Review of laser-based communication systems in space missions

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Outline

- A brief history on space communication
- Introduction of optical communication into the scenario
- Lunar Laser Communications Demonstration (LLCD)- 2013
- Working principle of laser communication in space mission
- Laser Communication Relay Demonstration (LCRD)- 2021
- TeraByte InfraRed Delivery (TBIRD)- 2022
- Summary

A little history…

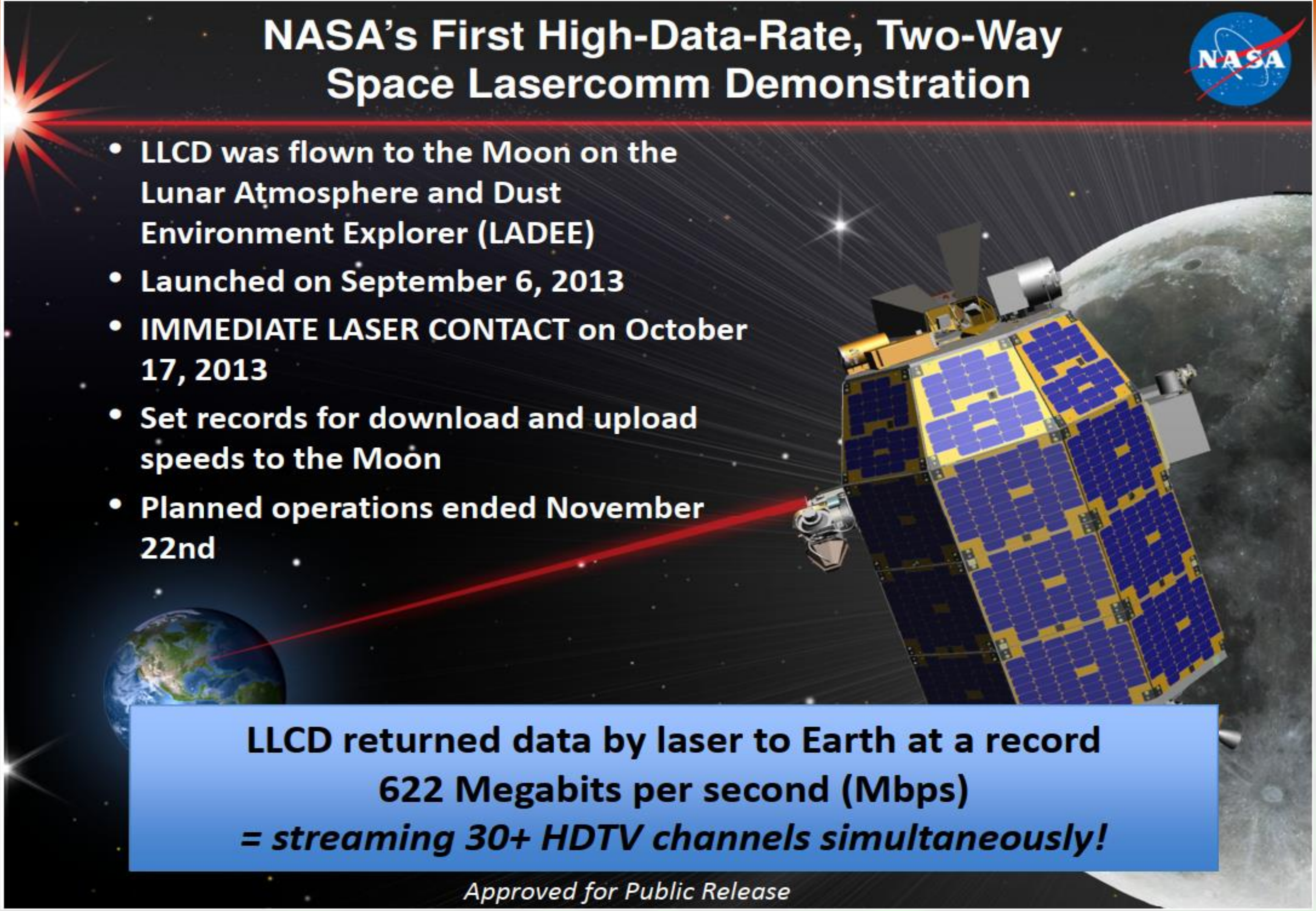
- NASA has always relied on radio communication systems to meet its data transmission and navigation needs.
- Lunar Recoinnaissance Orbiter (LRO) works with RF Ka-band at 100 Mbps.
- At the higher frequencies there is greater atmospheric and rain attenuation adding to increased free space loss.
- This needs to be compensated for with higher power transmission and/or high gain antennas with narrower beamwidths.

Band	Frequency
VHF	30 to 300 MHz
UHF	300 to 1000 MHz
L	1 to 2 GHz
S	2 to 4 GHz
C	4 to 8 GHz
★ X	8 to 12 GHz
Ku	12 to 18 GHz
★ K	18 to 27 GHz
★ Ka	27 to 40 GHz
V	40 to 75 GHz

https://www.nasa.gov/smallsat-institute/sst-soa/communications

A new spectrum

- Today's mission communication requirements have begun to stress the current communication networks' capabilities.
- One solution for NASA is to look beyond the radio and microwave portions of the electromagnetic spectrum.
- Optical links operate at a much higher frequency than RF links, generally at infrared or visible bands. Higher frequencies result in wider bandwidths which result in higher data rates.
- In optical fiber communication, data is transported through fibers while in free space, laser beam is beamed through optical telescopes.
- NASA is venturing into a new era of space communications using lasers, beginning with the Lunar Laser Communications Demonstration (LLCD).
- LLCD established the ability to encode data onto a beam of laser light.



