TeraByte InfraRed Delivery (TBIRD): Delivering 200 Gbps from Space to Ground

Jade Wang

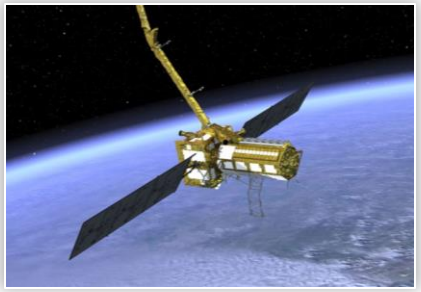
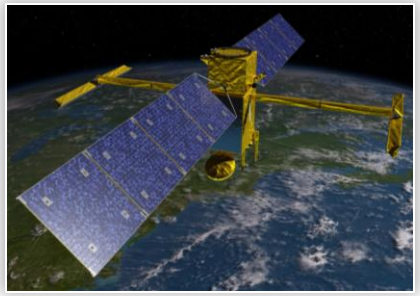
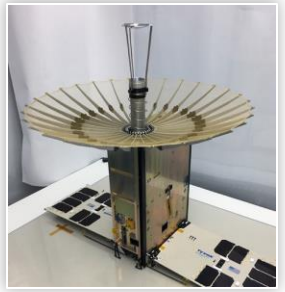
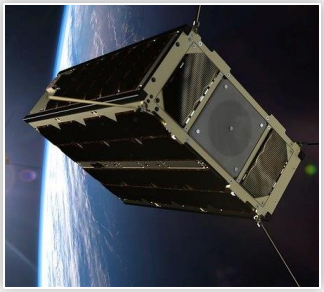
1 April 2025

This material is based upon work supported by the National Aeronautics and Space Administration under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

jpwang@ll.mit.edu

Large Data Volumes in Low Earth Orbit (LEO)

	Large and Medium Satellites			Small Satellites		
						
	Hyperspectral Imager Suite (HISUI) on International Space Station	NASA-ISRO Synthetic Aperture Radar (NISAR)	NASA Surface Water and Ocean Topography (SWOT)	JPL RainCube	GOMX-4B Hyperspectral Camera	UH Manoa Hyperspectral Thermal Imager (HyTI)
	In-orbit	(2024)	In-orbit	2019	In-orbit	(2023)
Data Volume	0.3 TB/day (“downlinked”)	4.8 TB/day (downlinked)	20 TB/day (generated) 1 TB/day (downlinked)	1 TB/day (generated)	2 TB/day* (generated)	8 TB/day (generated)

*Assumes 25% operational duty cycle

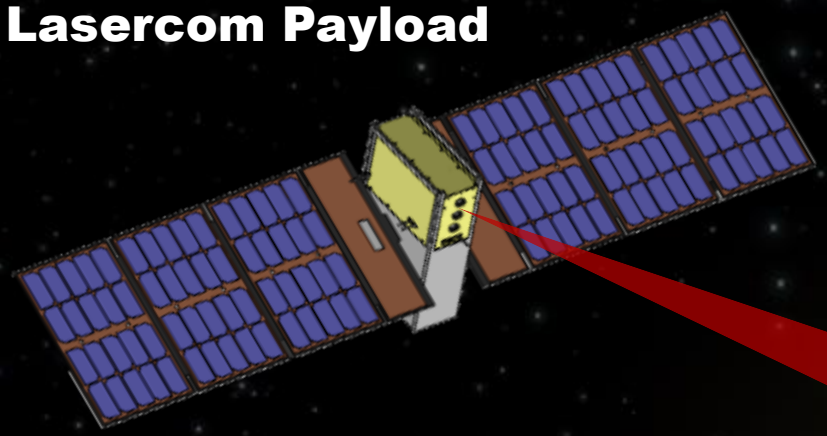
Image Credits, Left to Right: NASA, JPL, JPL, JPL, ESA, NASA

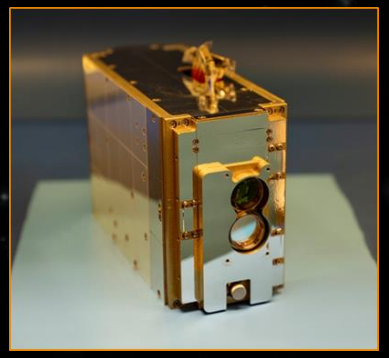
State-of-the-art instruments on LEO platforms can generate raw data volumes of terabytes per day

