
High-Reliability Lasercom System Design at MIT Lincoln Laboratory

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JPL Photonics Workshop

6 August 2020

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Outline

- **Overview of Lasercom at MITLL**
- **Building lasercom hardware from discrete fiber and electro-optic components—LLCD and LCRD**
- **Technology transfer to industry—LEMNOS**
- **Using advanced integrated photonic devices as black boxes—TBIRD**

A History of High-Impact Lasercom Development at MITLL

1985

1990

1995

2000

2005

2010

2015

2020

2025

Laser Intersatellite Transmission Experiment (LITE)



- Joint AF / NASA project (1985-8)
- To have flown on NASA Advanced Communications Technology Satellite (ACTS)
 - MIT LL: 4-ary PSK, heterodyne receiver at Mt Wilson, CA, 50-200 Mbps
 - NASA GSFC: Direct detection receiver
- Cancelled after CDR due to cash flow reduction
- AF continued to fund "Engineering Model" to qualify technologies

Laser Intersatellite Transmission Experiment

Early lasercom partnership between MITLL and GSFC

LITE EM demonstrated all key lasercom subsystems in space-qualified form- also revealed engineering challenges

The First Space Lasercom Successes: GeoLITE and ALEX (1997-2002)



- GeoLITE Lasercom Experiment**
 - Launched 18 May 2001
 - World's first successful demo of high-rate, space-based laser communications (12 June 2001)
- Airborne Laser Experiment ALEX Demonstrations (2002)**
 - World's first successful demo of air-to-space optical laser communications

GeoLITE

First space lasercom success

Mars Laser Comm Demonstration (MLCD) 2003-2005

- Developed architecture and technologies for deep-space lasercom
 - Capacity-limited high-rate optical links
 - Inertial stabilization of telescope
 - Hybrid tracking approaches
 - Efficient fiber lasers and amplifiers
 - Distributed receive apertures
 - Arrays of photon counting detectors
- Approach later demonstrated by LLCD (2013) and future JPL Deep Space Optical Comm (DSOC, 2022)

Established a lasercom architecture for high-rate deep-space links that has been highly influential in subsequent development efforts

Mars Laser Comm Demonstration

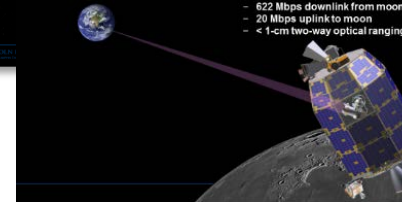
Established architecture for deep space lasercom

Lunar Laser Comm Demonstration

NASA's first space lasercom success

Lunar Laser Communication Demonstration NASA's First Space Lasercom (2013-2014)

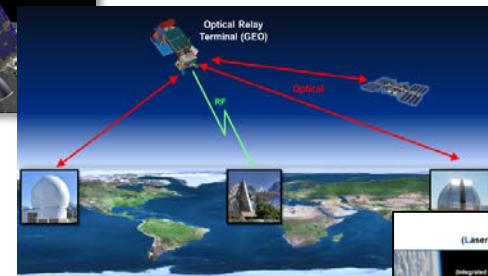
- LLCD was a tech demo on NASA's Lunar Atmosphere and Dust Environment Explorer
 - 622 Mbps downlink from moon
 - 20 Mbps uplink to moon
 - < 1-cm two-way optical ranging



Laser Comm Relay Demonstration

Optical relay pathfinder

Based on MITLL risk reduction hardware designs



Laser Enhanced Communications Navigation Operational Services

ISS to ground
ISS to Artemis

LEMNOS (Laser Enhanced Mission Communications Navigation and Operational Services)



Lunar Laser Communication Demonstration

NASA's First Lasercom Demonstration (2013-2014)

Technology demonstrator on NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE)

- 622 Mbps downlink from moon
- 20 Mbps uplink to moon
- cm-class real-time ranging
- Longest lasercom link demonstrated to date (and many other firsts)