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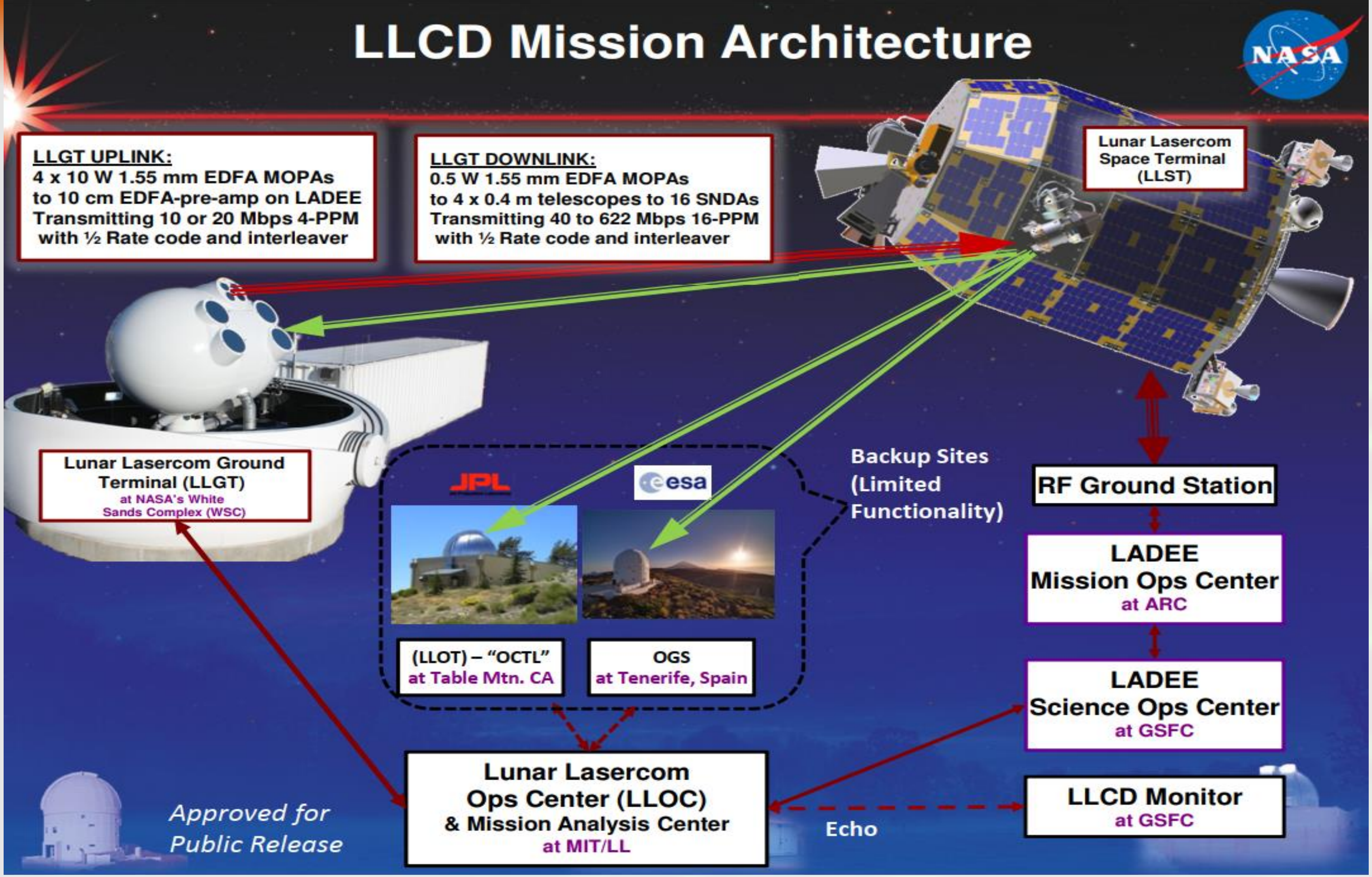
Presentation to the JHU Aerospace Affinity Group,
June 11th, 2014