TB: Terabyte

TeraByte InfraRed Delivery (TBIRD) Mission

6U CubeSat in LEO (~12 kg)
3U Lasercom Payload





- Leverage fiber telecom equipment for 200 Gbps burst delivery (TBs per pass)
- Achieve robust data transfer through atmospheric channel
- Demonstrate body pointing architecture with payload pointing feedback

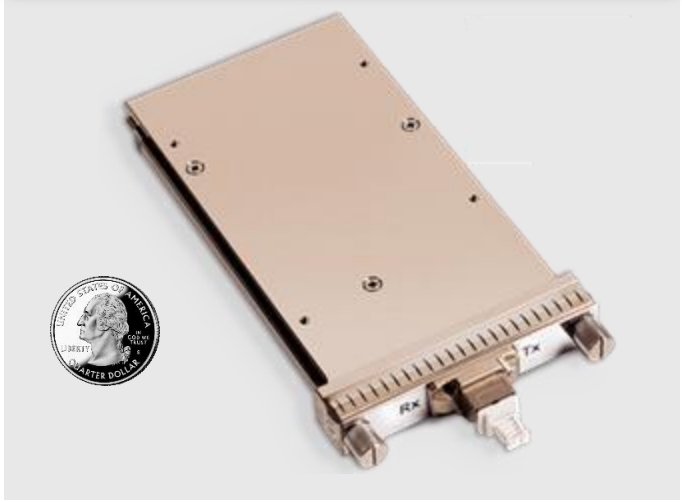
200 Gbps downlink

Ground terminal at JPL's Optical Communication Telescope Laboratory (OCTL) in Southern California

LEO: Low Earth Orbit
TB: Terabyte

Enabling Commercial Technologies

High-Rate Optical Modem



100 Gbps Fiber Telecom Transceiver Compact Form Pluggable (CFP)

~$10k/unit

Large, High-Speed Storage

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

~$100/unit

Optical Amplifier

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

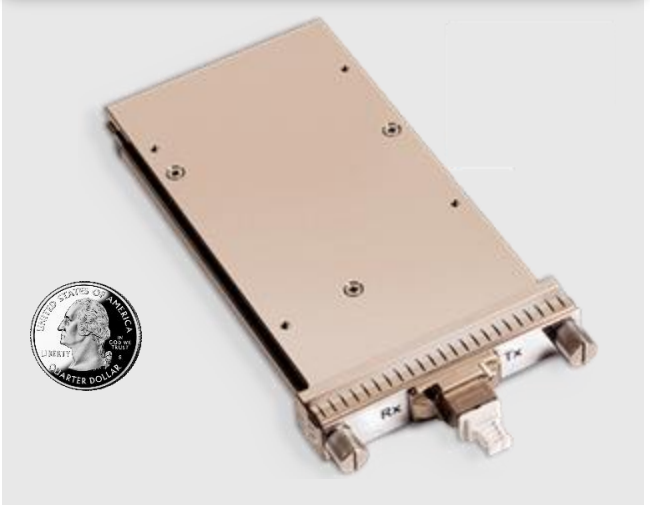
~$10k/unit

Highly integrated commercial components enable small, low-power, low-cost space terminal designs

TBIRD Objectives

1. Downlink >1 terabyte error-free in a pass
2. Demonstrate precision closed-loop body pointing
3. Validate use of terrestrial commercial off-the-shelf (COTS) components in space
4. Operate on multiple wavelength channels (2 x 100 Gbps)