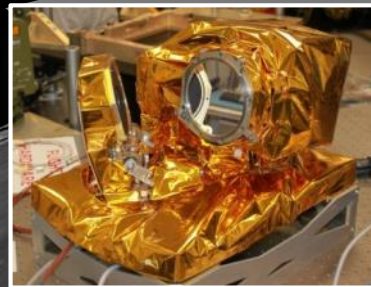


4 x 40-cm Collector
Photon-Counting Receiver

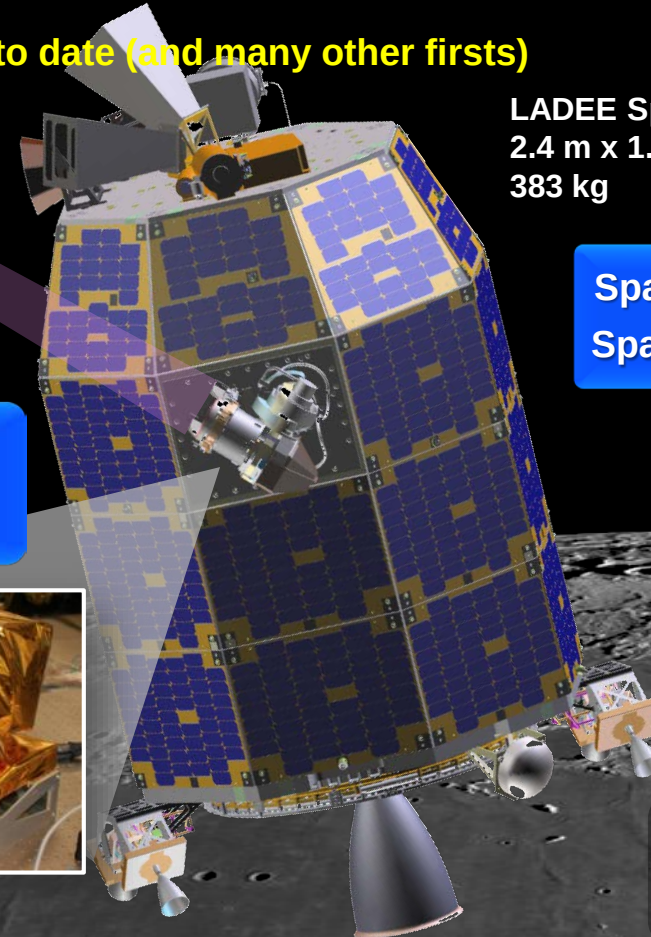


Lunar Lasercom
Operations Center
at MITLL

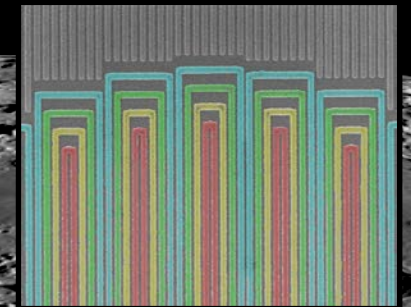
10-cm Transmit
Aperture
0.5-W Laser



LADEE Spacecraft
2.4 m x 1.8 m
383 kg



Space Terminal mass ~ 30 kg
Space Terminal power ~ 90 W

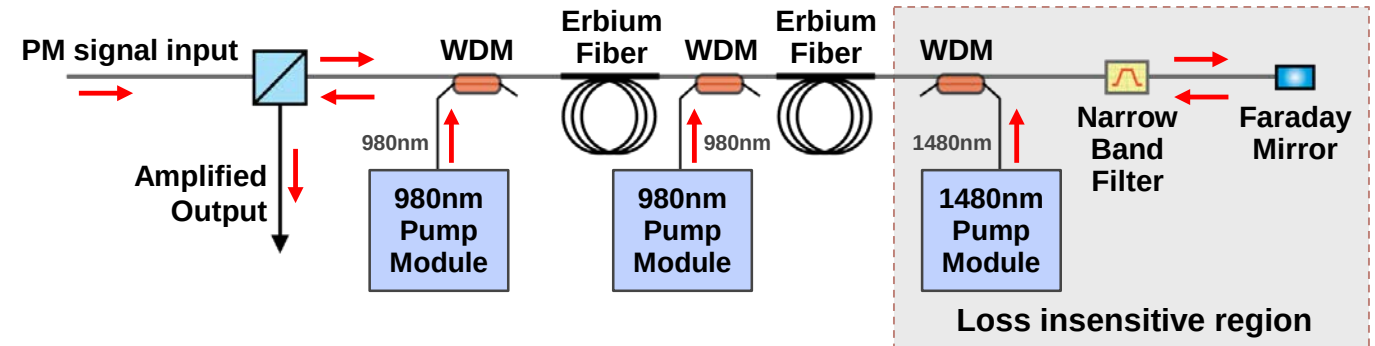


Superconducting Nanowire
Single-Photon Detector
(SNSPD) Array

Building Capable Lasercom Modems from COTS Telecom Parts

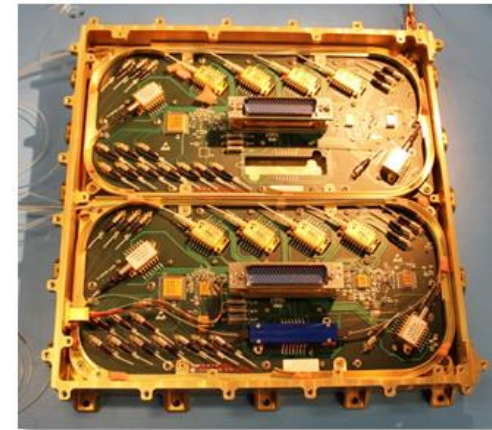
- Approach uses discrete telecom fiber-optic components
- Successful Methodology
 - Use best parts available, Telcordia qualified if possible
 - Upscreening for specific environment
- Parts have generally become more reliable
 - Higher power, more reliable pump lasers
- Parts have generally remained available despite turnover in vendors

0.5-W Double-Pass Amplifier



Caplan et al., CLEO 2000, paper CWJ3

Multi-rate DPSK Modem



Spellmeyer et al., SPIE 8917, 2014

Reliability & Upscreening Methodology

- **Single lot lifetime buys of Telcordia qualified parts when possible**
- **Eliminate known wear out mechanism that would limit required design lifetime**
 - e.g., radiation, fiber splices
 - No moving parts
- **Selected redundancy (e.g., pump lasers), must be balanced against design complexity**
- **Part types are shown to be suitable for use by**
 - Functional testing
 - Environmental testing: thermal-vac, shock and vibration, radiation
- **Specific COTS parts tested for workmanship through**
 - Functional testing
 - Screening tests

LEMNOS

(**L**aser **E**nhanced **M**ission Communications **N**avigation and **O**perational **S**ervices)

ILLUMA-T

(Integrated **L**CRD **L**EO **U**ser **M**odem and **A**mplifier **T**erminal)

1.2 Gbps return
51 Mbps forward
To ground via LCRD relay

August 2021 delivery to GSFC

July 2022 Launch on SpaceX Dragon

~ 6 month mission

O2O

(**O** Orion EM-2 **O**ptical Comm)

