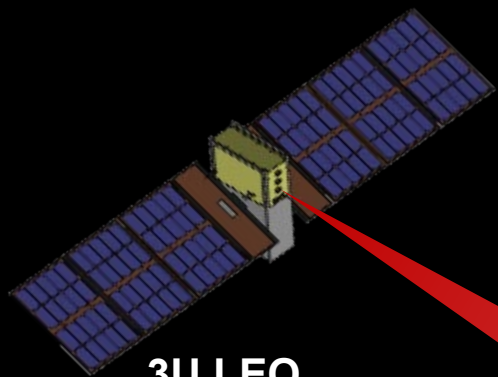

Terabyte Infrared Delivery TBIRD Overview

Dec 1, 2020

Terabyte Infrared Delivery (TBIRD)



**3U LEO
space terminal**

200 Gbps downlink

Target Goals

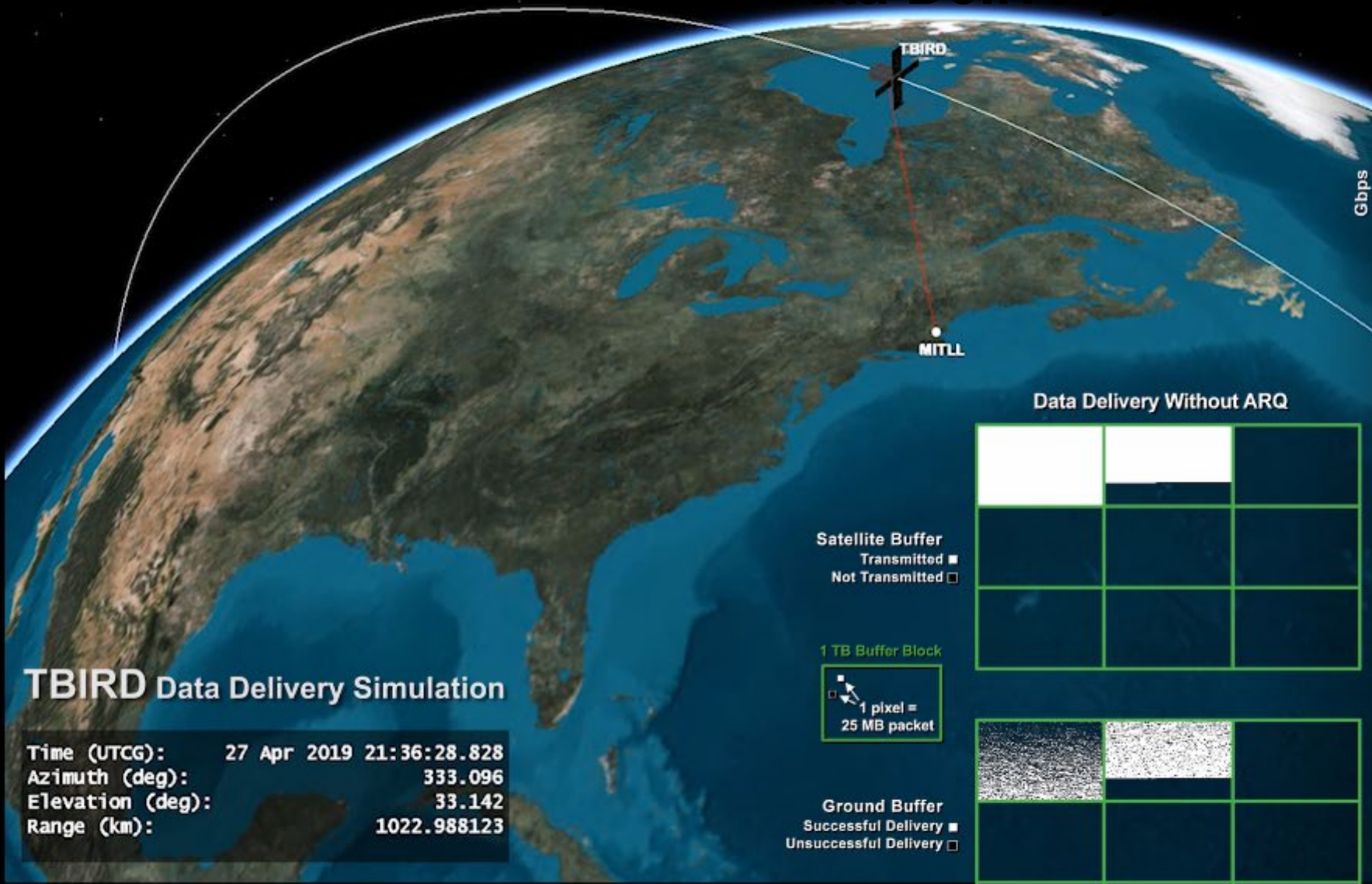
- Demonstrate burst data delivery architecture & protocols
- Compact, low cost space & ground terminals
- Leverage high rate COTS telecom equipment for 200 Gbps data delivery

Planned Demonstration

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

**Low-cost 40-cm
ground terminal**





TBIRD Data Delivery Simulation

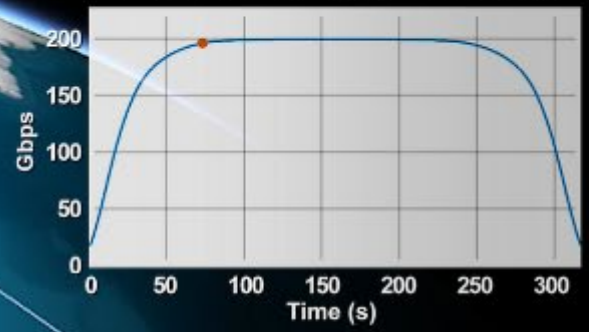
Time (UTCG): 27 Apr 2019 21:36:28.828
 Azimuth (deg): 333.096
 Elevation (deg): 33.142
 Range (km): 1022.988123

