - Communication and tracking services are available for Earth orbiting satellites in any orbit.
    - Up to 300 Mbps in Ku-band for low Earth orbiters
    - Support for TT&C services in any Earth orbit in S-band
    - Ground-based antennas provide communication with satellites in S-, X-, and Ka-bands
  - Communication support is available for launch phase of space flight as well as for communication support for re-entry and landing of vehicles.
    - Example: Space Network currently provides telemetry support to launch vehicles such as Sea-launch during powered flight
    - Example: Space Network provides communication support with Space Shuttle during re-entry including communication through plasma period.
  - Communication support for deep space missions including connections with Mars network orbiting relays and surface robots.

Current State-of-the-Art for AEDL Communication Capability

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- <u>**Current Lunar network:**</u>
  - Earth-based DSN antennas can currently provide S-band and X-band coverage of the near side of the moon.
  - <u>No capability is in place that allows communication to the back side of the moon</u>

- <u>**Current Mars Network:**</u>
  - EDL communication via direct-to-Earth long haul X (or Ka) Band to the Deep Space Network.
    - < 0.5 bps during EDL plus signal carrier dynamics
  - EDL UHF communication via relay services to one or more of the three Mars orbiters:
    - NASA Relay orbiters: Odyssey, Mars Global Surveyor
    - ESA Relay orbiter: Mars Express
    - 8 k bps during EDL but no data during plasma outage.
  - International use is enabled by common frequency / communication protocols.
  - The orbiters forward for proximity communications with AEDL assets via long haul X-band data relay back to Earth.

Existing Communication Capability Not Adequate for Future Exploration Program

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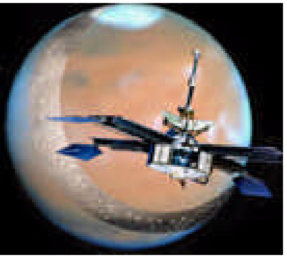
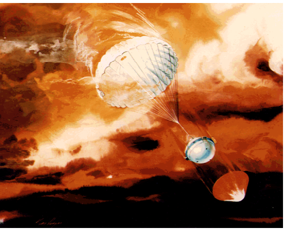
- Moon:
  - No lunar backside capability
  - Limited lunar pole coverage
- Mars:
  - Limited Mars comm data rates and numbers of connections
  - Limited surface coverage
- Possible to include international spacecraft via common (CCSDS) standards for spectrum, protocol, network for Moon & Mars
- Limited precision lunar and Mars navigation capability
- Space-based range capability does not meet rigor required by DoD/NASA concept
- Existing Earth-based relay (TDRSS) will suffer attrition over next few years if not replenished
- Large aperture DSN antennas (26m, 70m, 34m) aging & must be maintained / replaced over next few years

Why is Change Needed?

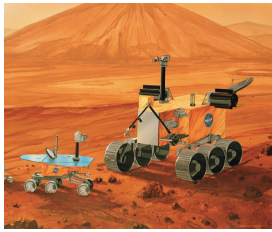
- **MRO will obtain high resolution images of only about 1% of Mars surface**
  - **This data rate limitation unnecessarily constrains the ability to understand the planet**
- **Future missions desire to do similar remote sensing as now done for the Earth**



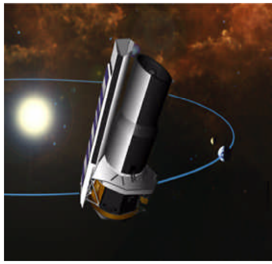
Preliminary solar system reconnaissance via brief flybys. → Detailed Orbital Remote Sensing. (e.g., MRO, JIMO)

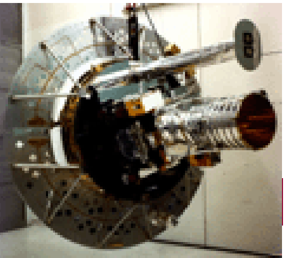


In situ exploration via short-lived probes. → *In situ* exploration via long-lived mobile elements. (e.g., MER, MSL)