80 Mbps return
20 Mbps forward
Direct to ground (WSC, TMF)

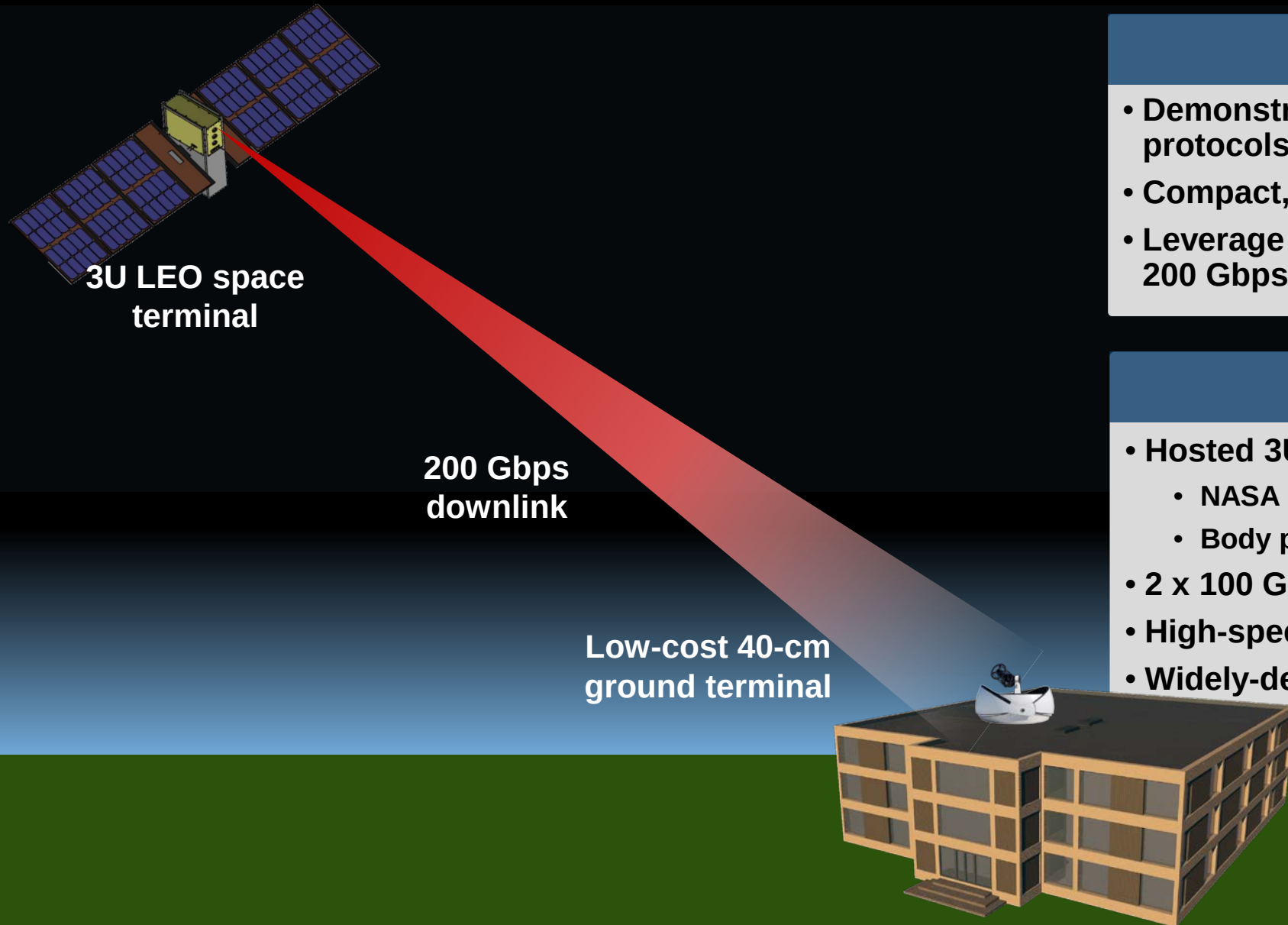
May 2021 delivery to KSC

June 2023 Launch on Orion/SLS

8-21 day mission

Technology transfer to create industrial vendor base is one of the program goals

Terabyte Infrared Delivery (TBIRD)