Satellite Buffer
 Transmitted ■
 Not Transmitted □

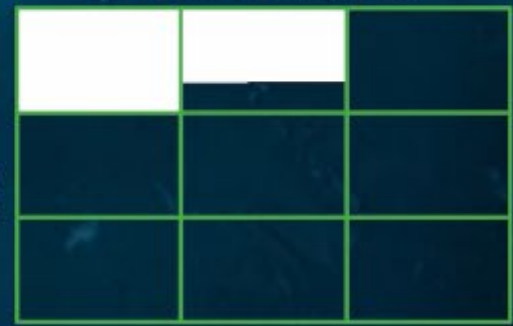
1 TB Buffer Block
 1 pixel = 25 MB packet

Ground Buffer
 Successful Delivery ■
 Unsuccessful Delivery □

Downlink Throughput (with ARQ)



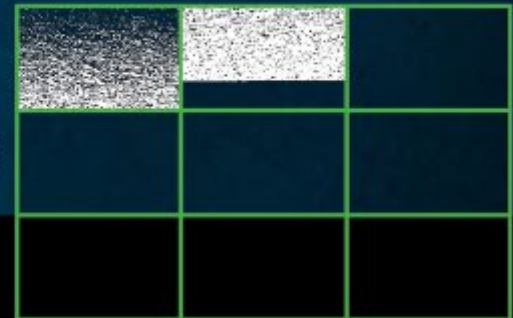
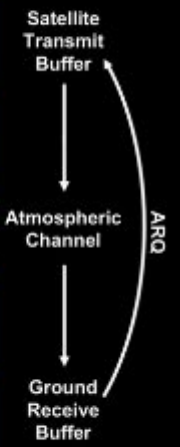
Data Delivery Without ARQ