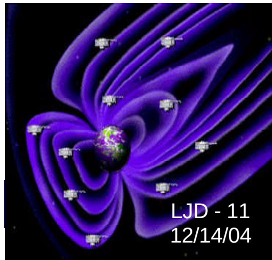


Low-Earth-orbit solar and astrophysical observatories. → Observatories located farther from Earth. (e.g., SIRTF, JWST)

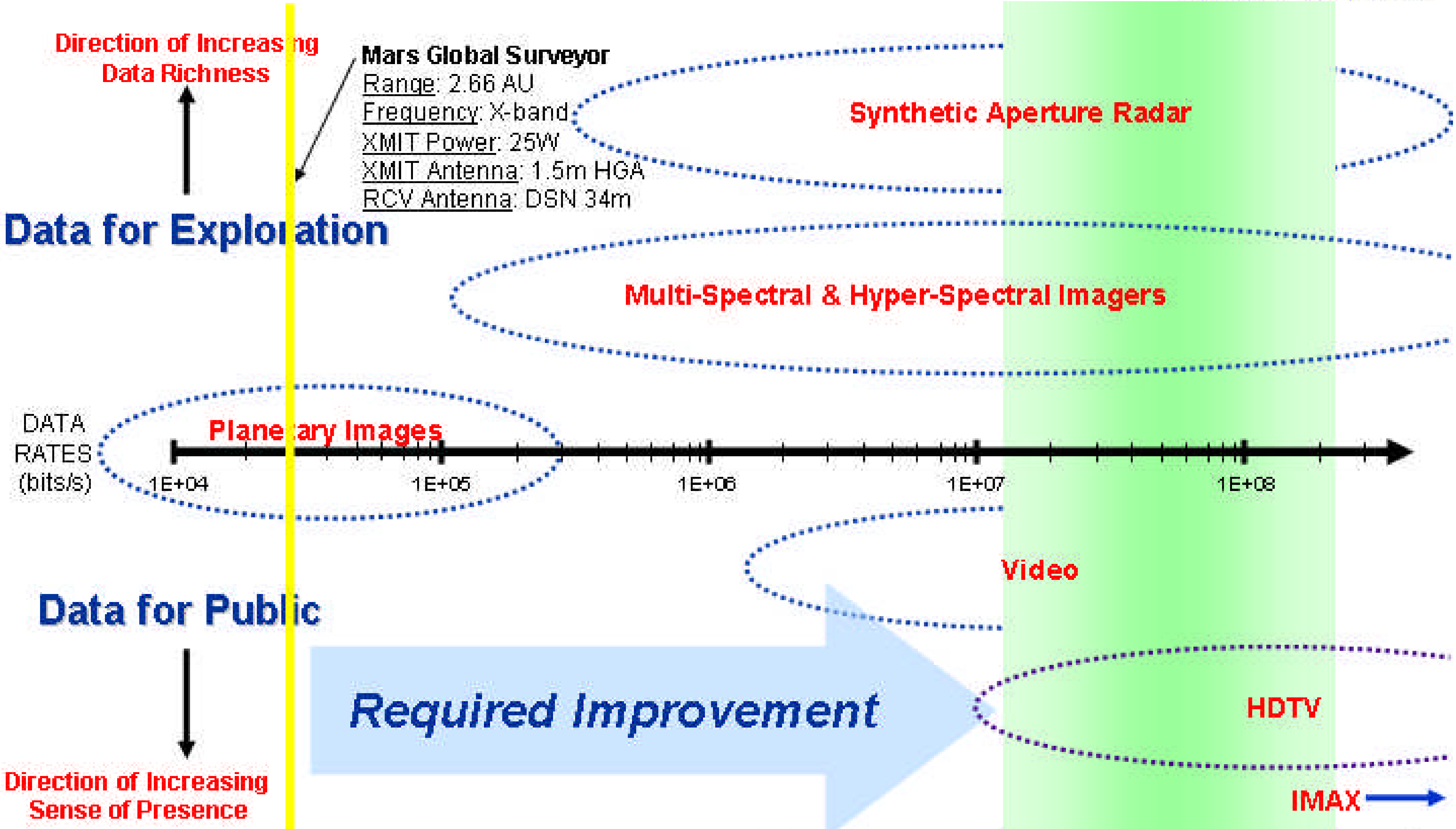




Single, large spacecraft for solar and astrophysical observations. → Constellations of small, low-cost spacecraft. (e.g., MMS, MagCon)