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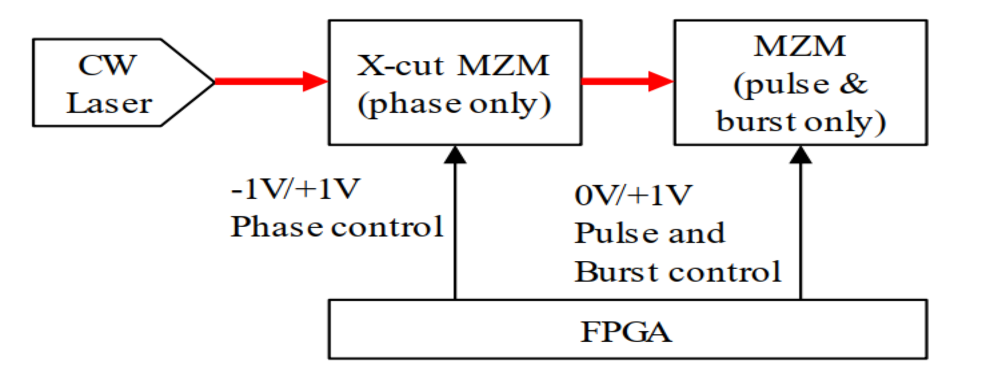
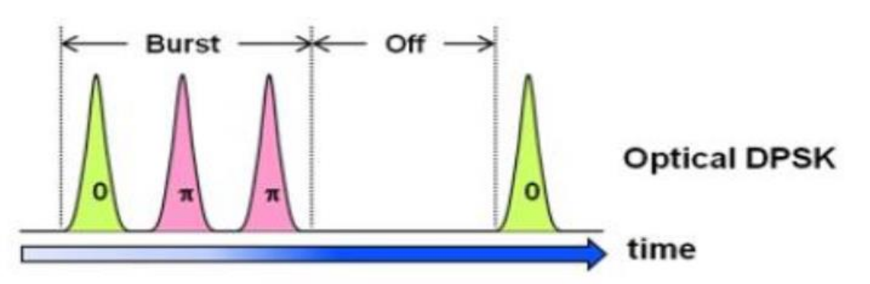
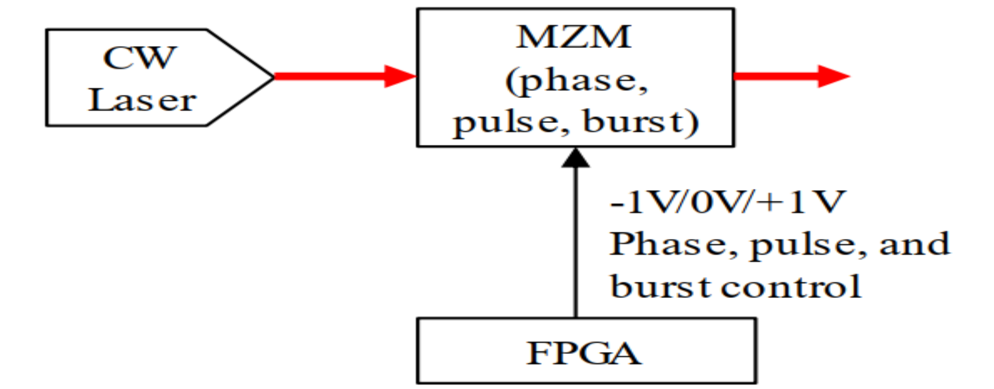
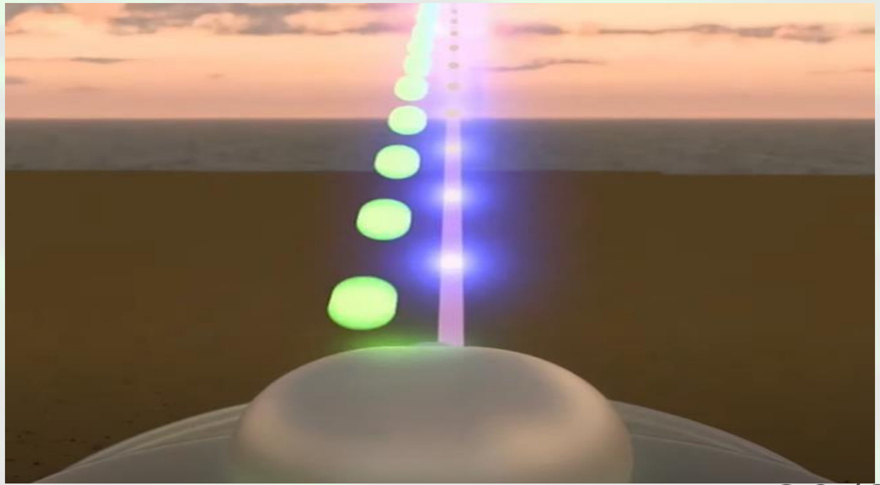
Compliant Optical waveform generation

- The generation of an optical waveform requires a system capable of generating an optical pulse with a phase of π radians, an optical pulse with a phase of 0 radians, or no optical pulse for every slot at the line rate of 2.880 GHz.







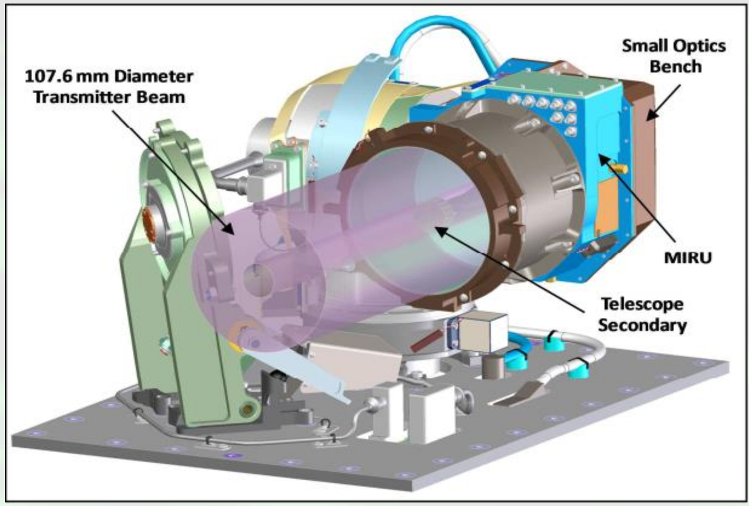


https://doi.org/10.1109/AERO50100.2021.9438448

https://www.youtube.com/watch?v=RRJIc5cNVAA&list=PLZdKwNtcnoh5y04yESuHoF10grShfl0Il&index=2

Lunar Lasercom Space Terminal (LLST)

- The optical module is a 10-centimeter Cassegrain telescope (using a primary concave mirror and a secondary convex mirror aligned about the optical axis to focus light on the detector).
- A wide field of view Indium-Gallium-Arsenide Detector provides spatial acquisition and coarse tracking of the optical uplink signal.
- A continuous wave laser at 1550 nm is coupled with a Lithium niobate optical modulator and accomplishes the electrical to optical data conversion.
- The amplification of the optical data to 0.5W is achieved by a two-stage Erbium-Doped Fiber Amplifier (EDFA). Each stage is pumped with two grating stabilized 976 nm pump lasers.