Data Delivery With ARQ



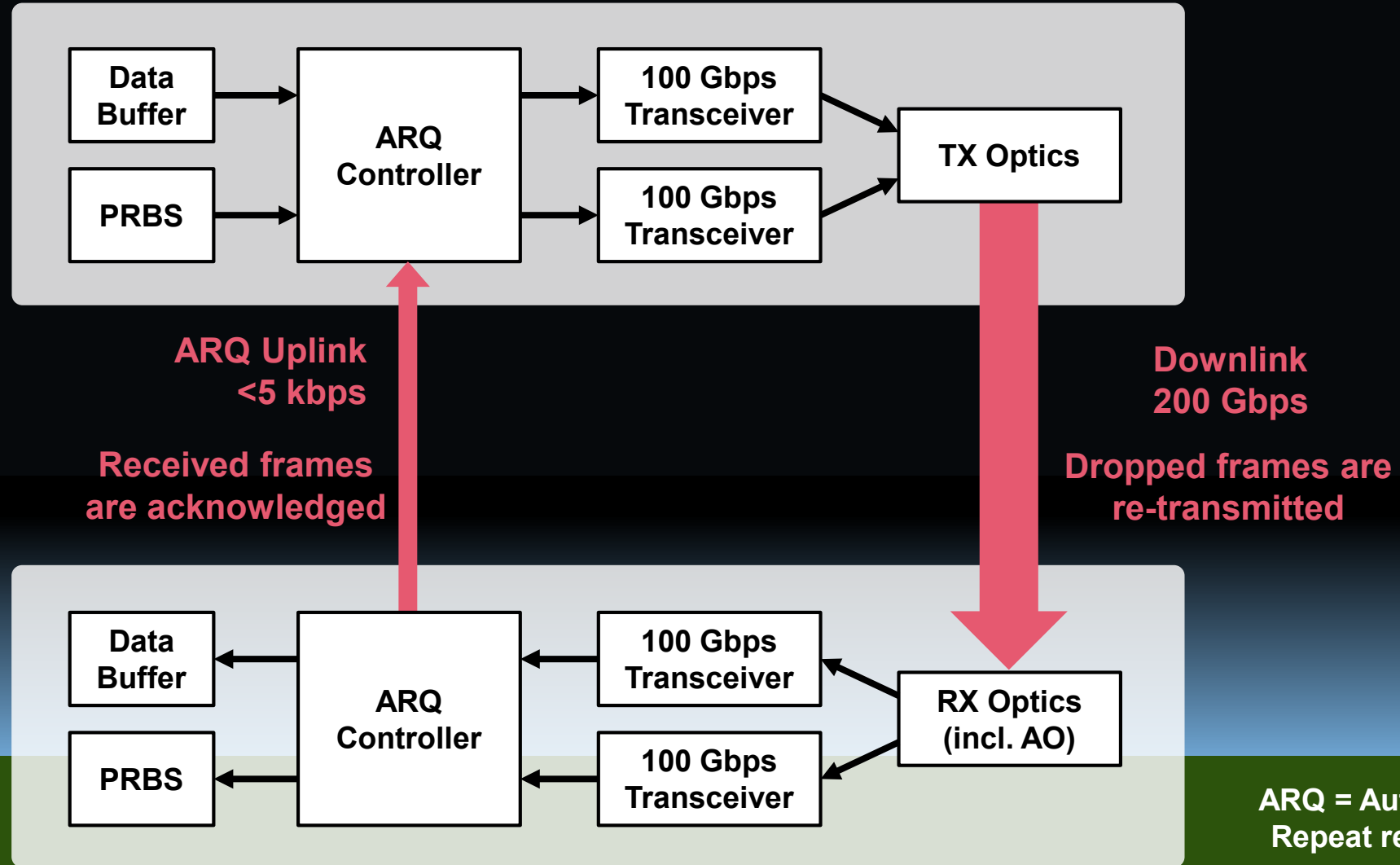
ARQ = Automatic Repeat reQuest



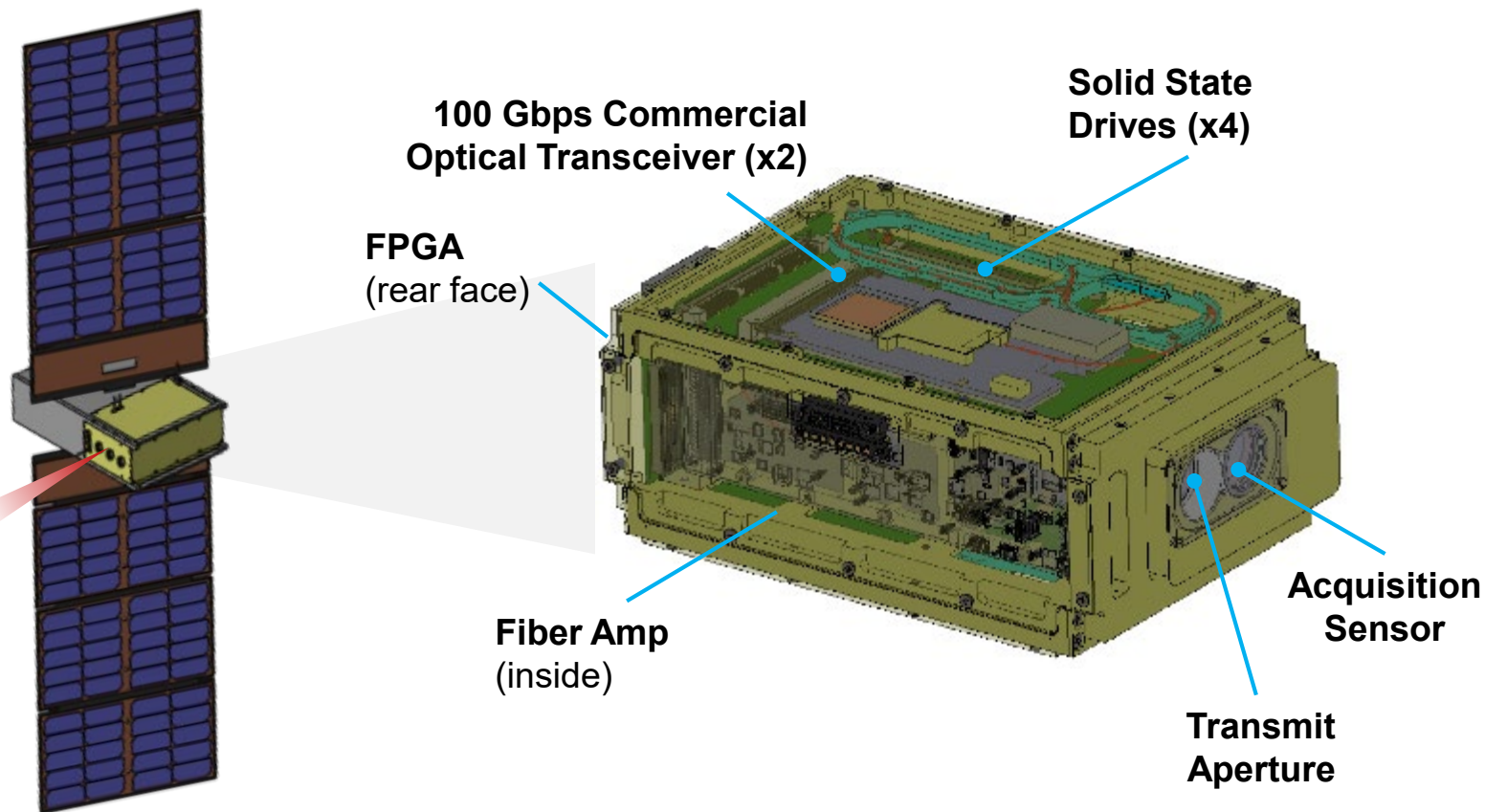
What TBIRD Demo Will Accomplish

- **Demonstration of high-volume data delivery from low-Earth orbit to ground**
 - TB's per day to a single ground station
 - Orders of magnitude higher than alternative approaches (relay or DTE)
- **CubeSat-scale optical comm payload**
 - Body pointed
 - Based on low-cost COTS parts
 - Can be accommodated on many other spacecraft
- **Integrated large high-speed buffer**
 - TBs of capacity
 - 100+ Gbps readout
- **Small widely-deployable ground terminal**

TBIRD Comm Architecture (CubeSat Demo)



