National Aeronautics and Space Administration

LASER COMMUNICATIONS RELAY DEMONSTRATION

bridging the gap to the next era of space communications

Overview of NASA's Laser Communications Relay Demonstration

April 2012

Bernard Edwards
NASA Goddard Space Flight Center
(301) 286-8926
Bernard.L.Edwards@nasa.gov

Goddard Space Flight Center | JPL | Space Systems Loral

Topics

- LCRD Demonstration Scenarios
- Mission Statement
- LCRD Mission Architecture
- Leveraging NASA's Lunar Laser Communications Demonstration
- Two Modulations in Space
- Flight Payload Configuration
- Ground Terminals
- LCRD Higher Layer Protocols
- Summary

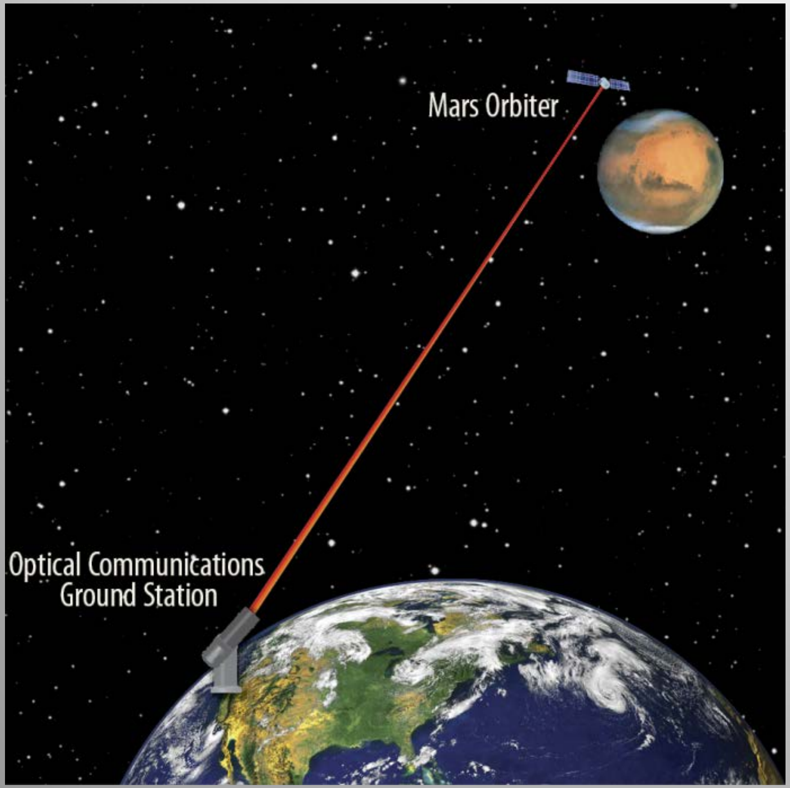
The LCRD Project

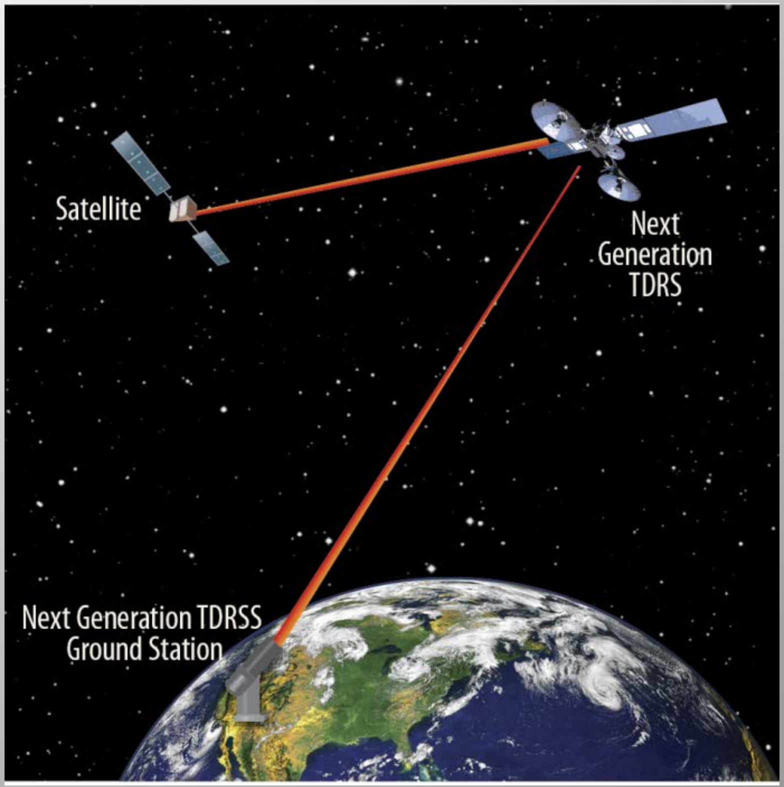
- The Laser Communications Relay Demonstration (LCRD) Project is a joint effort between:
  - NASA Goddard Space Flight Center
  - NASA Jet Propulsion Laboratory
  - MIT Lincoln Laboratory

- The LCRD Flight Payload will fly on a Loral Commercial Communications Satellite as a hosted payload
  - Loral was competitively selected

- LCRD will leverage the knowledge, experience, and technology developed from previous NASA and MIT Lincoln Laboratory optical communications work, especially the Lunar Laser Communications Relay Demonstration (LLCD)
  - LLCD is a short duration optical communications experiment between the Moon and Earth

LCRD Demonstration Scenarios





- Deep Space Direct to Earth or Deep Space Relay Scenarios
- Use of PPM modulation
- Demonstration of coding, link layer, and network layer options

- Near Earth Direct to Earth or Next Generation TDRS Scenarios
- Use of DPSK or PPM modulation
- Demonstration of coding, link layer, and network layer options

Mission Statement

- The Laser Communications Relay Demonstration (LCRD) will demonstrate optical communications relay services between GEO and Earth over an extended period, and thereby gain the knowledge and experience base that will enable NASA to design, procure, and operate cost-effective future optical communications systems and relay networks.