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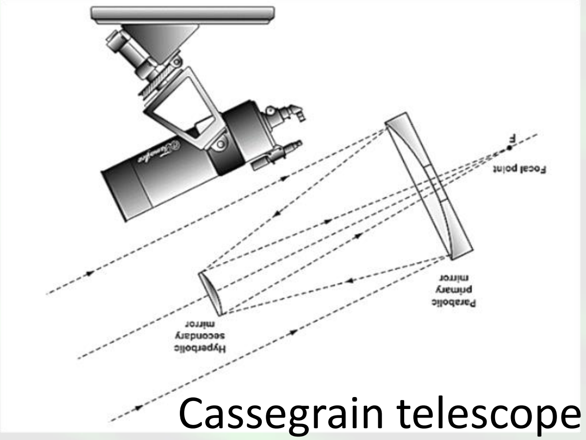
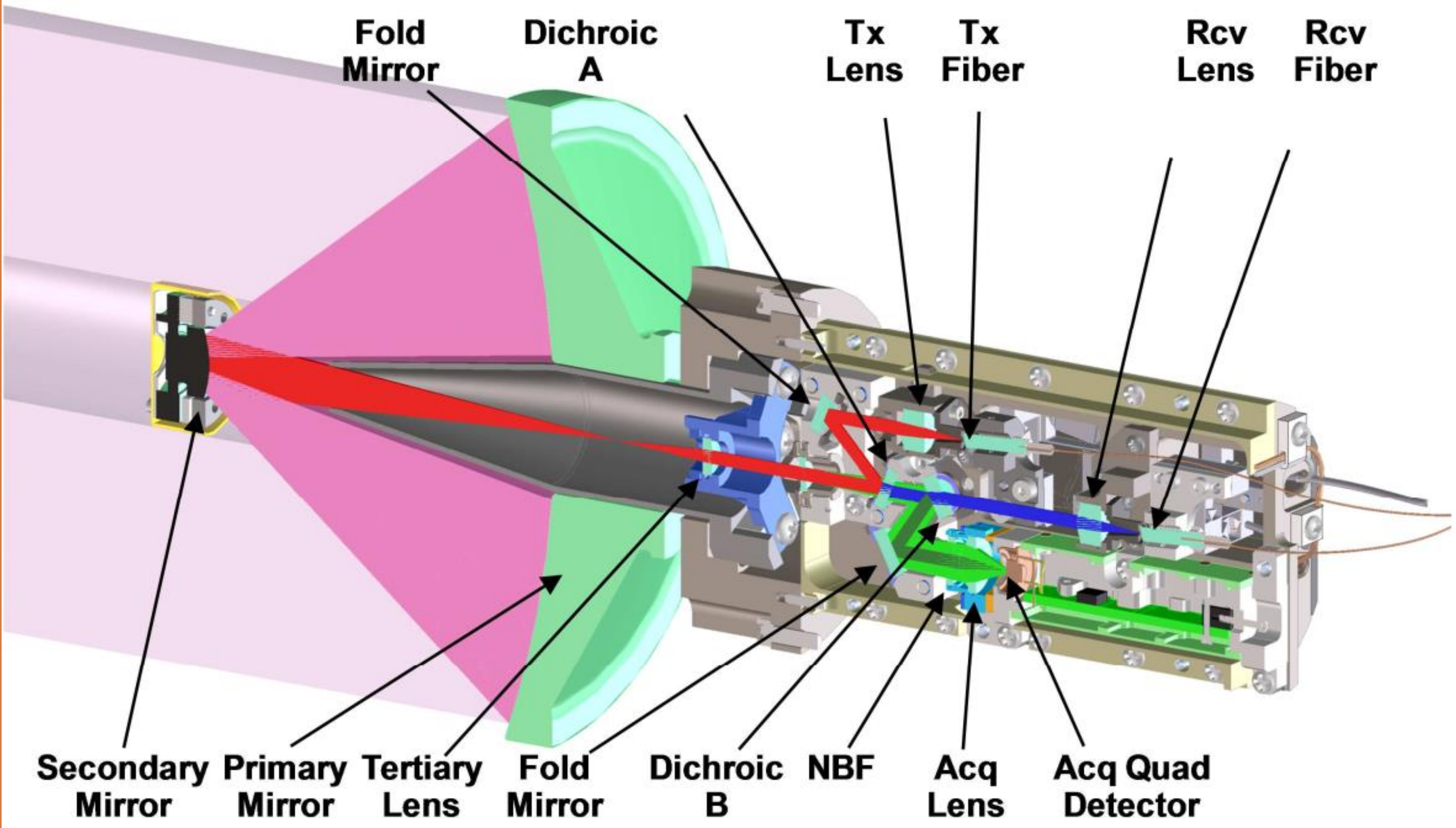
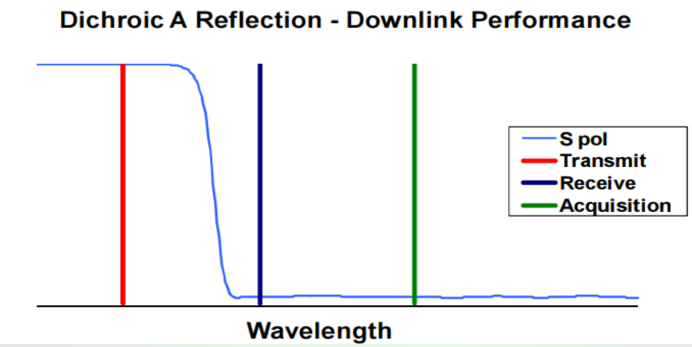