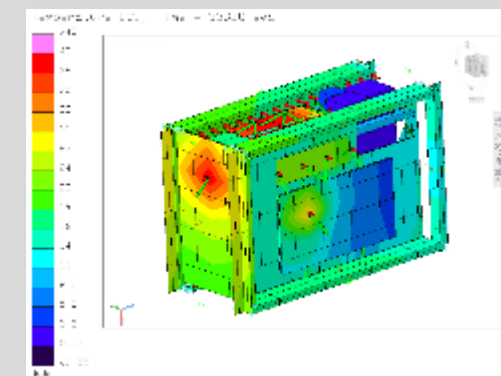
Payload Mechanical Layout



Payload Specs

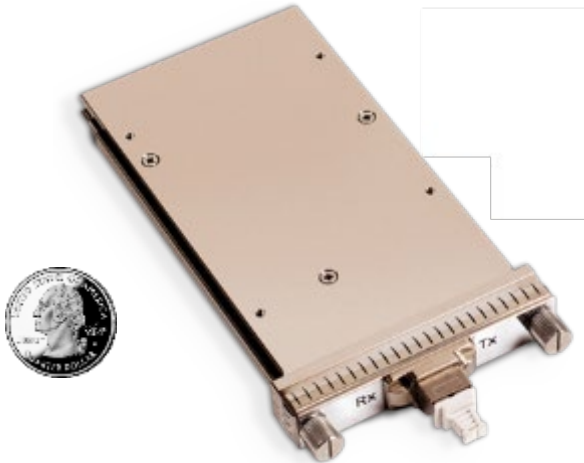
- ~3U volume
- ~3 kg
- 130W peak during short pass
 - < 1 nJ per transmitted bit
 - For comparison:
2W, 200 Mbps X-band = 10 nJ/bit

Thermal Analysis



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
Must be upscreened to validate performance in space environments**

TBIRD Ground Terminal

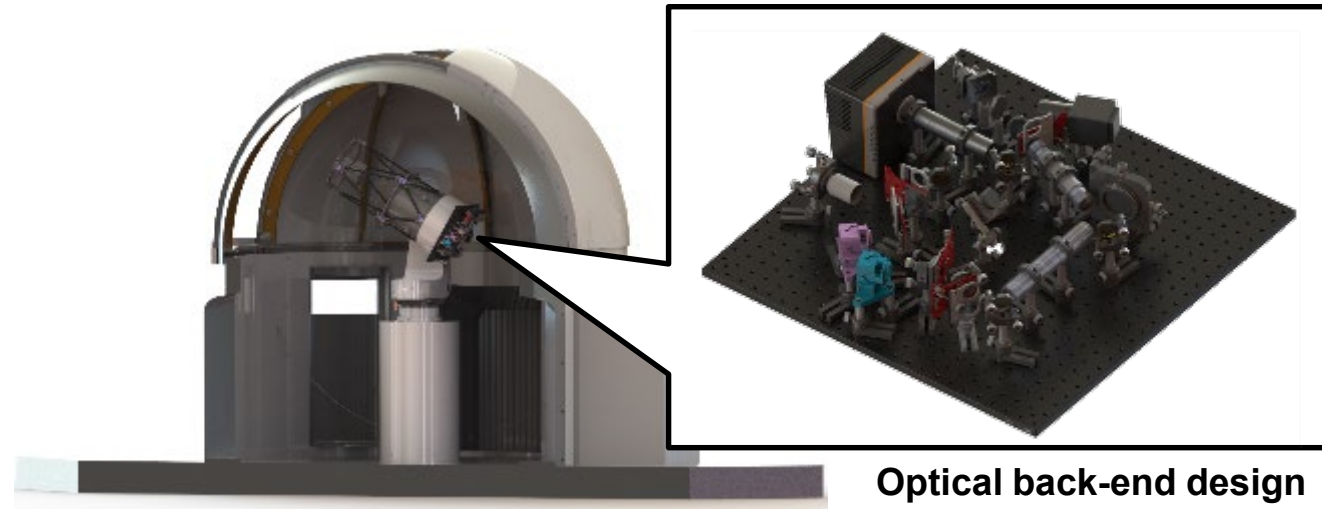
- **Terminal features**
 - Fast-slewing COTS L-mount
 - 17" COTS telescope
 - Custom adaptive-optics for fiber coupling
 - 4-beam uplink beacon (sub-apertures of primary)
- **Supports 200 Gbps LEO Downlink**
 - 1000 km link range at low elevation angles
 - $10 \mu\text{W}/\text{m}^2$ irradiance at RX aperture
 - 2x100-Gbps fiber-telecom transceivers
 - Dual-polarization QPSK signaling



COTS Telescope
Installation (Sept 2020)