Doing Similar Remote Sensing at Other Planets as We do Today at Earth



The Challenge: Capabilities are needed in deep space communication that will accommodate orders-of-magnitude increase in science data and at least a doubling of the number of supported spacecraft over the next 30 years

- The present DSN architecture is not extensible to meet future needs in a reliable and cost-effective manner
- NASA must develop a comprehensive strategy for deep space communications that meets the forthcoming dramatic increase in mission needs in a reliable and cost effective manner
  - Optical communication, which will take at least another decade to mature and two to be operational, has development risk and may not be appropriate for all missions or mission phases
  - Radio communication will remain the backbone of deep space communications at least the next two decades

The Current DSN Will Not Meet Future Needs

- Even the largest DSN antennas (70m) do not come close to meeting the needs of NASA's future mission set
- Maintenance of the 40-year-old 70m antennas is very expensive (continual software/hardware patches; parts difficult to obtain)
  - NRAO shut down its 25-year-old 43m telescope due to high O&M costs
- A solution is needed soon since old antennas can be prone to catastrophic failure (i.e, metal fatigue)
  - When the large DSN antennas were built, they were 64m in diameter and had a 30% duty cycle
  - After Voyager passed Saturn, the 64m were remade into 70m: added 1M pounds/70m antenna and now have an 80% duty cycle.

NRAO's 30-year old 90m Antenna in its Ultimately Relaxed State:
Higher duty cycle → Metal fatigue

Assumed Requirements (cont'd)