- LCRD is the next step in NASA eventually providing an optical communications service on the Next Generation Tracking and Data Relay Satellites

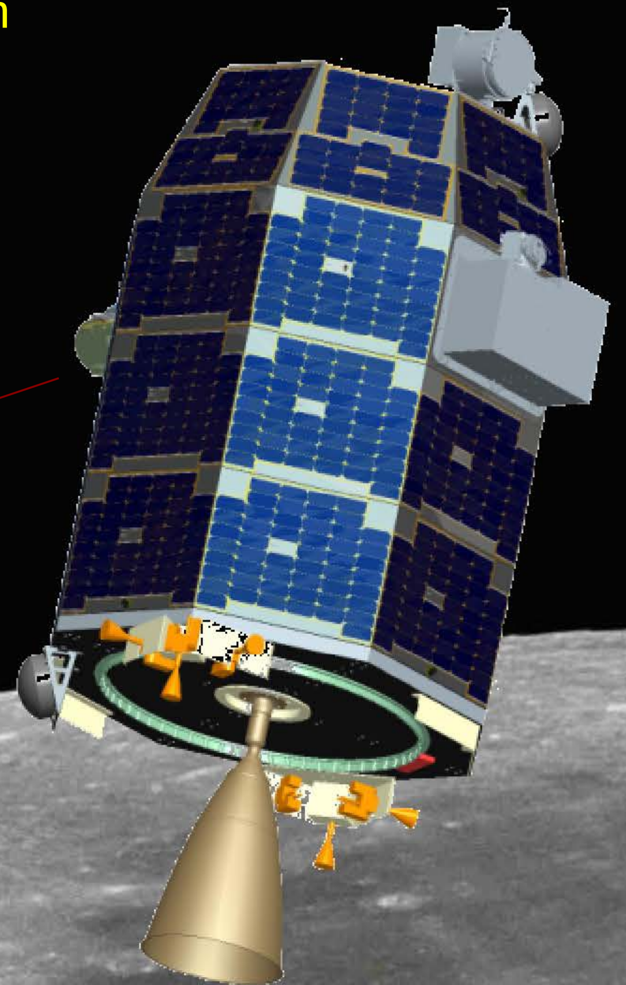
- LCRD will demonstrate some optical communications technologies, concepts of operations, and advanced networking technologies applicable to Deep Space missions

LCRD Mission Architecture

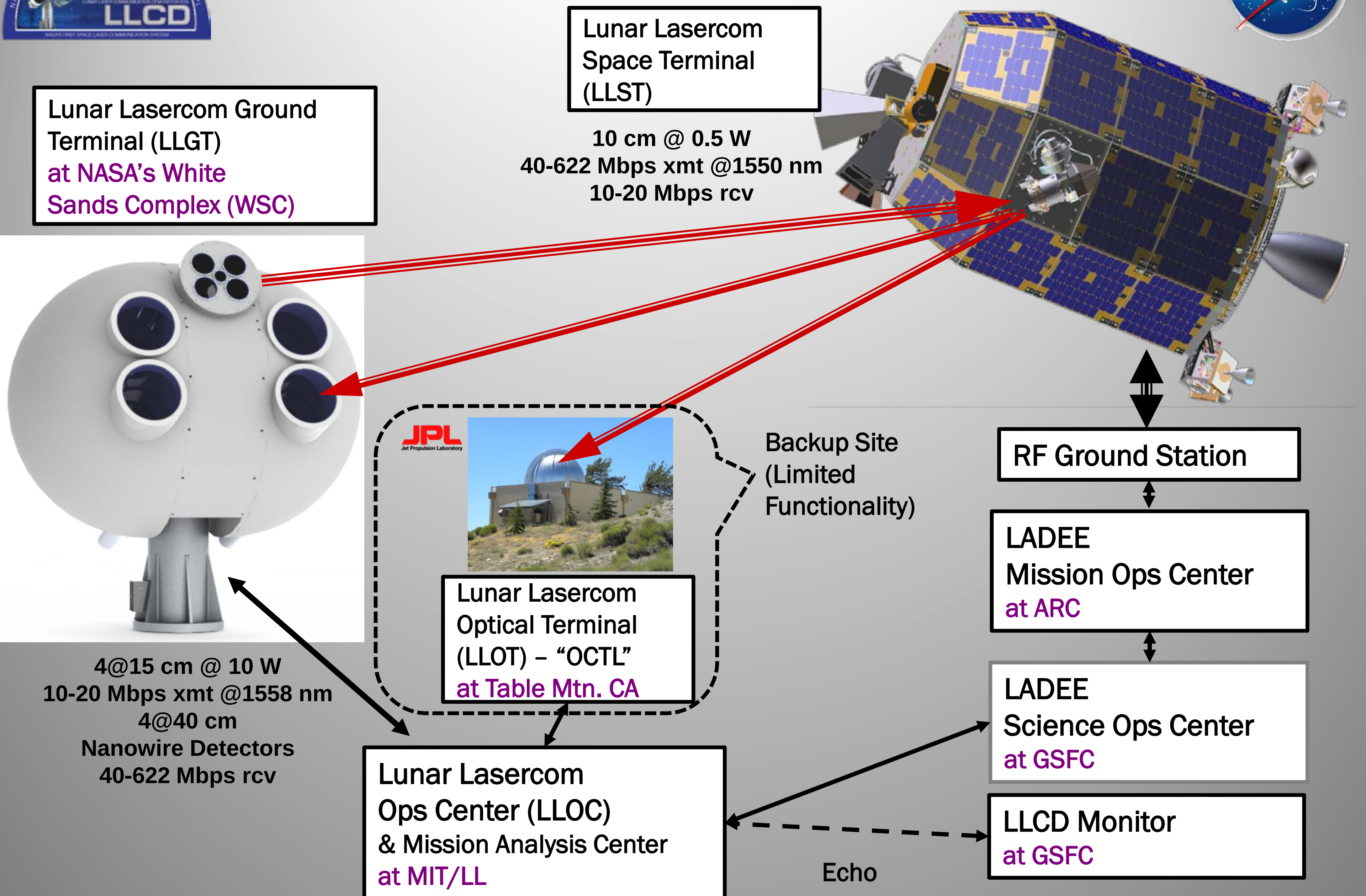
- ❑ Commercial Spacecraft Host
- ❑ Flight Payload
  - Two Lunar Laser Communication Demonstration (LLCD) based Optical Modules
  - Two LLCD Pulse Position Modulation Modems
  - Two Multi-Rate Differential Phase Shift Keying Modems based on a MIT Lincoln Laboratory Design
  - Two Optical Module Controllers
  - High Speed Electronics to interconnect the two terminals, perform data processing, and to interface with the host spacecraft
- ❑ Two Optical Communications Ground Stations
  - Upgraded JPL Optical Communications Telescope Laboratory (Table Mountain, CA)
  - Upgraded LLCD Lunar Laser Ground Terminal (White Sands, NM)
- ❑ LCRD Mission Operations Center
  - Connected to the two LCRD Optical Communications Ground Stations
  - Connected to the Host Spacecraft Mission Operations Center