Dome Construction
at Millstone Hill



Optical back-end design

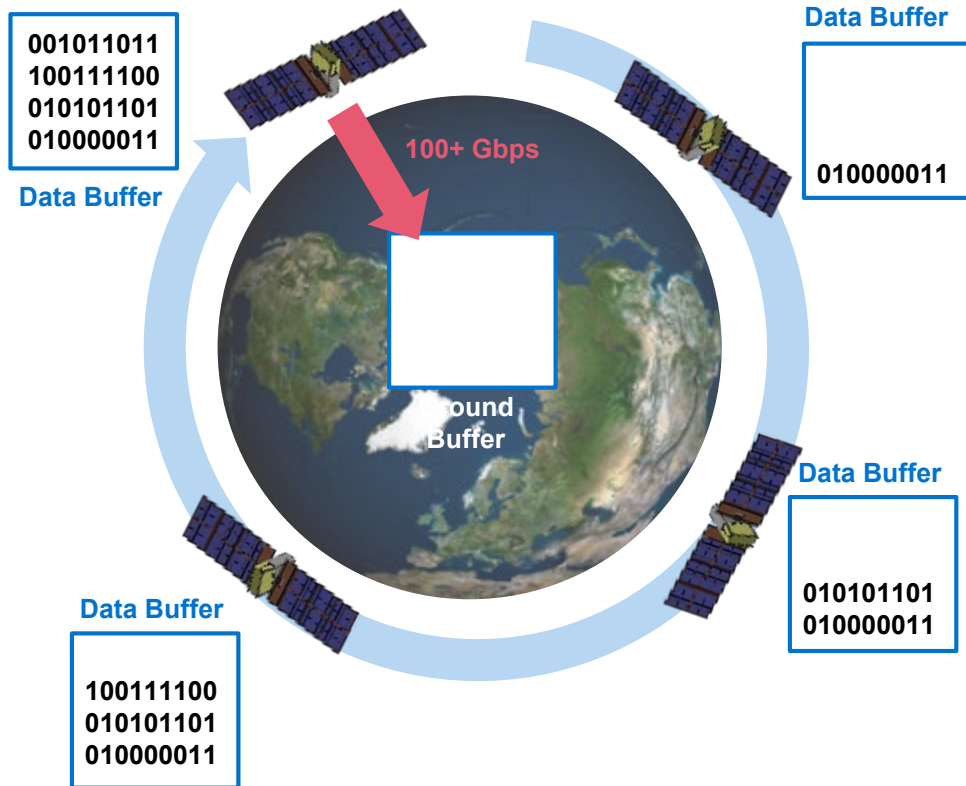
Summary

- **TBIRD design delivers high data volume in a compact, low SWaP package**
 - Leveraging 100 Gbps commercial telecom transceivers
- **Demonstrated successful operation of horizontal link with prototype hardware**
- **Payload and ground terminal builds in progress**
- **Launch scheduled for December 2021**

Backup

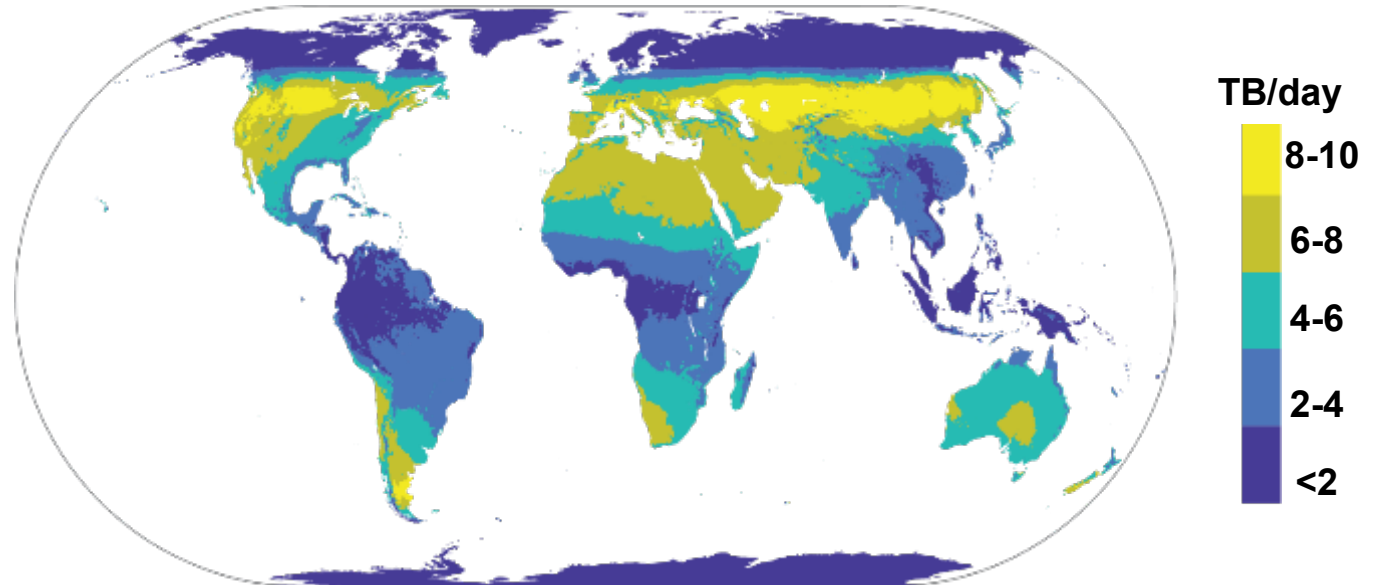
TBIRD Burst Data Delivery

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

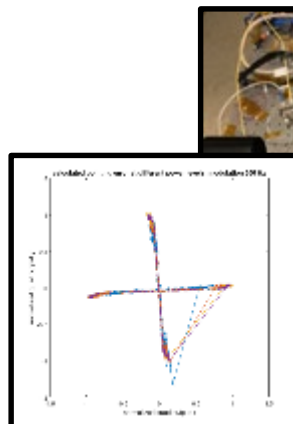
The TBIRD system is capable of delivering many TBytes per day from LEO to a delay-tolerant ground user

Space and Ground Terminal Development

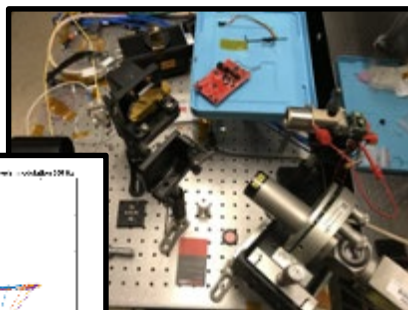
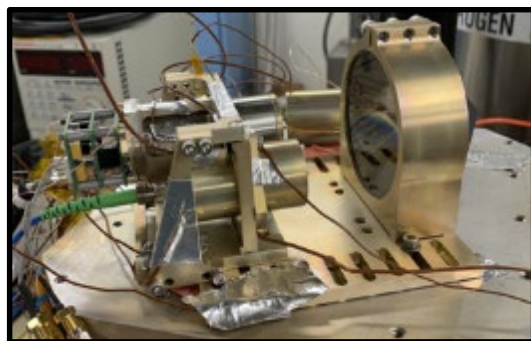
Space Terminal