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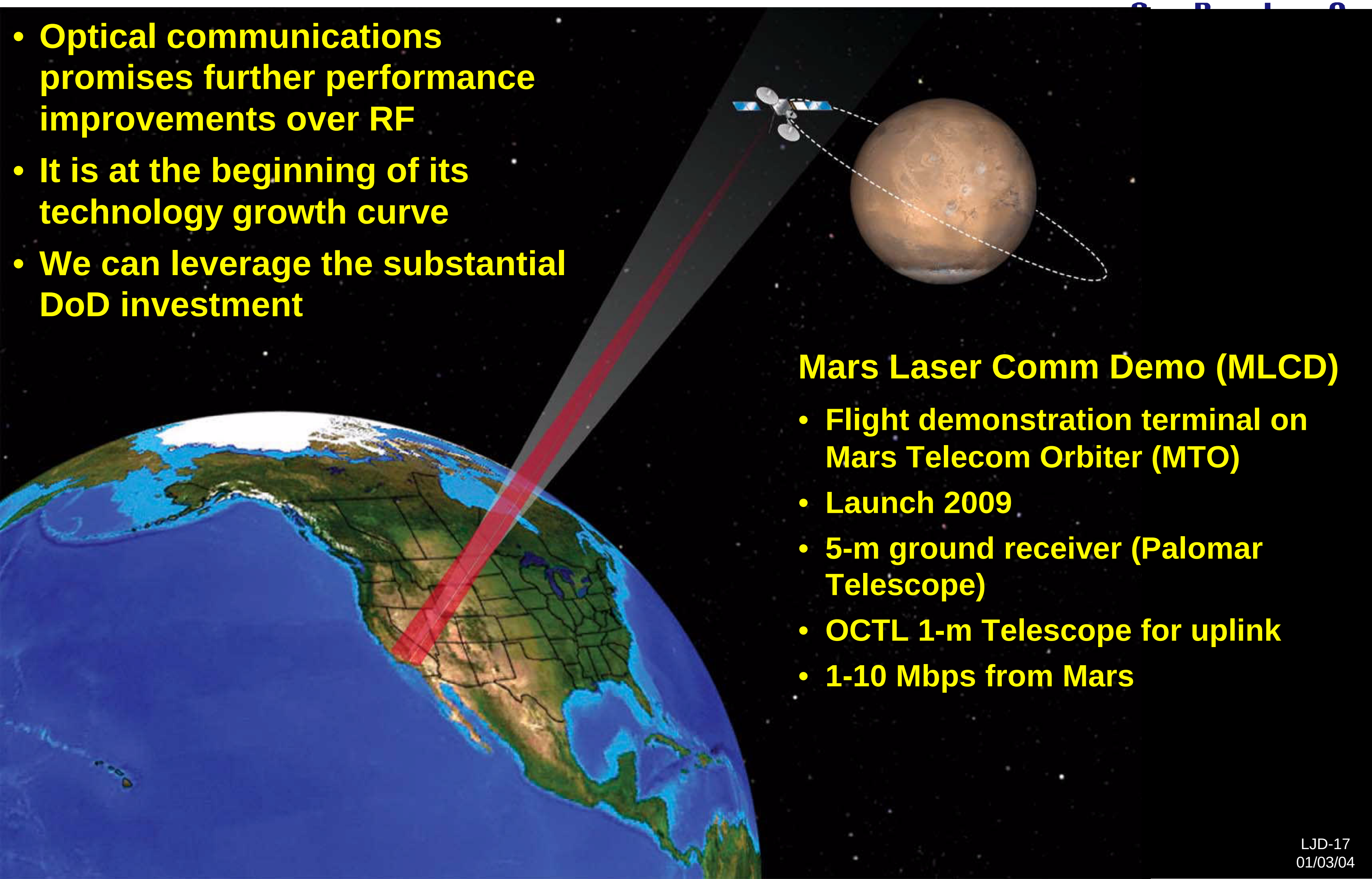
- Human missions to the Moon
  - Continuous communication capability for vehicles and crew
  - Communications for critical flight events over the backside of the Moon
  - Human surface operations on the back side of the Moon South Pole region requiring voice and data transport services between elements as well as to and from Earth

- Human missions to Mars
  - Continuous connectivity supporting Human missions
  - Communication supporting operations on the Martian surface including communication between units on the surface and connections to and from Earth
  - Connectivity to vehicles during critical events
  - Connectivity to vehicles and probes on the Martian surface
  - High data rate instruments operating on the Martian surface and in orbit around Mars

Assumed Data Rate Scenario

- Data rates are major drivers
- Must be developed from assumed activities at destinations
- Developed set of characteristic data rates for typical data types (i.e. HDTV, Hyper-spectral imaging, Audio, etc)
- Apply data rates to activities
- Provides threshold data rates