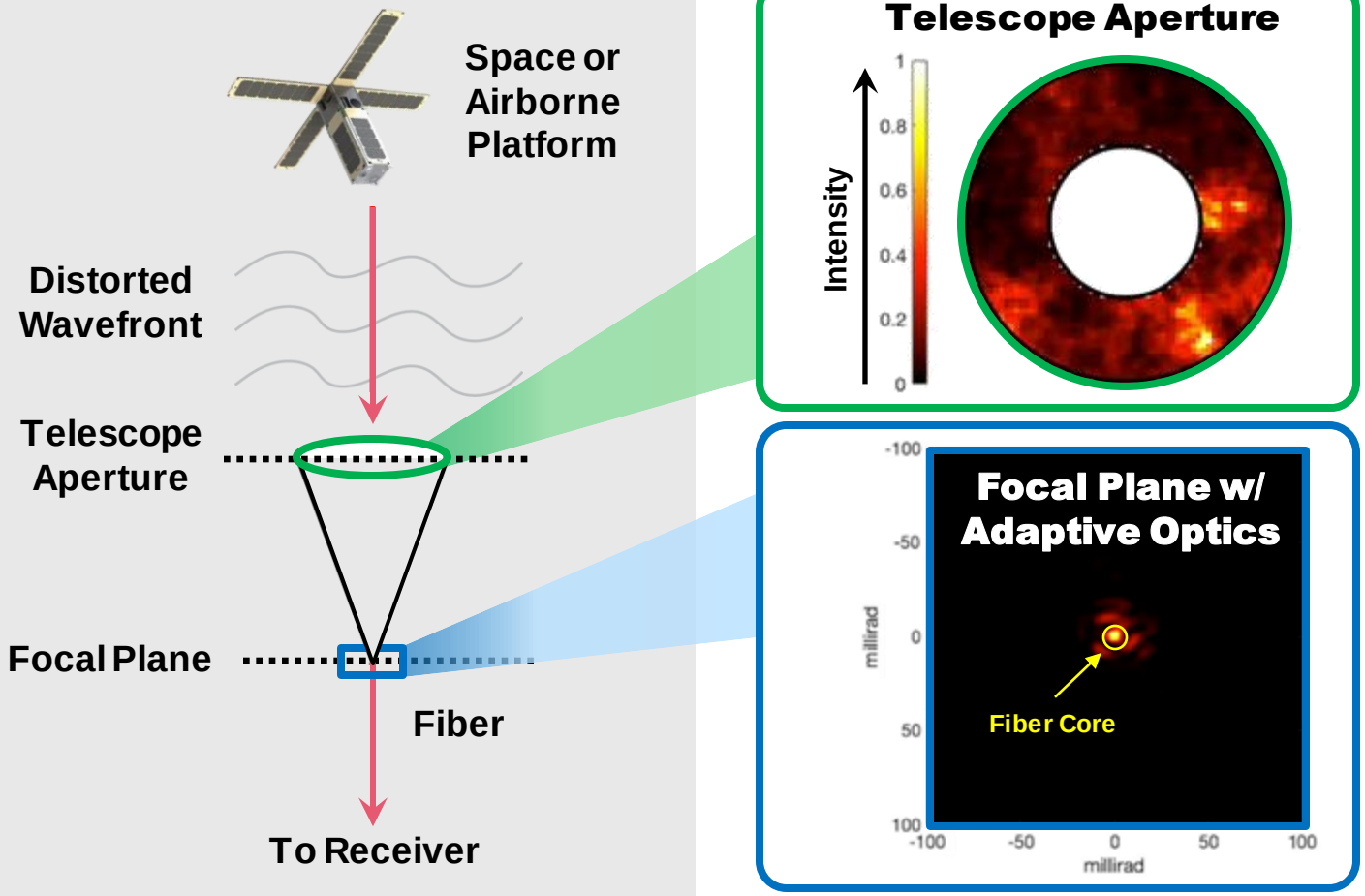
100 Gbps COTS Transceiver Terrestrial Fiber Telecom



- Dual-polarization QPSK
- ASIC for DSP and FEC

COTS: Commercial Off-the-Shelf
QPSK: Quadrature Phase Shift Keying
DSP: Digital Signal Processing
FEC: Forward Error Correction
ASIC: Application-specific Integrated Circuit