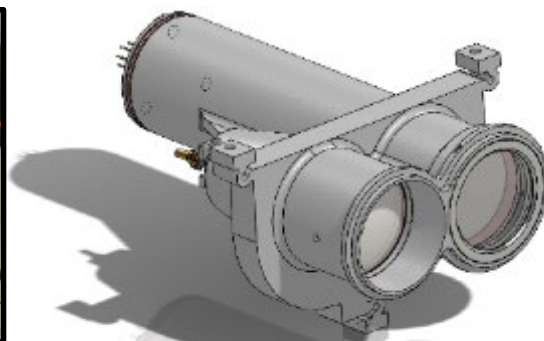
Prototype TBIRD w/ Rev B



Uplink Prototype Testing in Progress



Prototype Optical Subassembly Testing



Redesign Underway

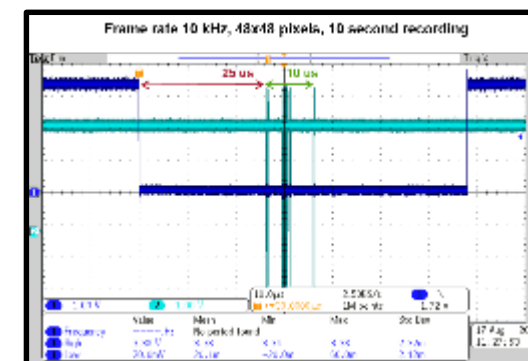
Ground Terminal



Dome Construction at Millstone Hill



COTS Telescope Installation (Sept 2020)



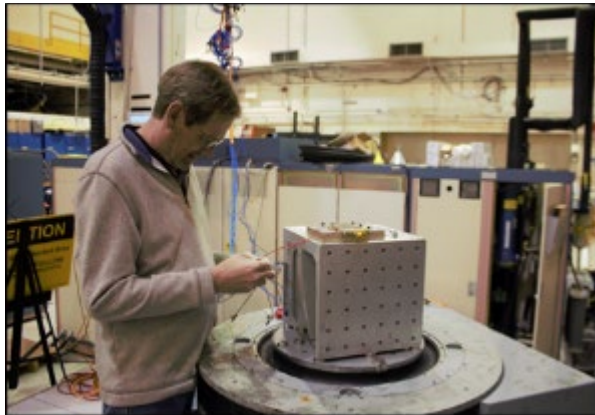
Jitter Testing Validated Commercial Server Approach



Ground Station Back-end Optics Delivered

Risk Reduction for Space Environments

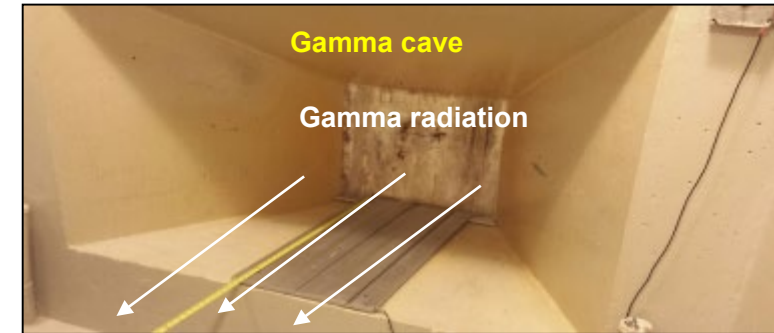
Shock / Vibration



Thermal/Vacuum



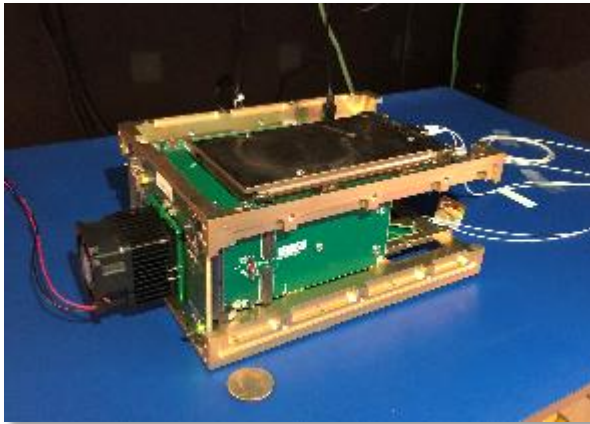
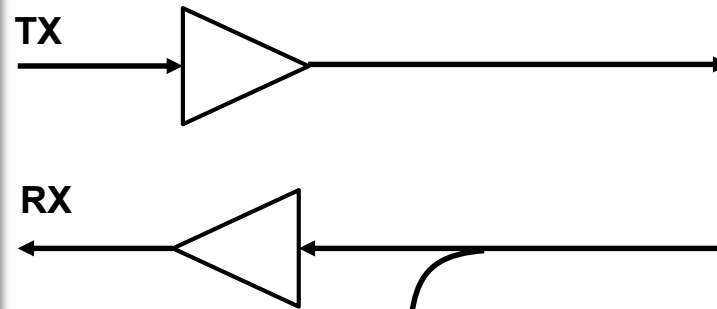
Radiation