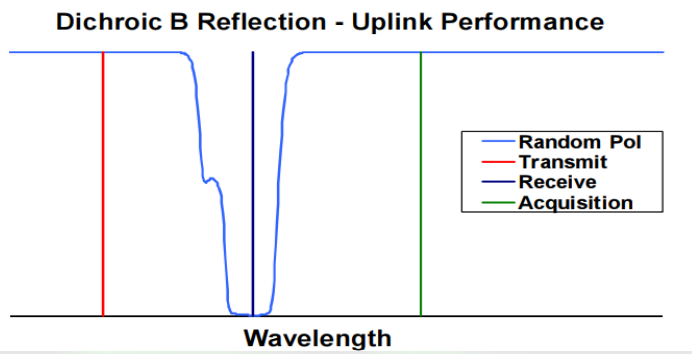
Cassegrain telescope

By Szőcs Tamás Tamasflex - Own work, CC BY-SA 3.0, https://en.wikipedia.org/w/index.php?curid=25089001

LLST Optical train and Optical Assembly







https://doi.org/10.1117/12.2304194

Lunar Lasercom Ground Terminal (LLGT)

- The LLGT telescope array consists of eight telescopes - 4 uplink transceivers and 4 downlink receivers -on a common T-bar elevation over-azimuth mount.
- The uplink transceivers are based on custom 15-cm refractive telescopes. Each transceiver includes a custom back-end optical system that includes fiber-launching optics for transmitting a 10 W uplink beam.
- The back-end optics also include mechanisms for adjusting output beam divergence and aligning transmit and receive boresights.
- The downlink receivers are commercial 40-cm Cassegrain telescopes mated to custom back-end optics (similar to that of uplink transceivers).

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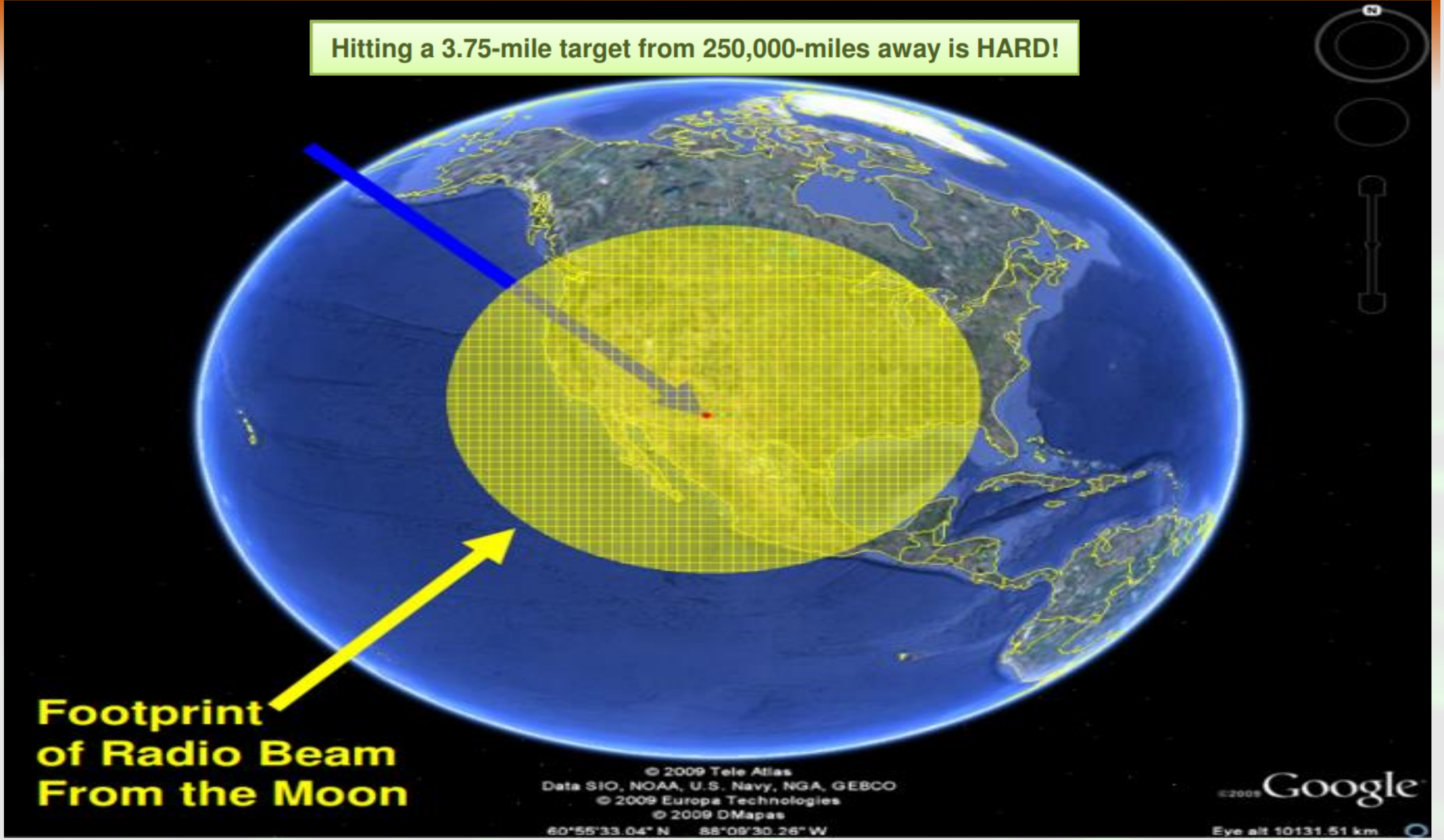

Active tracking system with a broad beam from the ground and the space terminal use this to precisely locate the ground terminal