Impact of Atmospheric Turbulence on Fiber-Based Receivers



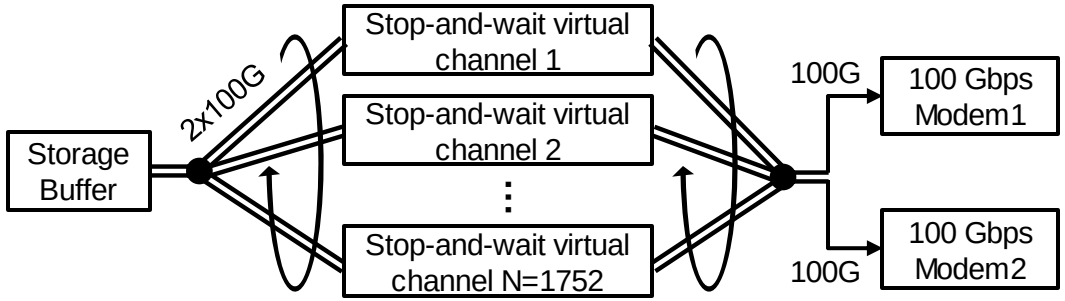
- Turbulence causes **scintillation**
  - Power-in-bucket fluctuations

- Turbulence causes **coupling loss**
  - Adaptive optics system attempts to correct wavefront
  - Spot wanders and breaks up

Communications architecture must be robust to atmospheric fading

TBIRD Automatic Repeat ReQuest (ARQ)

Space Terminal



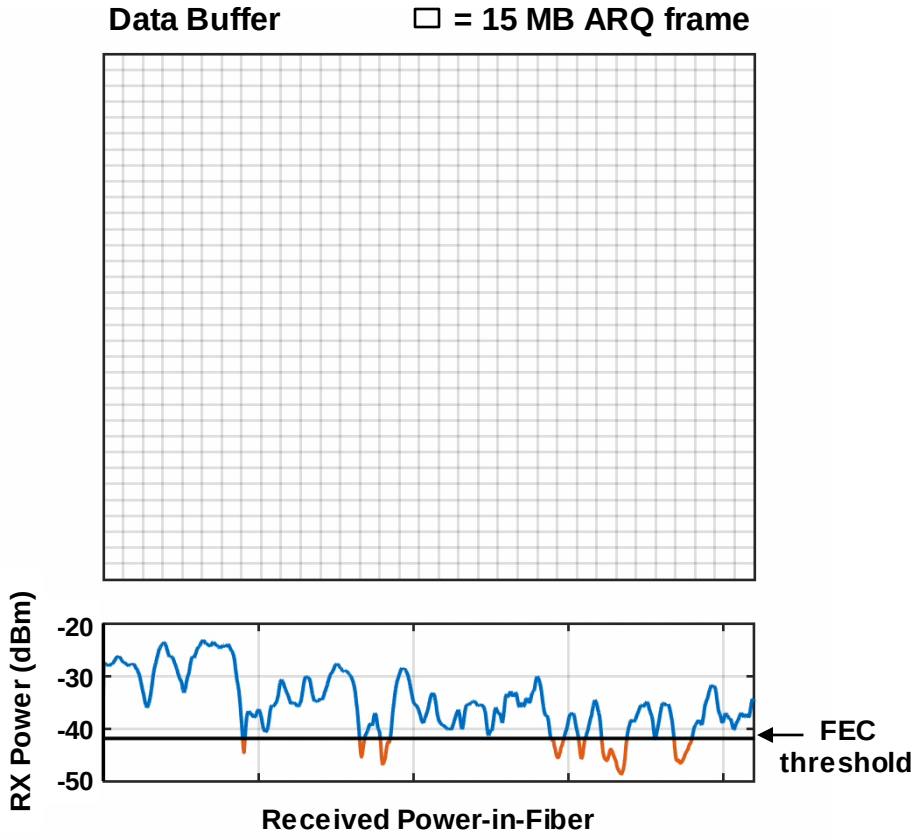
- **Selective-repeat ARQ**
- **Large ARQ frames (15/30 MB)**
- **~2000 virtual channels**