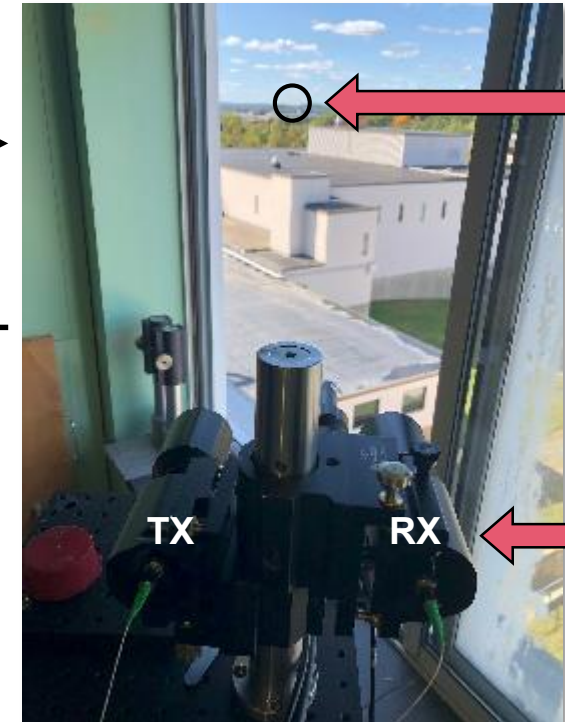
COTS components validated in space environments

100 Gbps Horizontal Link Testbed

100 Gbps TX and RX



3-km Atmospheric Link



Retro-reflector

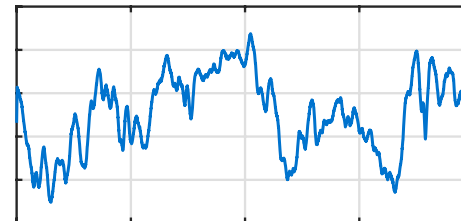
4-cm fiber collimators (2x)

Emulated Uplink (FPGA)

- 1-3 kbps ARQ messages
- 7 ms LEO round-trip time

✓ Frame 1
✓ Frame 5
✓ Frame 4
...

RX ARQ Frame Telemetry

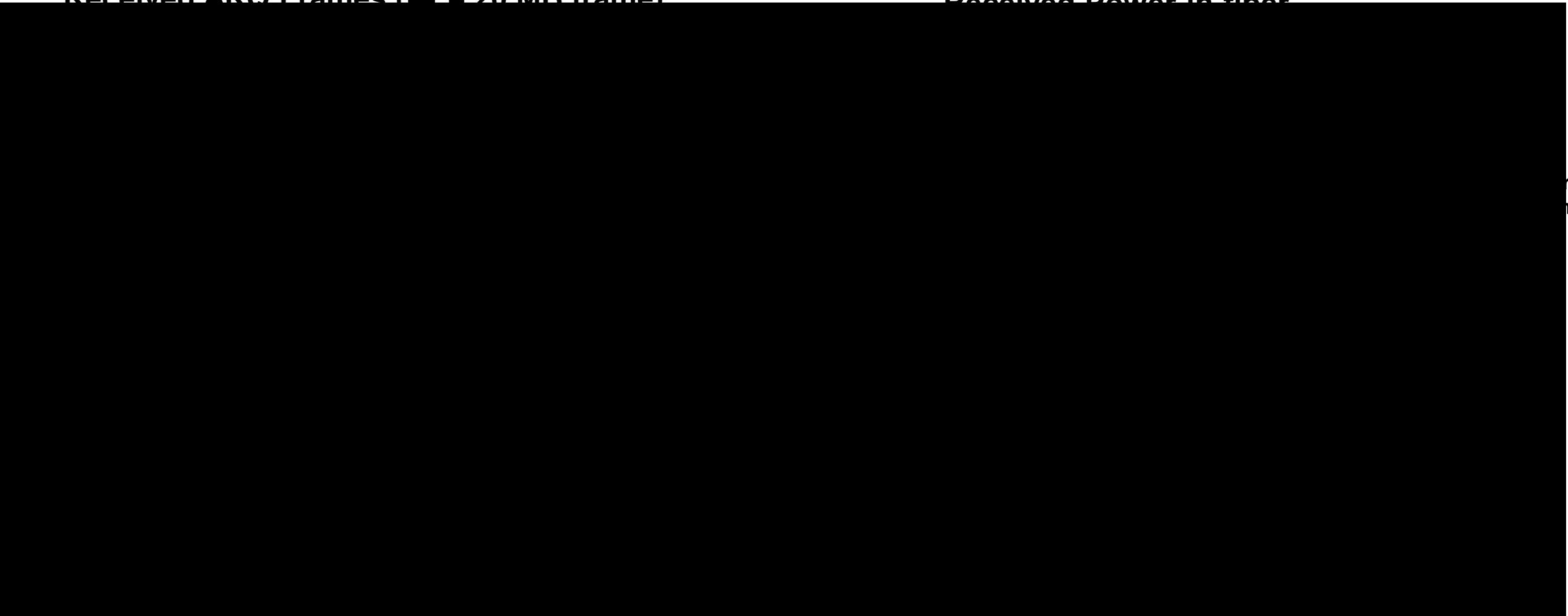


RX power-in-fiber

Playback of 100 Gbps Horizontal Link Performance

Received ARO Frames (■ = 20 MB frame)