LCRD Leverages NASA's Lunar Laser Communication Demonstration (LLCD)

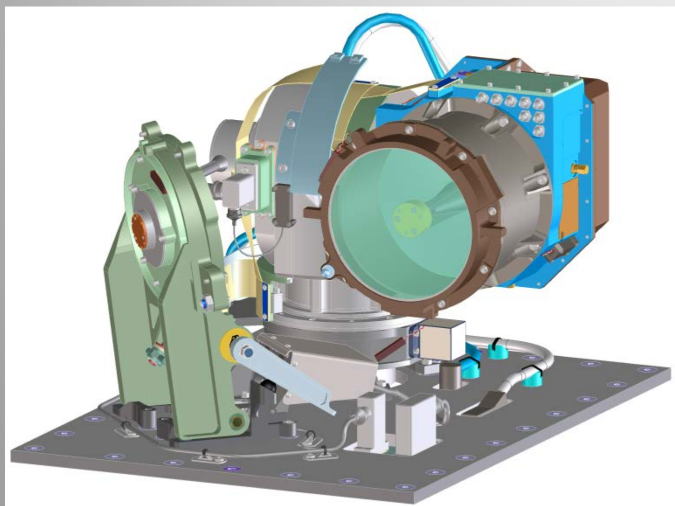
- **NASA's First High Rate Space Lasercom**
- Space terminal to fly on Lunar Atmosphere and Dust Environment Explorer (LADEE)
- Launch: No Earlier than 2013 from Wallops Island on Minotaur V
  - 1 month transfer
  - 1 month lasercom
    - 250 km orbit
  - 3 months science
    - 50 km orbit
    - 3 science payloads
      - Neutral Mass Spectrometer
      - UV Spectrometer
      - Lunar Dust Experiment



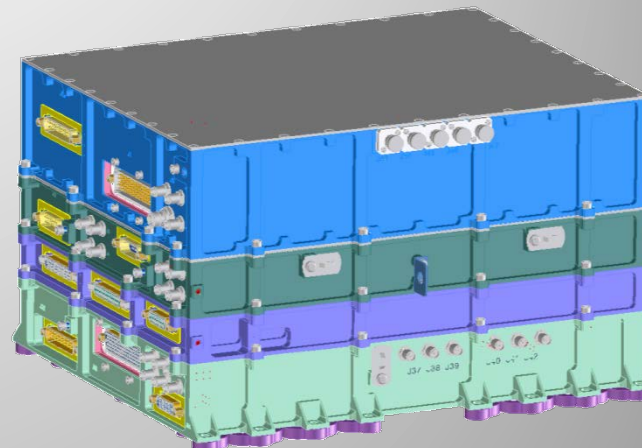
LLCD Architecture



Lunar Lasercom Space Terminal (LLCD)

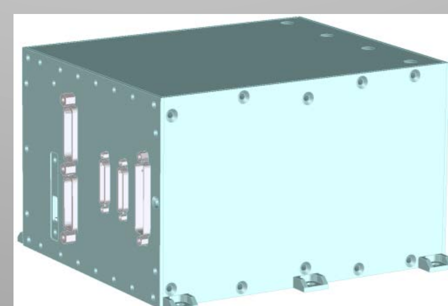


- Optical Module (OM)
  - Inertially-stabilized
  - 2-axis gimbal
  - Fiber coupled to modem transmit and receive

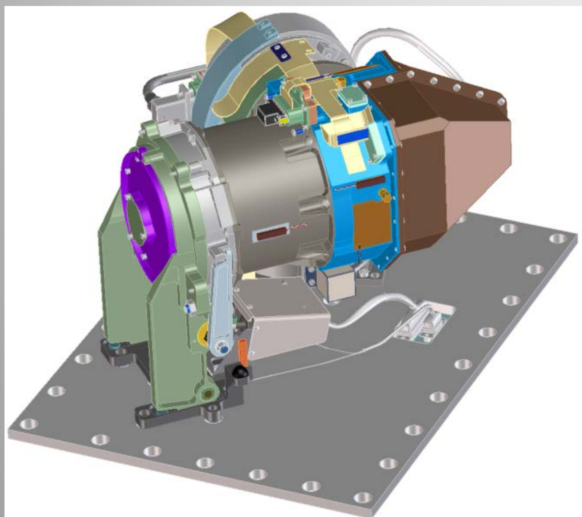


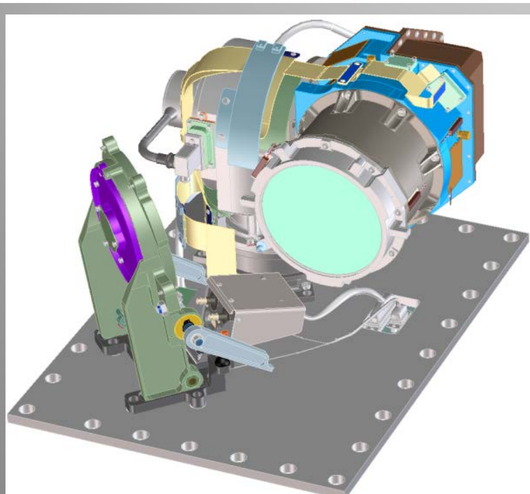
- Modem Module (MM)
  - EDFA transmitter
  - Optically-preamplified receiver
  - CODECs and data interfaces
  - Data interface to spacecraft