Optical Communications

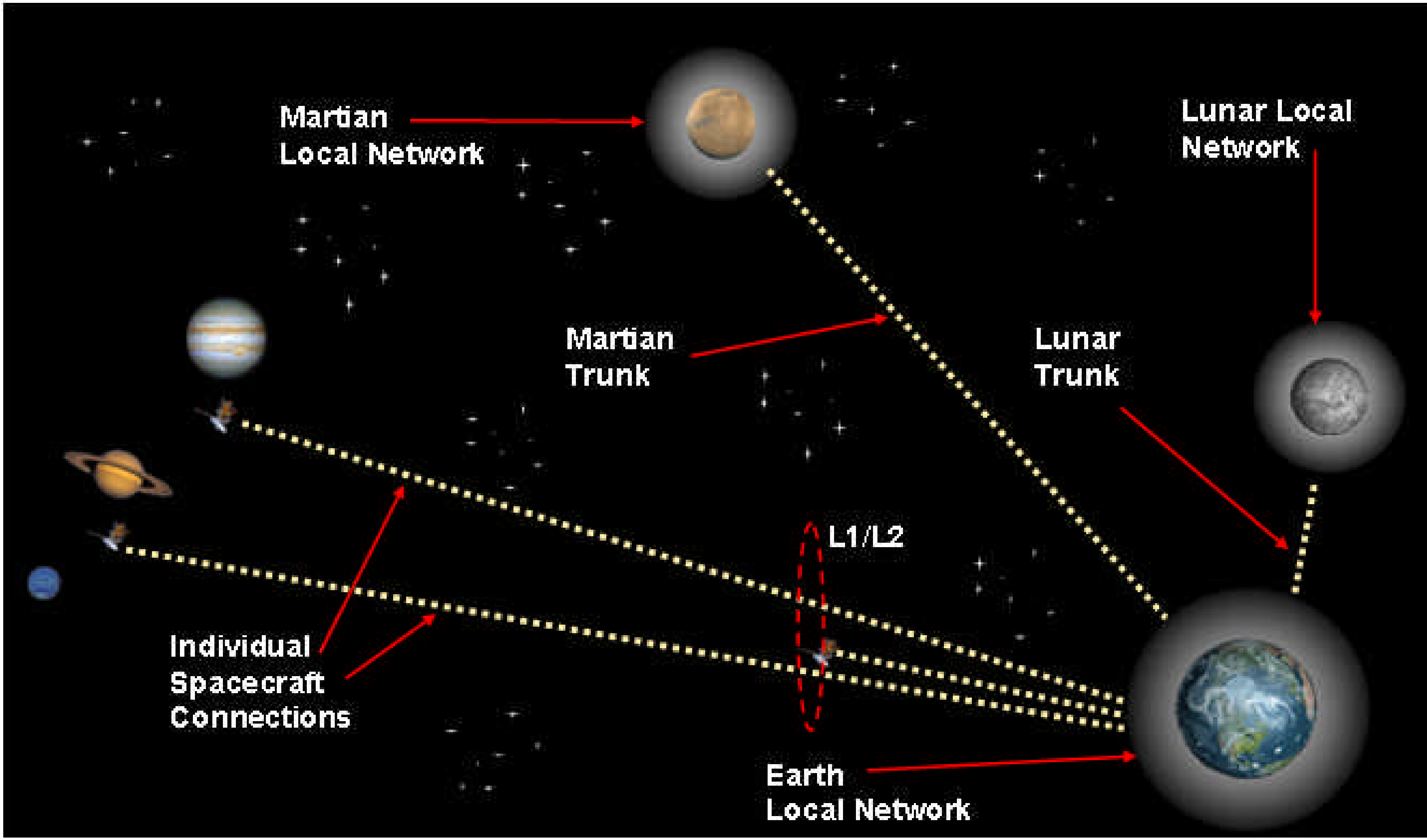


- Optical communications promises further performance improvements over RF
- It is at the beginning of its technology growth curve
- We can leverage the substantial DoD investment