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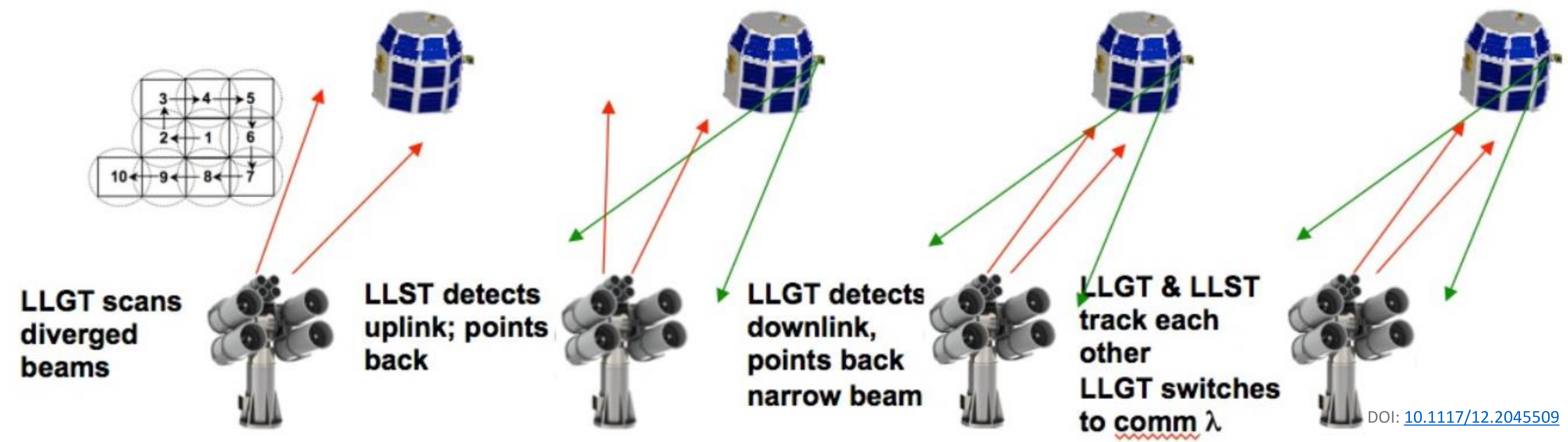
Acquisition sequence employed by LLCD



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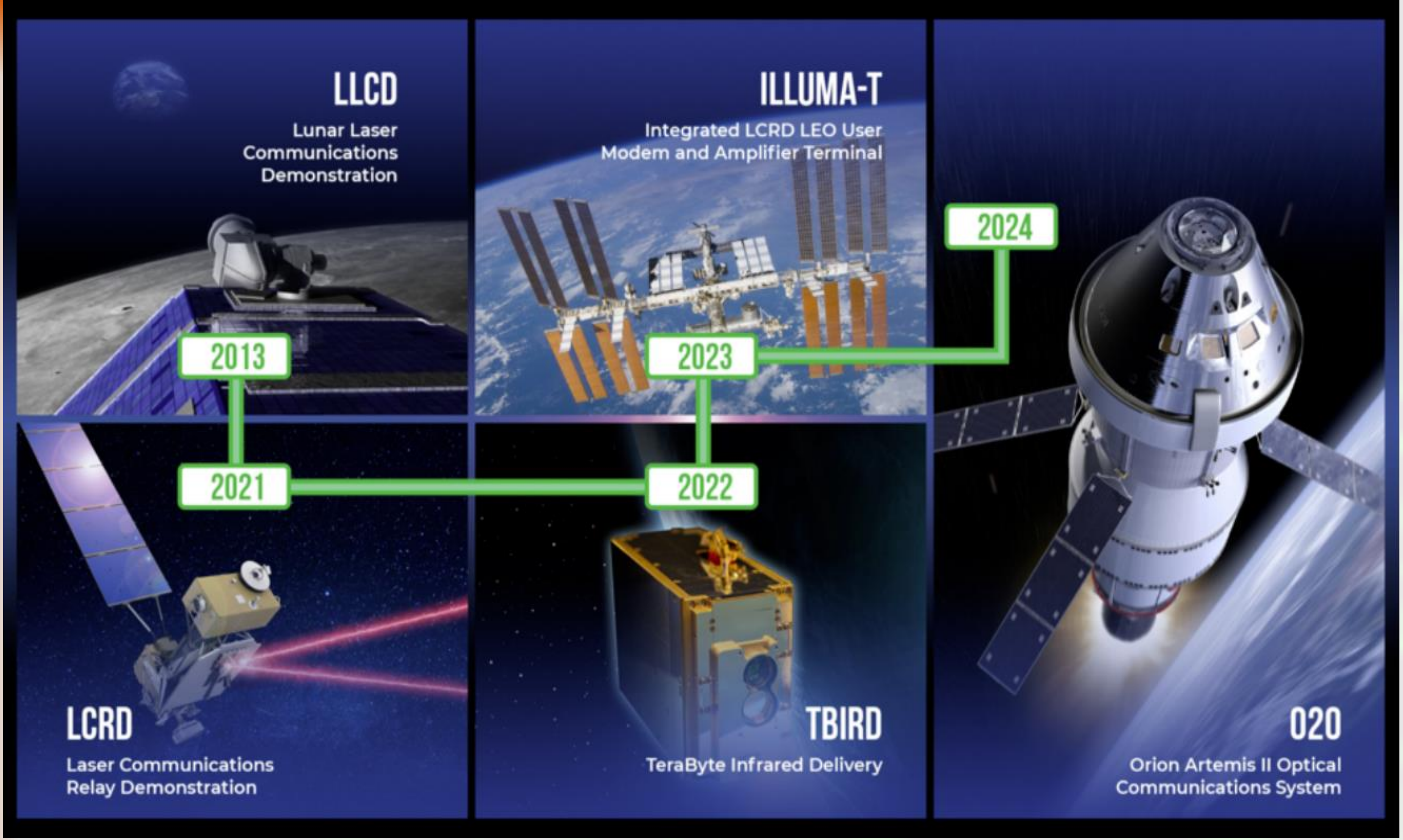
- **The wavelengths of each transmitter are detuned to allow for non-coherent combining of the signals at the space terminal.**
- **To operate the system in the presence of atmospheric turbulences while preserving the polarization of the downlink signal, a polarization-maintaining fiber is used to couple the receiver telescopes to the detectors.**
- **The amount of lasercomm sessions to about 5 per day.**