Target Goals

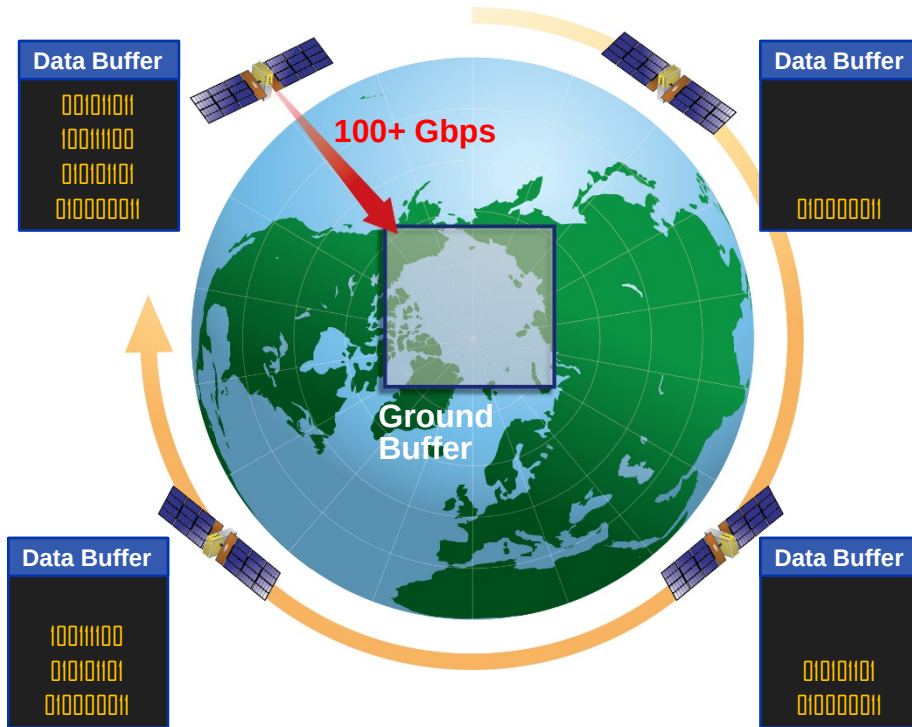
- Demonstrate burst data delivery architecture & protocols
- Compact, low cost space & ground terminals
- Leverage high rate COTS telecom equipment for 200 Gbps data delivery

Planned Demonstration

- Hosted 3U payload on 6U CubeSat
 - NASA Small Sat Pathfinder Tech Demo
 - Body pointing
- 2 x 100 Gbps coherent transceivers
- High-speed readout from space buffer
- Widely-deployable ground terminal