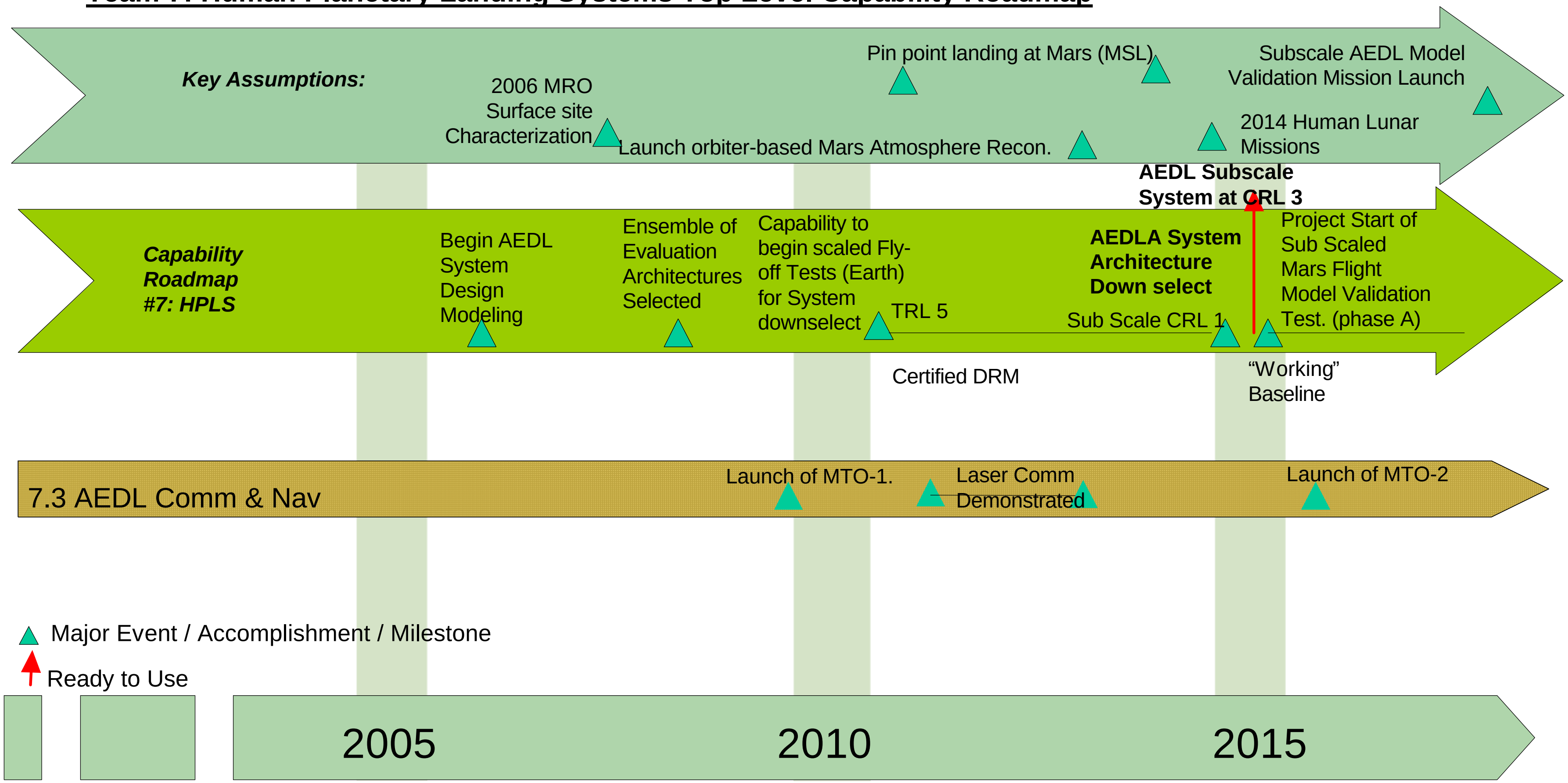
Mars Laser Comm Demo (MLCD)

- Flight demonstration terminal on Mars Telecom Orbiter (MTO)
- Launch 2009
- 5-m ground receiver (Palomar Telescope)
- OCTL 1-m Telescope for uplink
- 1-10 Mbps from Mars