3 major time-scales of signal disruption

- **Turbulence and fading in millisecond time scale**
  - taken care in hardware with error correcting code
- **Delay time round trip Earth-Moon: about 2.5 seconds**
  - nothing much can be done as we still deal with Physics in light speed
- **Cloud coverage (a major issue)**
  - fixed with DTN (Disruption Tolerant Networking)
  - back-up ground terminals
  - back-up RF communication

Advantages of laser communication

- Laser communications systems provide missions with increased data rates compared to traditional radio waves.
- Bandwidth increases of 10 to 100 times more than radio frequency systems.
- Additionally, optical communications provides decreased size, weight, and power requirements.
- Smaller size means more room for science instruments.
- Less weight means a less expensive launch.
- Less power means less drain on the spacecraft’s batteries.
- With optical communications supplementing radio, missions will have unparalleled communications capabilities.



https://www.nasa.gov/feature/goddard/2022/the-future-of-laser-communications

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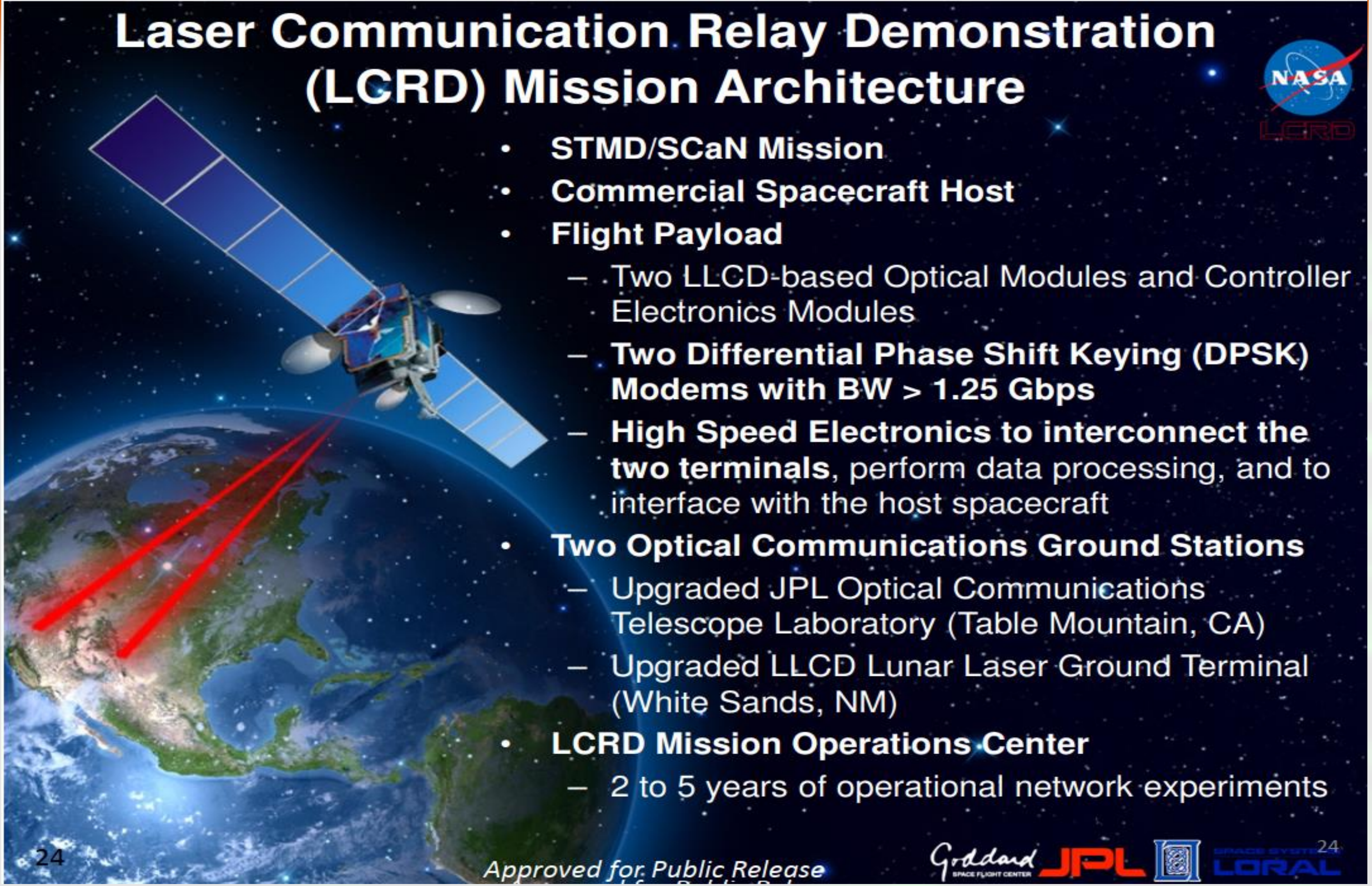