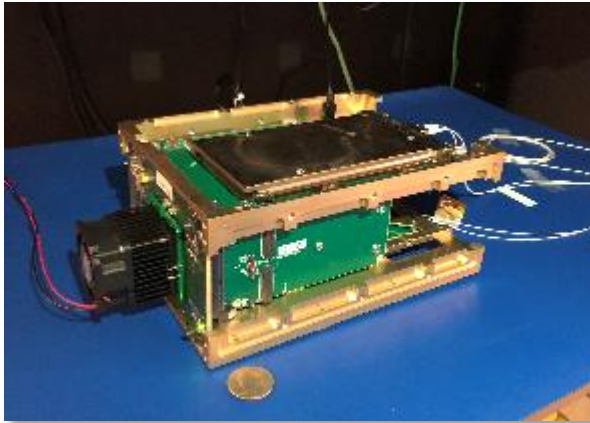
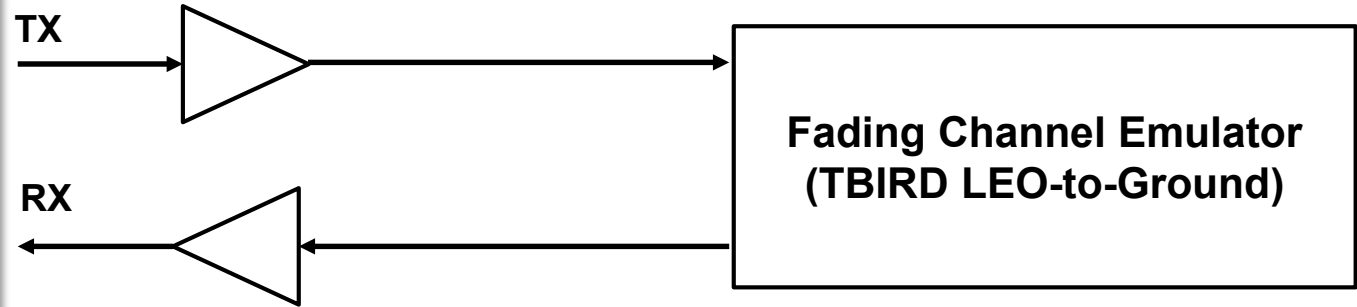
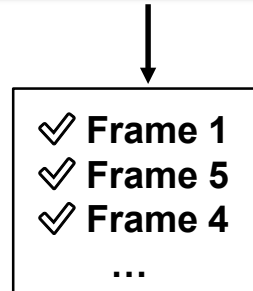
Received Power in fiber



hold

100 Gbps LEO-to-Ground Testbed

100 Gbps TX and RX

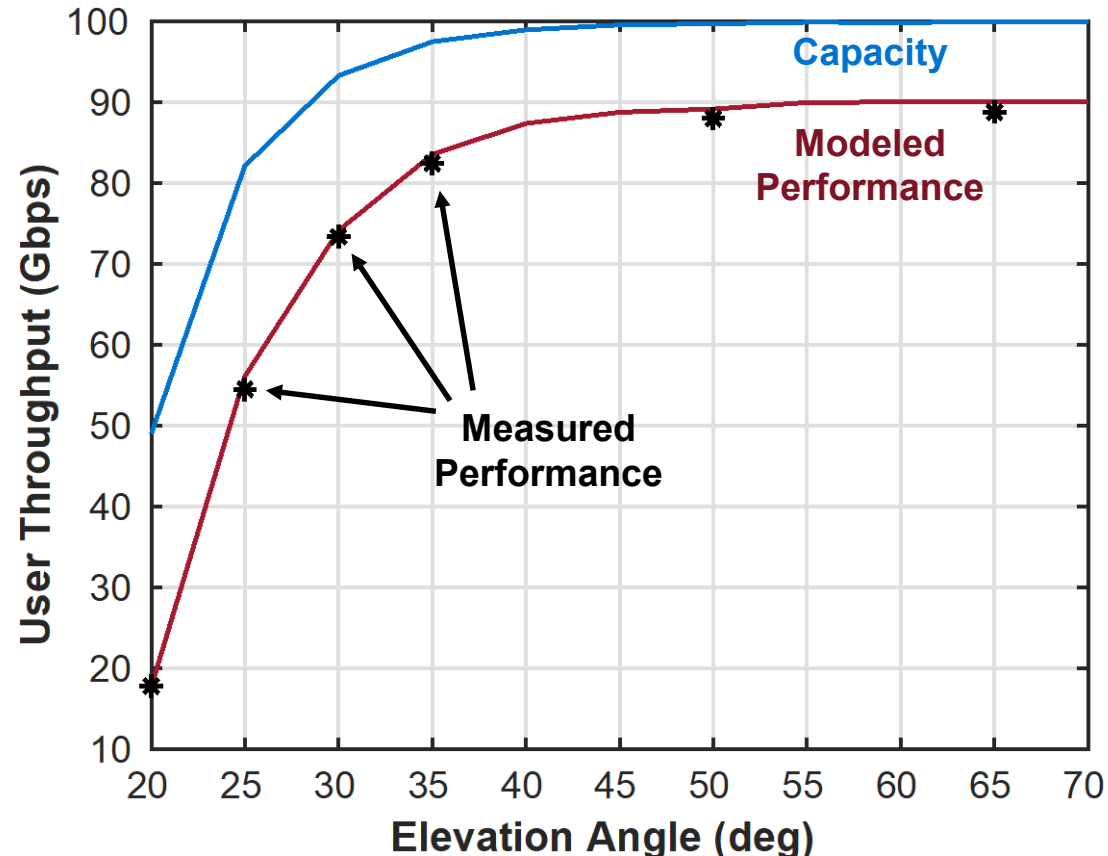


**RX ARQ Frame
Telemetry**

**Emulated Uplink
(FPGA)**

- 1-3 kbps ARQ messages
- 7 ms LEO round-trip time

Performance in Emulated LEO-to-Ground Channel



Modeled performance accounts for:

- ARQ uplink rate constraint (3 kbps)
- Nonzero receiver recovery time (2 ms)
- ARQ overhead (10%)

~90 Gbps error-free throughput achieved over emulated LEO-to-Ground channel at moderate elevation angles