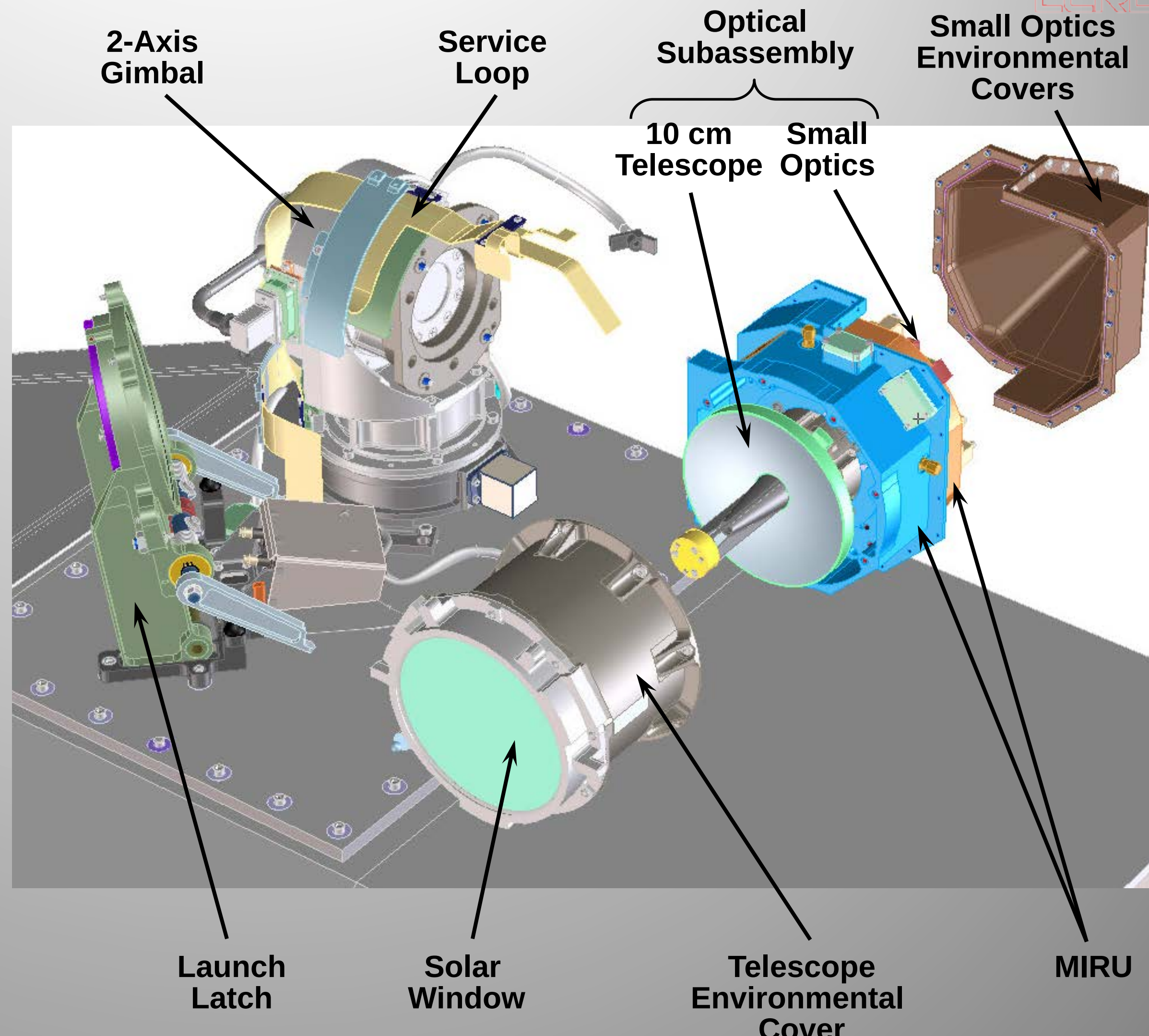
- Controller Electronics (CE)
  - OM, MM control
  - CMD/TLM interface to S/C



Optical Module (OM) Configuration

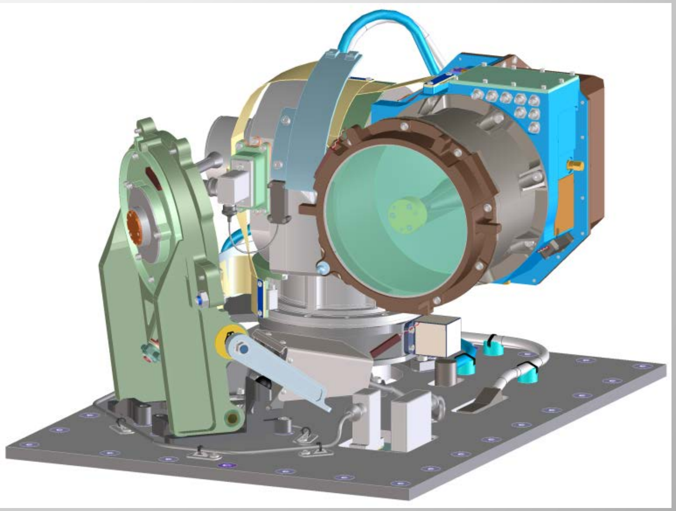






LCRD Optical Terminal
(Based on LLCD Optical Terminal)

- Wavelength: 1550 nm
- Mass: 69 Kg
- Power: 130 W DC
- Optical Transmit Power: 0.5 W
- Telescope Diameter: 108 mm
- Data Rates: 2.880 Gbps using DPSK and 622 Mbps using PPM
- MIT Lincoln Laboratory Design