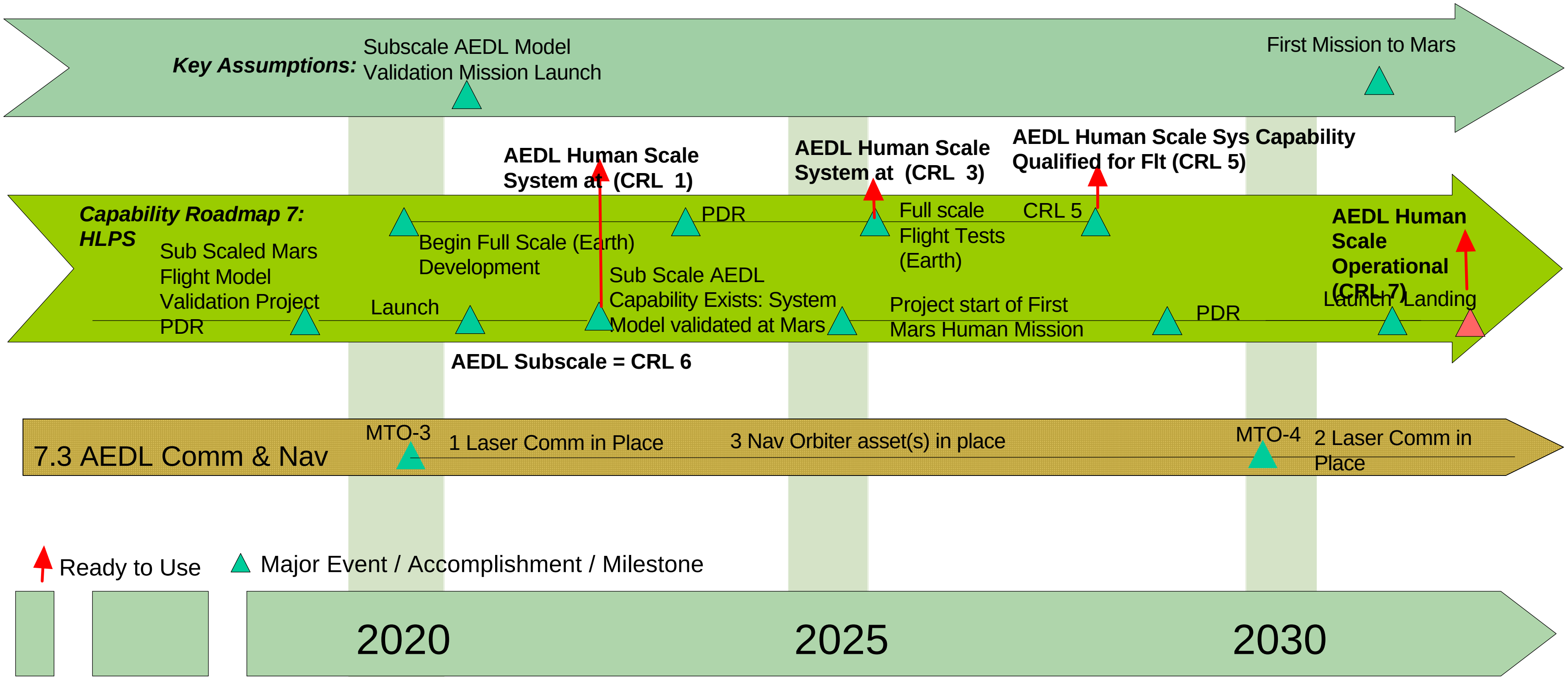
Top Level Communication Architecture ~2030



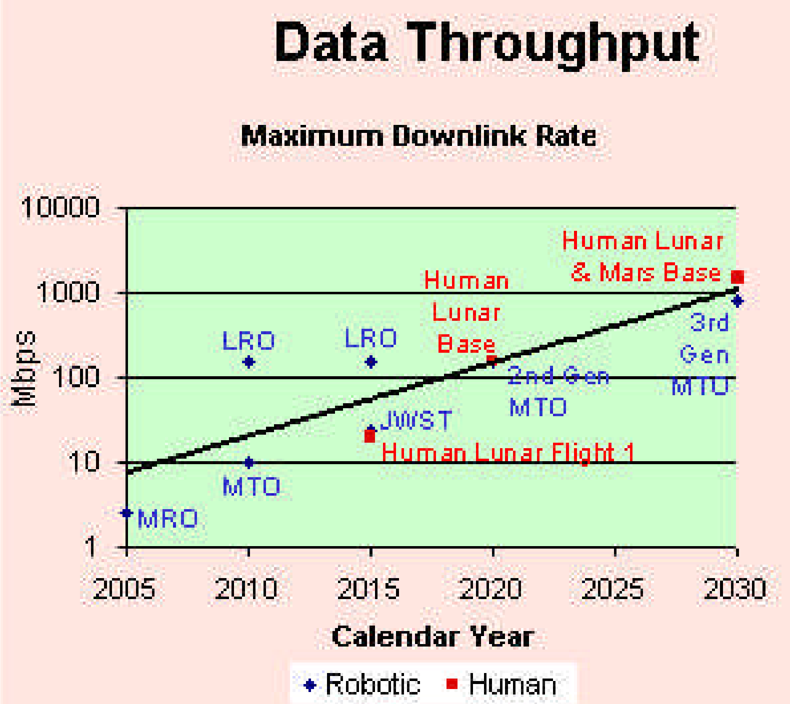
Team 7: Human Planetary Landing Systems Top Level Capability Roadmap