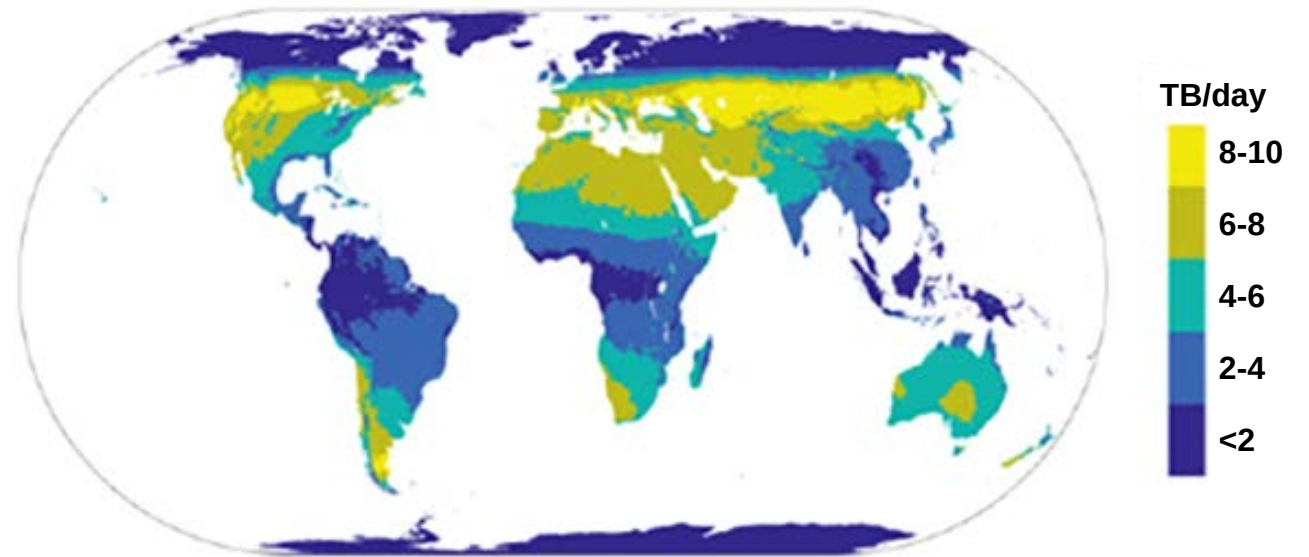
TBIRD Burst Data Delivery

Data Delivery Concept



Average Terabytes per day from LEO to Earth

600-km LEO, 51° inclination, single ground station

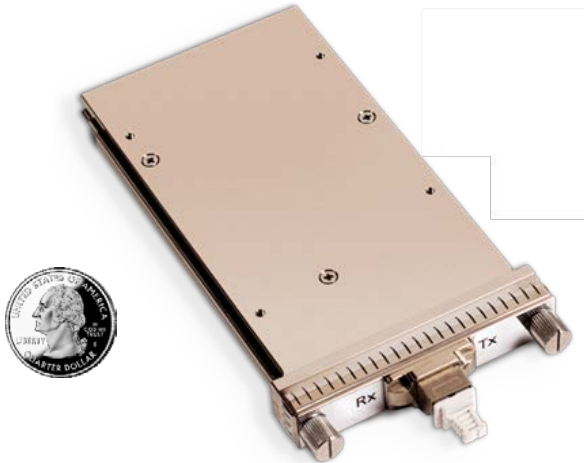


Link analysis accounts for cloud statistics

The TBIRD system is capable of delivering many TBytes per day from LEO to a delay-tolerant ground user

Enabling Commercial Technologies

High-Rate Optical Modem



100 Gbps Fiber Telecom Transceiver
Compact Form Pluggable (CFP)

Large, High-Speed Storage



>500 GB, >25 Gbps Readout
Solid-State Drive (SSD)

Optical Amplifier



~1W Erbium Doped Fiber Amplifier
Optical C-Band (~1550nm)

- Highly integrated COTS components enable small, low-power space terminal designs
- System design treating some components as functional 'black boxes'

Risk Reduction for Space Environments

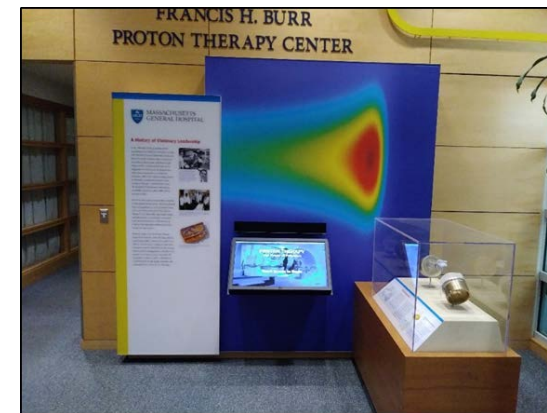
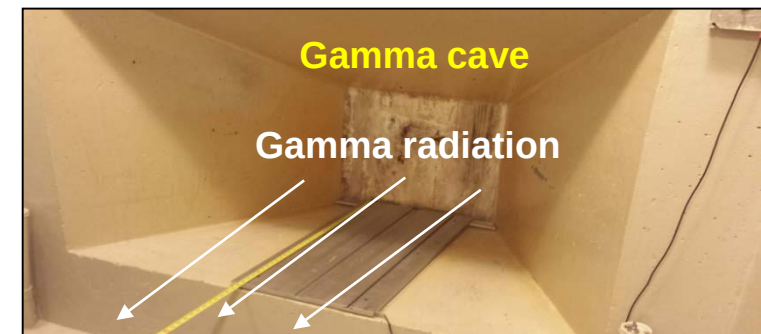
Shock / Vibration