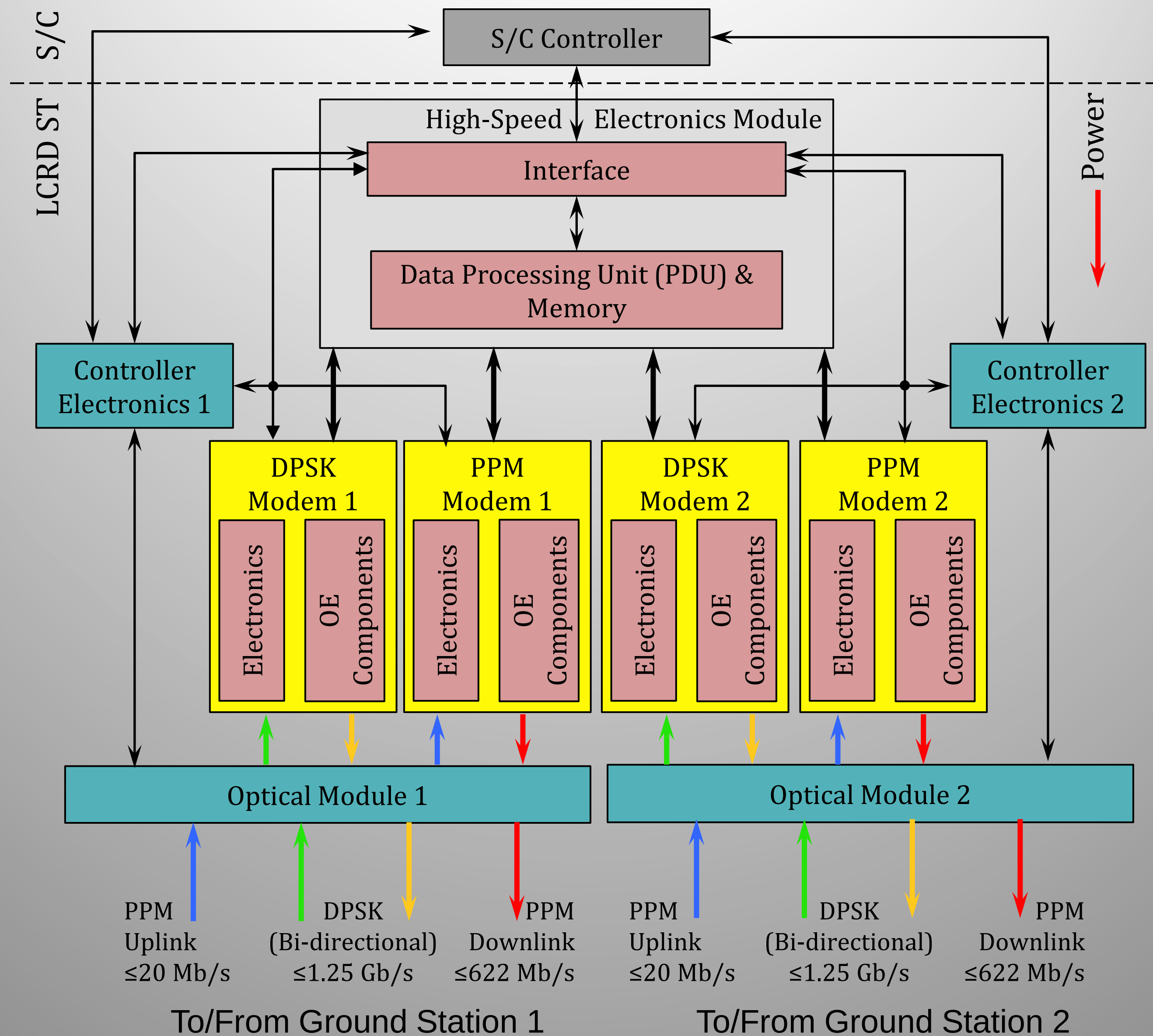
❑ Complete LCRD Flight Payload is Composed of Two LCRD Optical Terminals:
  - Two Lunar Laser Communication Demonstration (LLCD) based Optical Modules
  - Two LLCD Pulse Position Modulation Modems
  - Two Multi-Rate Differential Phase Shift Keying Modems based on a MIT Lincoln Laboratory Design
  - Two Optical Module Controllers
  - High Speed Electronics to interconnect the two terminals, perform data processing, and to interface with the host spacecraft

Two Modulations in Space

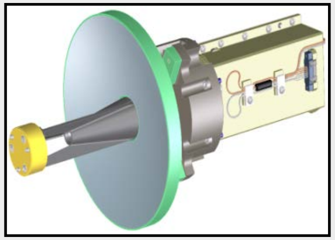
- Why Photon Counting and Pulse Position Modulation?
  - Extremely photon efficient and thus ideal for long haul deep space communications
  - Reduces the user burden (mass and power) in Near Earth applications such as Sensor Webs
  - However, high rate utility in Near Earth applications is problematic due to lack of photon counting detector for space
    - For example, baseline for the Lunar demonstration (LLCD) is 622 Mbps on the downlink, but only 10 Mbps on the uplink

- Why Differential Phase Shift Keying?
  - Less photon efficient compared to photon counting PPM, but can easily be space qualified at high data rates
    - For example, for a 100 Mbps uplink, using DPSK is significantly less efficient than a comparable PPM link to a photon counter detector in space.
  - Allows growth for Near Earth applications to 10's of Gbps

LCRD Flight Payload Block Diagram

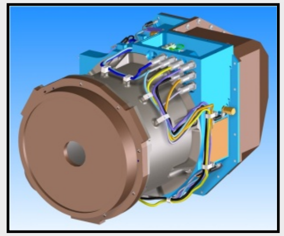


Optical Module Subassemblies via Commercial Industry



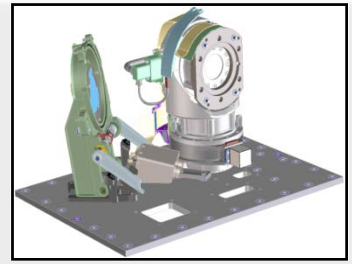
Optical Subassembly

- Be primary & secondary mirror, small optics bench, Be structure



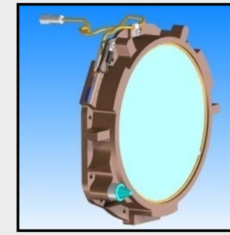
Inertially Stable Platform

- Based on ATA MIRU*



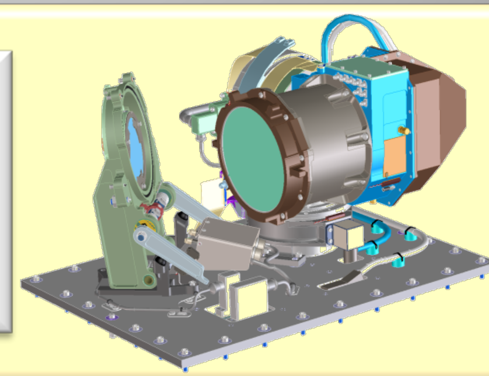
Gimbal & Latch

- Two axis gimbal based on Moog rotary actuators



Solar Window Assembly

- Subassemblies built & tested at vendor sites
- Vendors being qualified by MIT Lincoln Laboratory
- LCRD Optical Modules assembled, integrated & tested at NASA's Goddard Space Flight Center