100 or 200 Gbps Downlink

~2 kbps Uplink Feedback

~kbps sufficient for kHz class fading dynamics

Ground Terminal



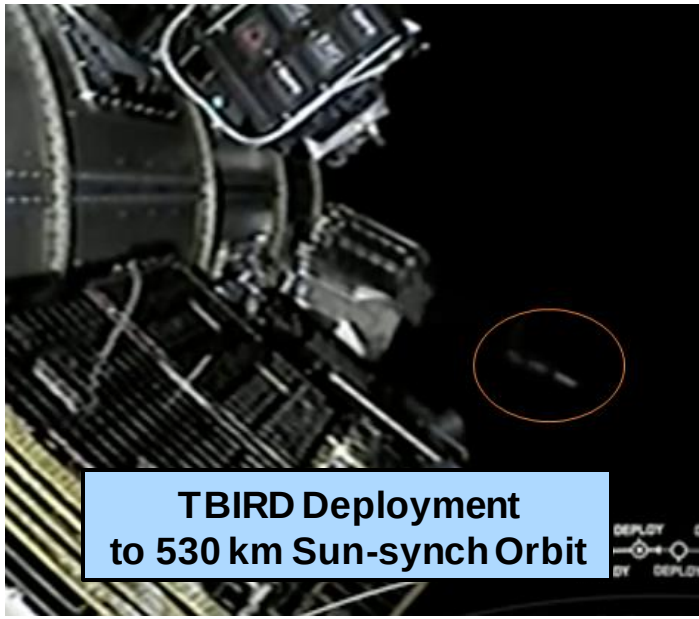
FEC: Forward Error Correction

TBIRD Demonstration

Environmental Testing
(Vibration and Thermal Vacuum)

Payload Delivery for
Spacecraft Integration

Launched and Deployed
May 25, 2022



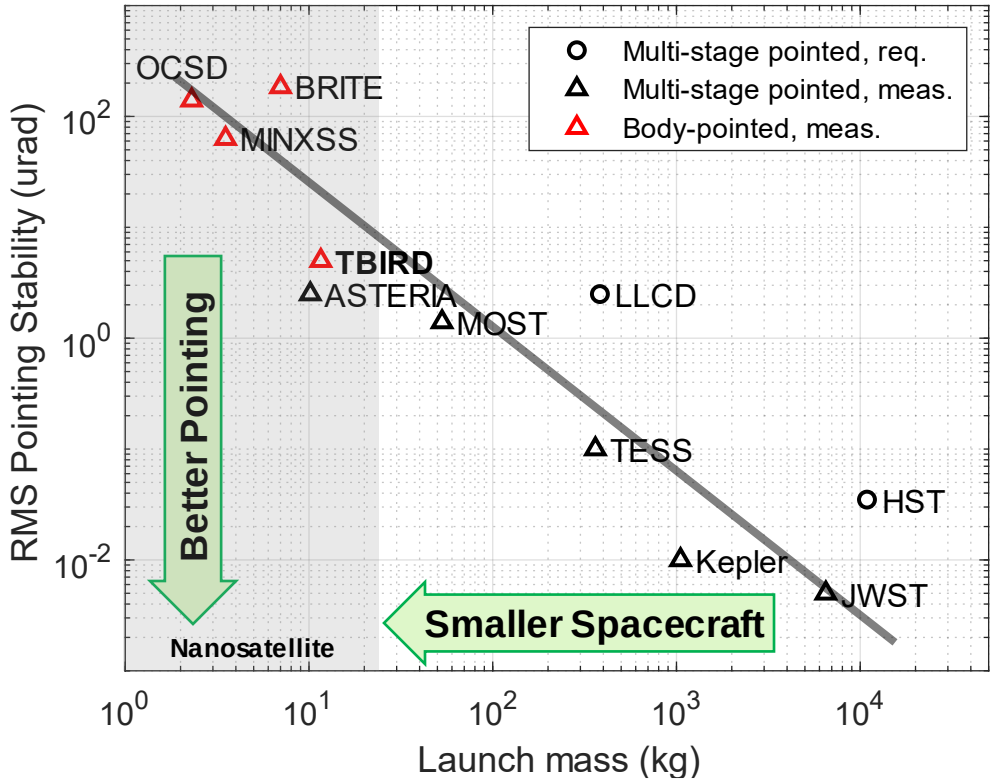
TBIRD Deployment
to 530 km Sun-synch Orbit

Lasercom Operations
90+ Passes to Date

State-of-the-Art in Nanosatellite Pointing

- TBIRD pointing stability is 5 urad (1 arcsec) RMS, 1-axis
- TBIRD has demonstrated best-in-class body pointing performance
- First nanosatellite to achieve arcsecond-class pointing at high slew rates (up to 1 deg/s)
- TBIRD pointing feedback improves body-pointing by an order of magnitude
- Substantial improvement in commercial bus performance