Team 7: Human Planetary Landing Systems Top Level Capability Roadmap

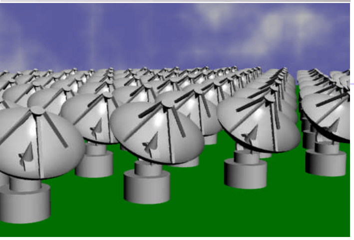


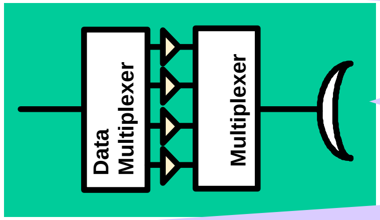
Data Readiness

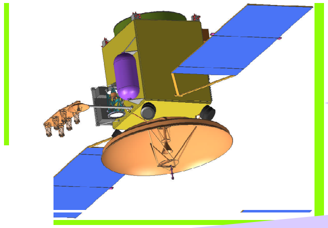


- **Mars robotic and lunar human missions drive maximum data rates up by almost 3 orders of magnitude over next 25 years – probably an underestimate.**

Some Key Technology Areas







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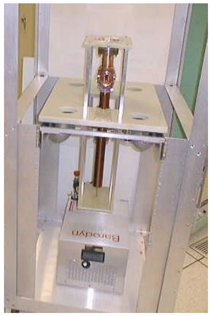

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- Ka-band communications
  - 4x performance gain and increased bandwidth
- High power spacecraft comm
  - Take advantage of Project Promethius
- Large arrays of small antennas
  - Earth infrastructure of the future
- Optical communications
  - New infrastructure for high bandwidth
- Error-correcting codes
  - Protect data sent through deep space
- Data compression
  - Use links efficiently
- Ultra-stable clocks (including spaceborne)
  - Perform precision navigation
- Communications standards
  - Guarantee quality & interagency cross-support

Figures of Merit

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FOM	Description
Visibility	Assets must have at least 1 visible relay back to Earth at all times (human missions). 10-degree minimum elevation angle
Orbit Stability	Measure of effort to maintain relay orbits: Delta-V for 5-yr period
Failure Tolerance	Percent visibility with 1 relay lost → % of data volume with 1 loss
Navigation Utility	Accuracy measured by Geometric Dilution of Precision; impact of spatial distribution of navigation data source errors
Mission Evolvability	Ability to modify assets by inserting technology * modifying design to meet changing exploration / science goals. Five criteria: programmability, pre-planned product improvement, open architecture, planned technology insertion, planned utilization
Adaptability	Ability to change operations in response to circumstance/environment change. Two criteria: programmability, operational flexibility
Link Capacity	Combination of aggregate data rate, data volume and latency
Scalability	Ability to expand capacity beyond initial deployment. 8 criteria, as ability to: add relays, add transponders, add frequencies, reuse spectrum, increase efficiency, increase locations served, increase data rates, improve other growth features
Sustainability	Cost to replace relay(s) to maintain a constellation for 5 years
User Burden	Effort required by users to use comm services provided. User burden is standardized, so this FOM is used to penalize options that fail to meet the standard or to reward options that reduce user burden

Comm & Nav. Integration

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- **CRM #7 Human Planetary Landing Systems is working closely with CRM # 5 Telecommunications & Navigation**

- **CRM #7 is relying on work by others to provide Nav & Comm. Capability to AEDL**

Charts Credits: Les Deutsch, Jet Propulsion Lab
Robert Spearing, Michael Regan & CRM #5 Comm. & Nav. Team Members