* ATA = Applied Technology Associates, MIRU = Magento-hydrodynamic Inertial Reference Unit

Minimum of Two Ground Stations

- LCRD will upgrade the Lunar Laser Communications Demonstration (LLCD) Ground Terminal developed by MIT Lincoln Laboratory
  - This is an array of small telescopes with a photon counter for PPM
  - Adaptive Optics and support for DPSK will be added

- JPL will upgrade the JPL Optical Communications Telescope Laboratory (OCTL) to form the LCRD Optical Ground Stations (LOGS)
  - This is a single large telescope design
  - Adaptive Optics and support for DPSK will be added

- All stations will have atmospheric monitoring capability to validate optical link performance models over a variety of atmospheric and background conditions

LCRD Will Upgrade the LLCD LLGT System

- Modem and control subsystems
  - Designed and fabricated by MITLL
  - Uses a Photon Counter Detector for the PPM link
  - DPSK Modem will be added
  - Housed in 40-foot shipping container

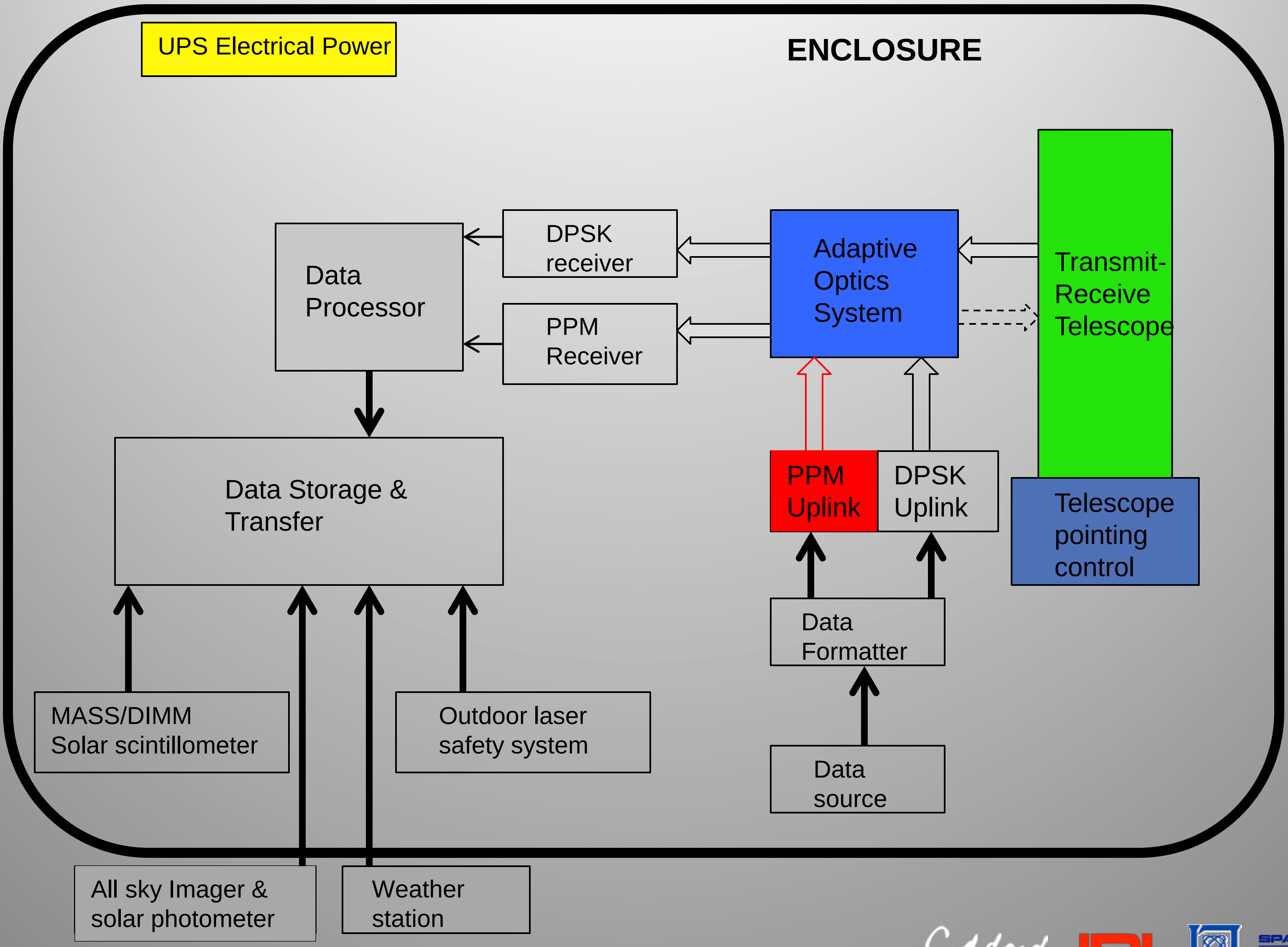
- Mount and optics subsystems
  - Designed and fabricated by MITLL
  - Adaptive Optics will be added

Interconnected via electrical cables and optical fibers.
To be assembled and tested at MITLL, then partly disassembled and reassembled later at the ground station location.