Pointing Stability for Precision Pointed Missions



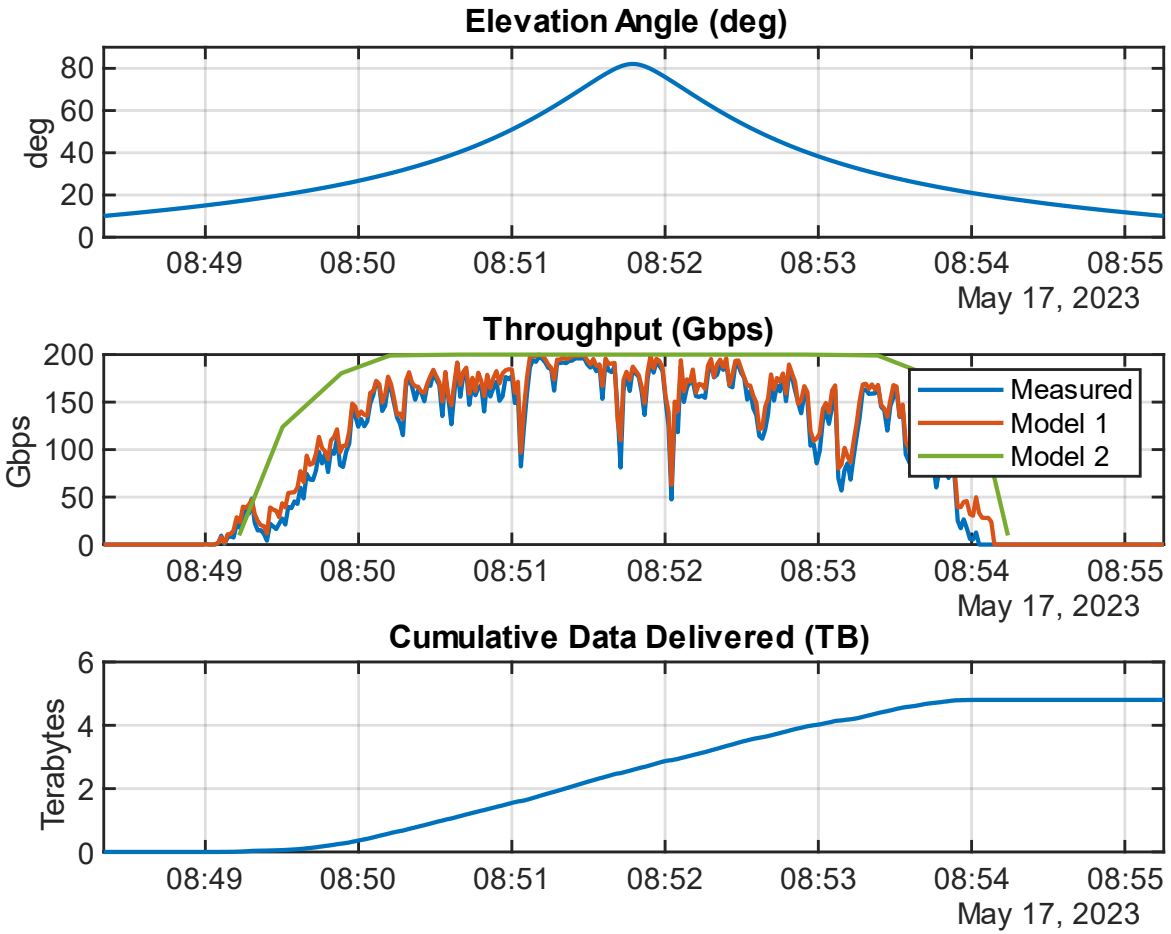
TBIRD has demonstrated the best body-pointing to date at high slew rates

RMS: Root Mean Squared

Data Delivery Example 5/17/23

- Operated in 200 Gbps mode
- Downlinked 4.8 TB error-free in 5 minutes
- Reached 200 Gbps throughput for brief periods
- TBIRD demonstrated fastest downlink from space