Thermal/Vacuum

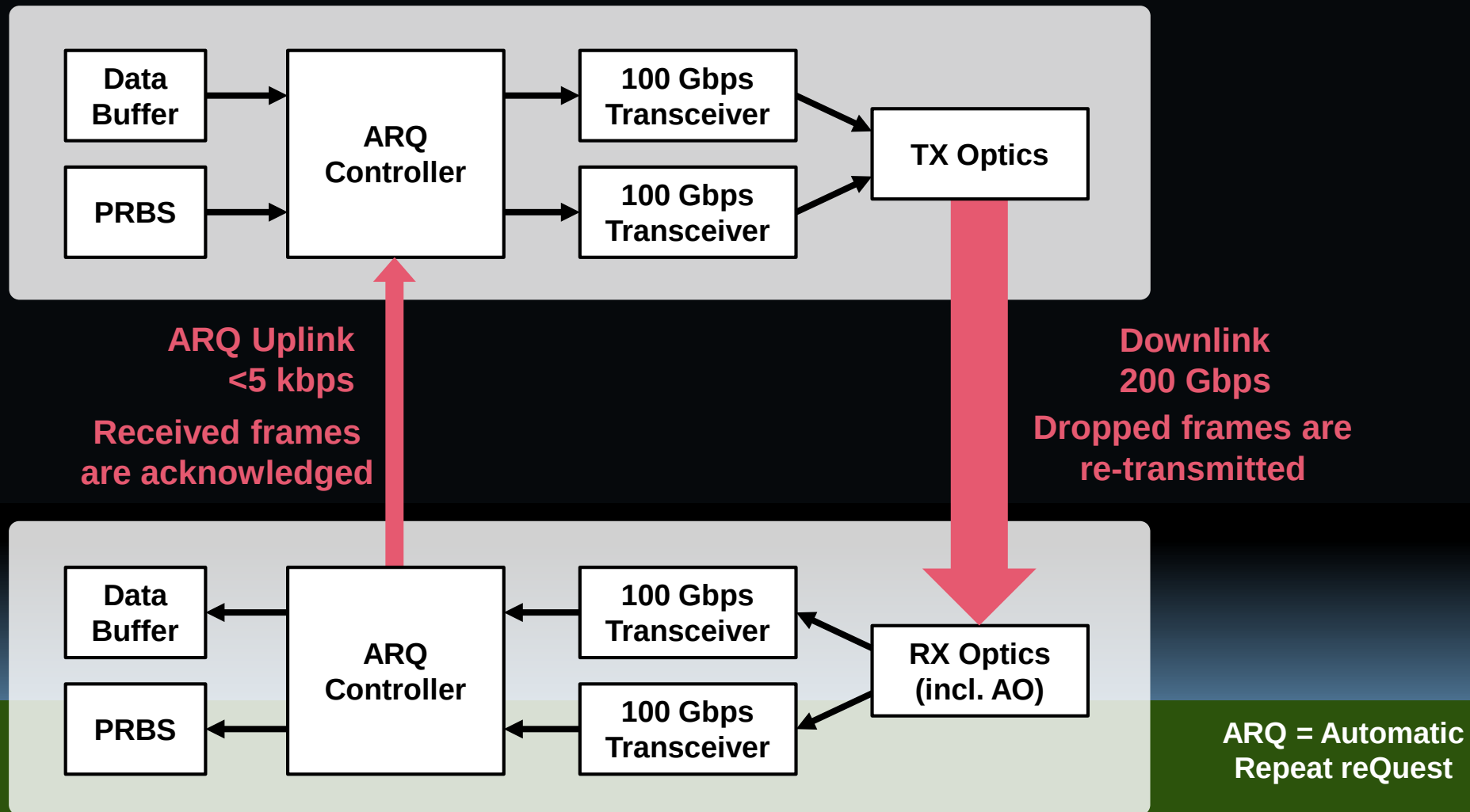
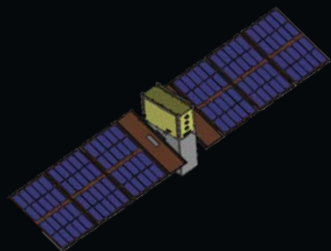


Radiation



Key COTS components validated in relevant space environments

TBIRD Comm Architecture



ARQ protocol enables COTS transceiver to function on fading channel

Summary

- **MITLL/NASA collaboration has advanced lasercom state-of-the-art**
- **LLCD and LCRD leveraged high-reliability COTS telecom components**
- **LEMNOS using similar COTS telecom technology while advancing technology transfer to industry**
- **TBIRD is a pathfinder in using integrated photonic devices for ultra high data rates**