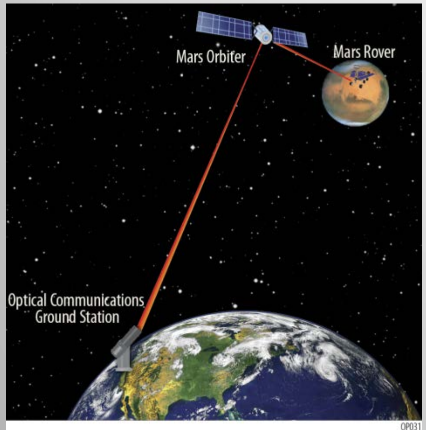
LCRD Optical Ground Station (LOGS) Goals and Technologies

- LCRD will enhance JPL's existing Optical Communications Telescope Laboratory to support a high bandwidth optical communications link with a GEO satellite
- Technologies
  - Instruments to monitor sky and atmospheric conditions
  - Adaptive optics correction of atmospheric turbulence effects
  - Remote ground station control capability
  - Deep space (PPM) and near-Earth (DPSK) modulation formats
  - System to support safe laser beam propagation through navigable air and near-Earth space
  - Network protocols to ensure data distribution and delivery

LCRD Optical Ground Station (LOGS) High Level Conceptual Design

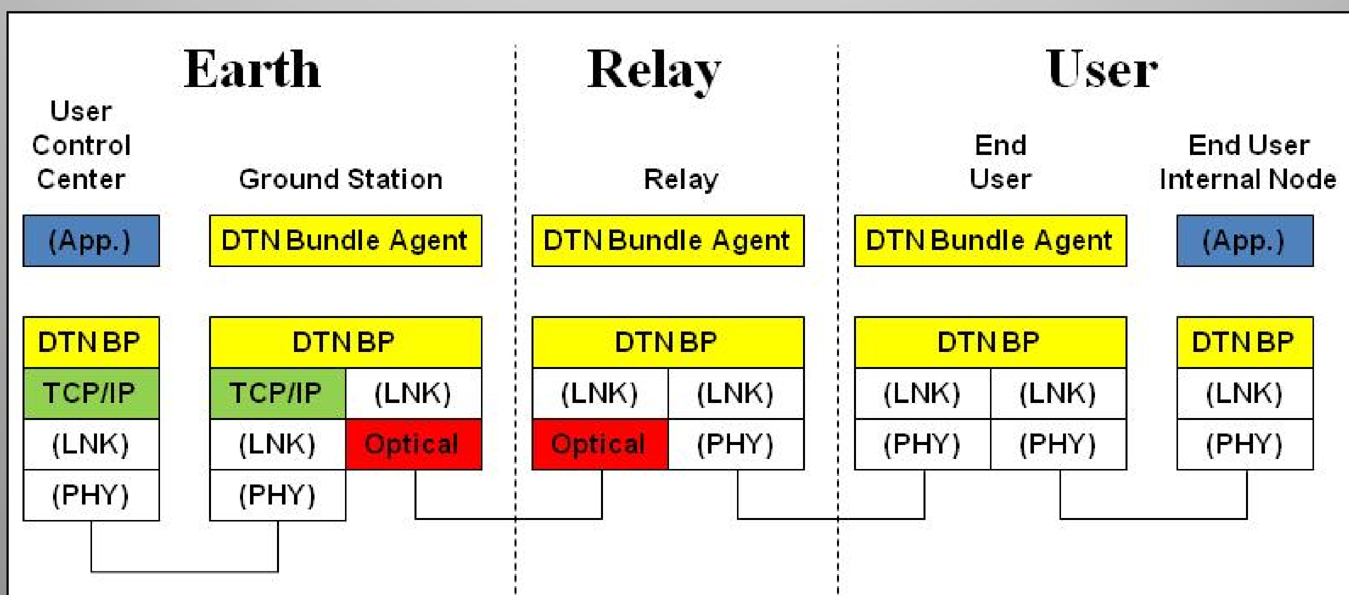


LCRD Higher Layer Protocol Deep Space Applicability



Mars Relay Scenario Concept

- LCRD includes technology development and demonstrations beyond the optical physical link
- Delay Tolerant Networking (DTN) protocols will be incorporated onboard at target data rates applicable to Mars or L1/L2 relay trunk lines producing flight hardware and software
- Relay operations without "Earth in the loop" requirements for user support will be demonstrated developing associated ops concepts, procedures, and flight software

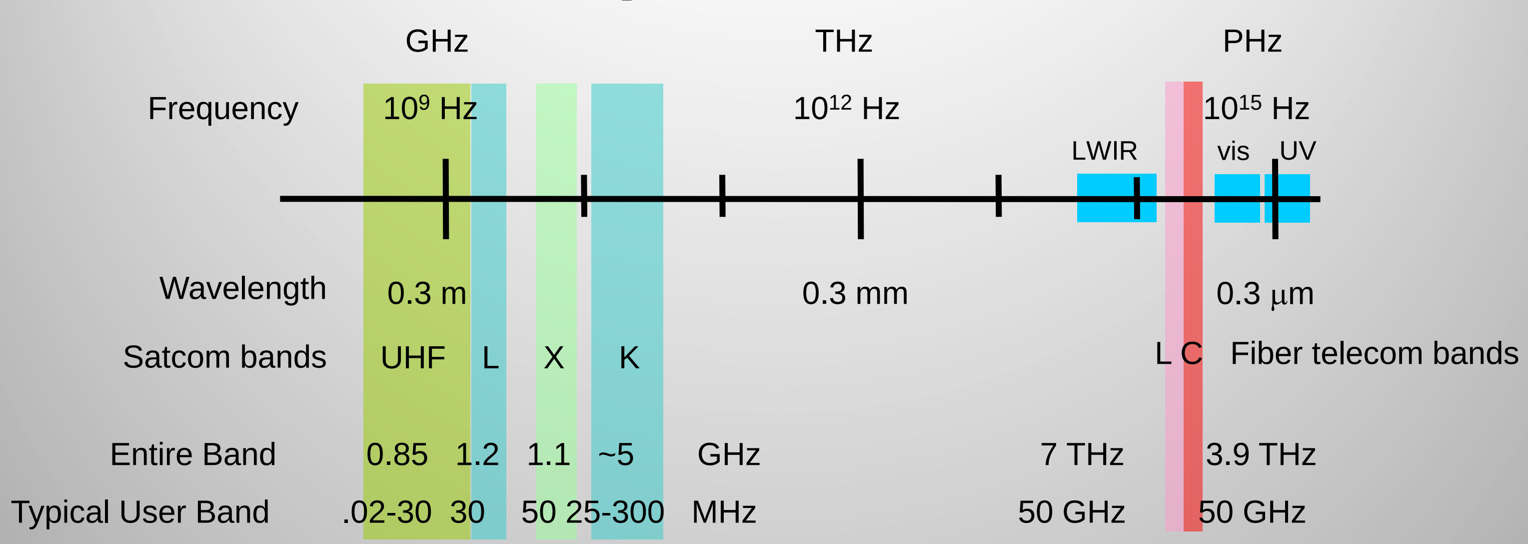


Summary

- The LCRD optical communications terminal leverages previous NASA and MIT Lincoln Laboratory designs
  - The LCRD optical module is based on the Lunar Laser Communications Demonstration (LLCD) optical module
  - The Pulse Position Modulation modem is based on the LLCD design
  - The Differential Phase Shift Keying modem is based on a DPSK modem designed by MIT Lincoln Laboratory
- With a demonstration life of at least two years, LCRD will provide the necessary operational experience to guide NASA in developing an architecture and concept of operations for a worldwide network
- LCRD will provide an on orbit platform to test new international standards for both Near Earth and Deep Space missions for future interoperability
  - LCRD includes technology development and demonstrations beyond the optical physical link
  - Delay Tolerant Networking (DTN) protocols will be incorporated onboard at target data rates applicable to Mars or L1/L2 relay trunk lines
- NASA can go from this demonstration to providing an operational optical communications service on the Next Generation Tracking and Data Relay Satellites