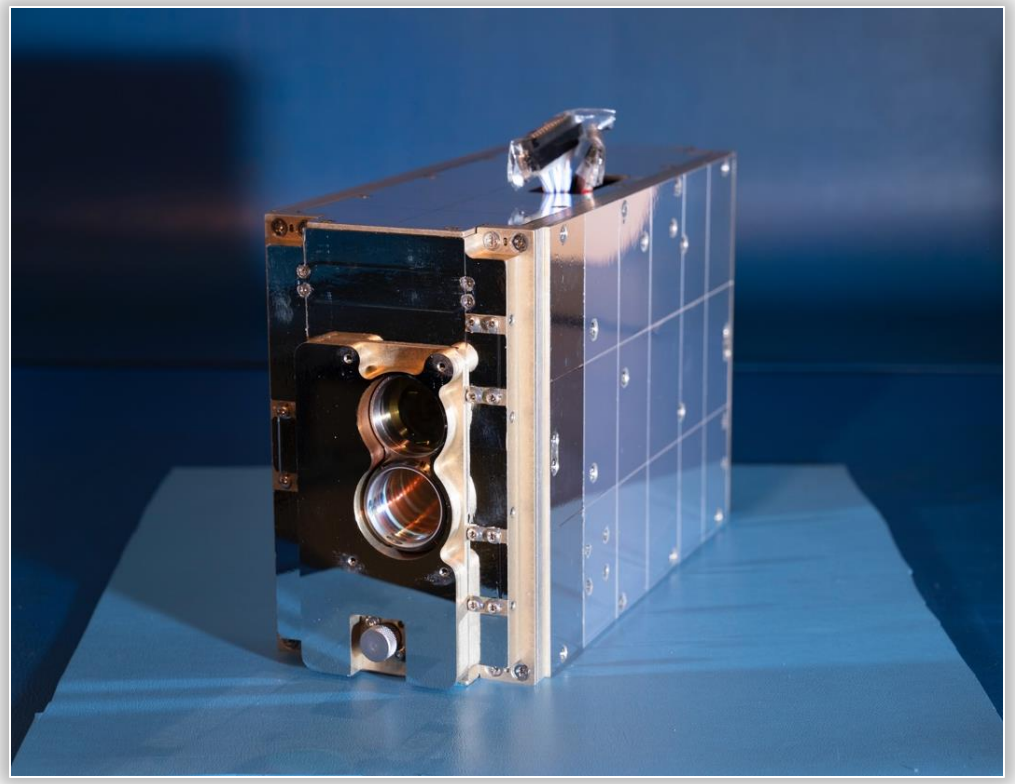
Fastest data connection between a satellite in orbit and a ground station



TB: Terabyte

Mission Highlights to Date

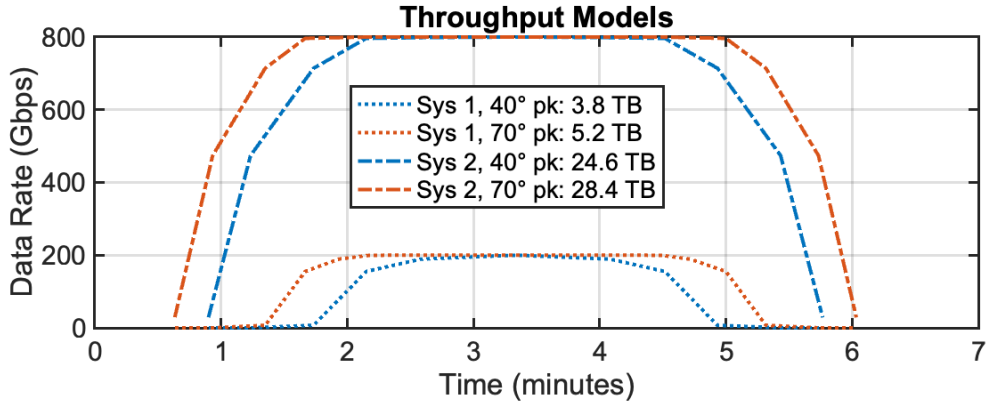
- **TBIRD operated successfully for 2+ years: May 2022 – Sept 2024**
- **Key achievements**
  - **~5-urad Cubesat closed-loop body pointing**
  - **100/200 Gbps downlinks from LEO**
  - **Downlinked >1 terabyte error-free in 20 passes through the atmosphere at 2 ground stations**
  - **Performed end-to-end transfer from space buffer to ground buffer at 100 Gbps**
  - **Validated use of terrestrial COTS components in space**
- **All primary mission objectives met**
- **Technology now available**



COTS: Commercial Off-the-shelf
LEO: Low Earth Orbit

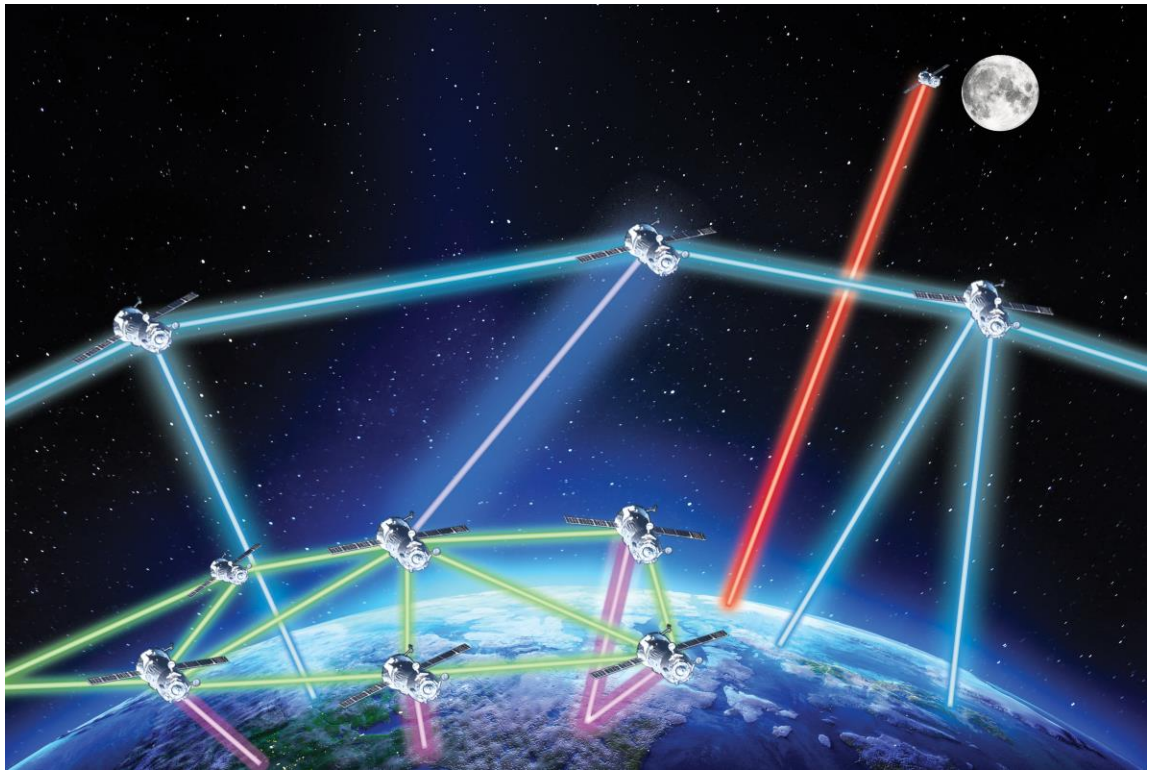
Implications for Future High Rate Lasercom Systems

- **Pointing accuracy demonstrated with TBIRD/PTD-3 (5 urad RMS) could support much narrower lasercom beams**
- **Narrower beams enable more data delivery with smaller ground terminals**



	TBIRD (Demonstrated)	System 1: Very small ground terminal	System 2: Higher data rate
Beamwidth (FWHM)	380 urad	100 urad	100 urad
Ground terminal aperture	100 cm	25 cm	60 cm
Max data rate	200 Gbps	200 Gbps	800 Gbps
Data delivery	Several terabytes per pass	Several terabytes per pass	Tens of terabytes per pass

Impact on Proliferated LEO Constellations



- Today's constellations focus on optical crosslinks with RF downlinks
- Bandwidth constraint on downlink can be eliminated through adoption of TBIRD-type technologies
- Crosslink and downlink capacity for pLEO constellations can be substantially increased through TBIRD technologies