BACKUP CHARTS

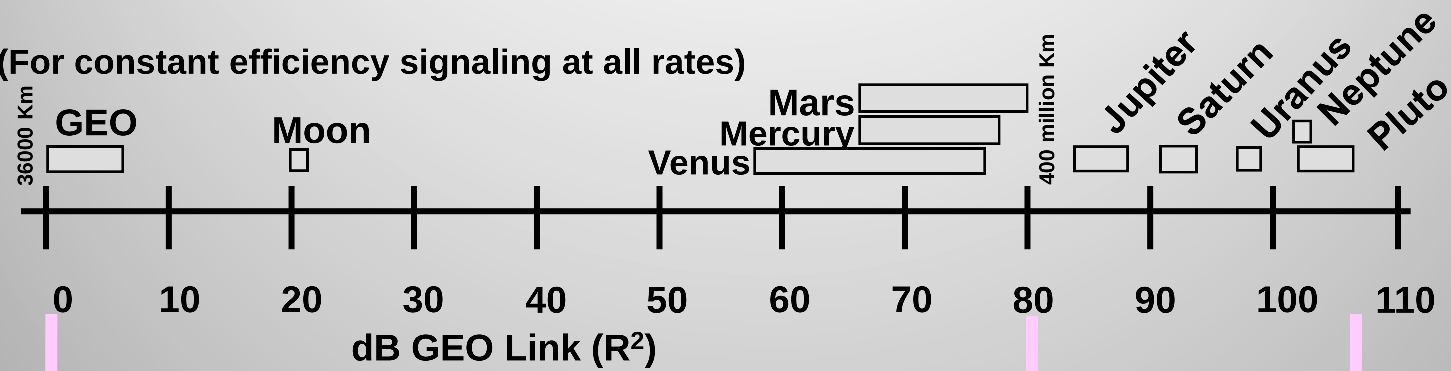
Benefits of Optical Communications



Features of extremely short wavelengths of IR light	System Potential	Improvement Over RF
Nearly infinite bandwidth (and fiber telecom components to make use of it)	- ***Extremely high data rates*** **in** ***unregulated bands*** - Use of extra bandwidth to achieve very high efficiency	10's of THz vs 50 GHz
Extremely high gain from small apertures	***Very small terminals***	Power delivery efficiency $10{,}000^2$ greater

Why is Deep Space Lasercom Different than Near Earth Lasercom?

(For constant efficiency signaling at all rates)



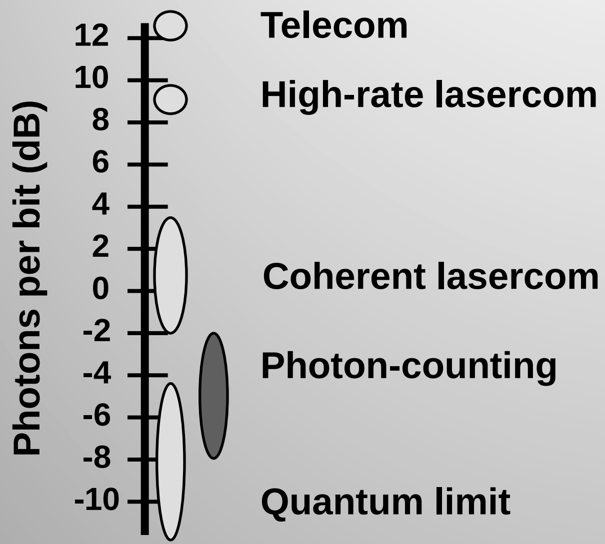
10 Gbps GEO using present near-earth technology **100 bps Mars** **0.25 bps Pluto**

Need 40 dB !

10^5 Gbps GEO required class of lasercom technology **1 Mbps Mars** **2.5 Kbps Pluto**

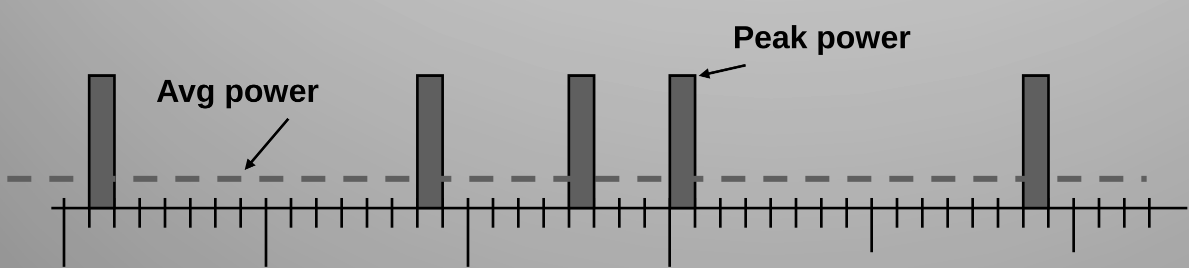
Efficient Signaling and Coding

Lasercom Efficiencies



- Very near quantum limit
- Does not require extreme spectral or spatial purity
- Well-matched to pulsed modulation (high peaks pwrs)
- Note: -7 dB photons per bit = 5 BITS PER PHOTON!

Example: 8-ary Pulse Position Modulation



Pulse in one of 8 = 2^3 slots (3 bits)

Very powerful Error-Correction Coding and Decoding implicitly deduces when a pulse is missed or when noise fills in incorrect pulses