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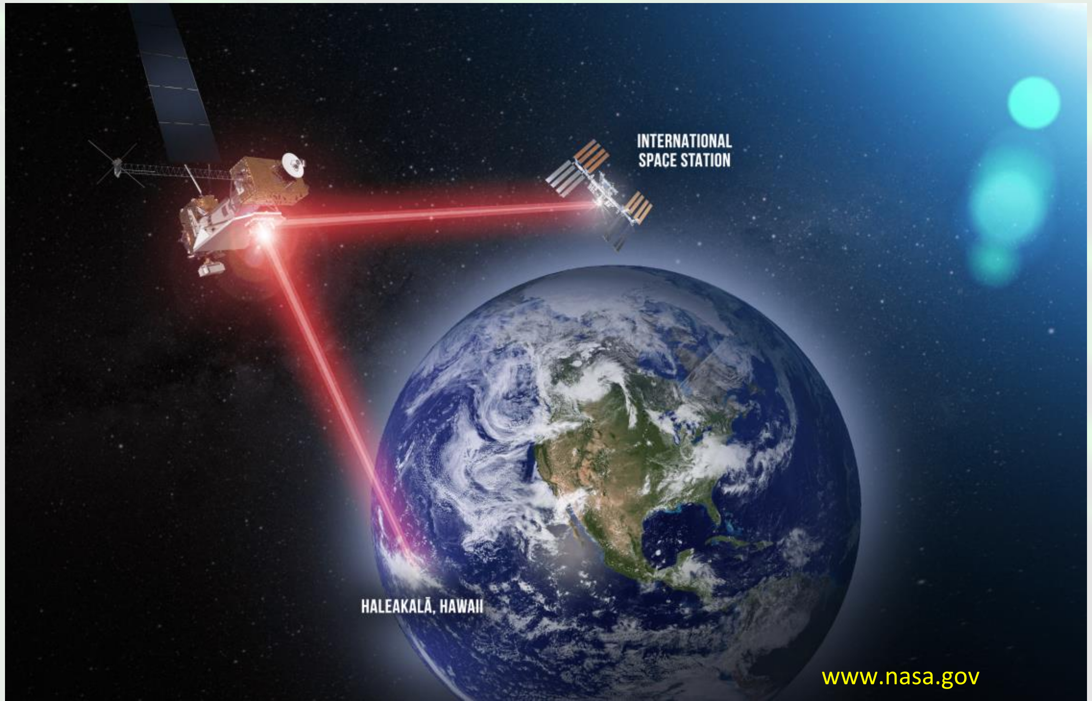
Laser Communication Relay Demo (LCRD)

- LCRD is built on the success of LLCD.
- While LLCD was demonstrated in lunar orbit (384,400 km), LCRD is in geo-stationary earth orbit (35,405 km).
- LCRD's ability to both send and receive data from missions and the ground stations makes the system two-way. Together, these capabilities make LCRD NASA's first two-way, end-to-end optical relay.



LCRD relay and its first user

- The LCRD payload was launched on December 7, 2021; hosted aboard the U.S. Department of Defense's Space Test Program Satellite 6 (STPSat-6).
- ILLUMA-T (Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal) will be first user of LCRD. It is hosted on ISS (International Space Station), orbiting at 430 km altitude.
- With LCRD relaying data for ILLUMA-T, this will be the first operational optical communications system for human spaceflight. ILLUMA-T will send data to LCRD at rates of 1.2 gigabits per second over optical links, allowing for more high-resolution experiment data to be transmitted back to Earth.
- This is almost double the rates of the LLCD, which transferred at 622 megabits per second.

LCRD test phase

- Until its first user (ILLUMA-T) is launched in 2023, LCRD will practice sending test data to and from its ground stations.
- This test data will be sent up through radio frequency signals from the mission operations center and then the LCRD spacecraft will reply over optical signals.
- This test data will include spacecraft health data; tracking, telemetry, and command data; and sample user data to ensure LCRD is properly operating.
- LCRD will test different cloud coverage scenarios, gathering valuable information about the flexibility of optical communications.

TeraByte InfraRed Delivery (TBIRD)

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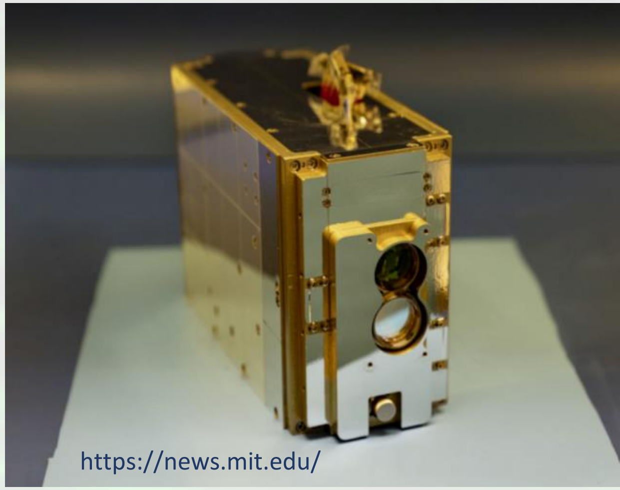
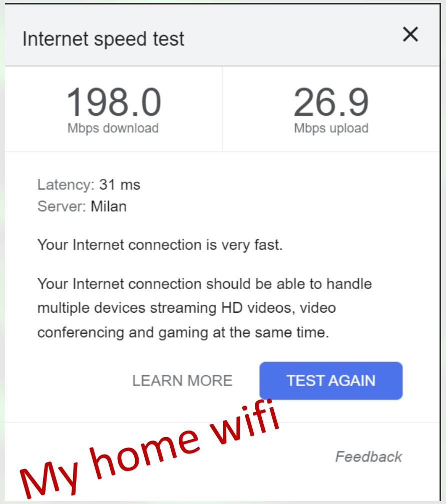
- The TBIRD payload was built by the MIT Lincoln Laboratory and integrated into NASA's CubeSat Pathfinder Technology Demonstrator 3 Satellite (PTD-3)
- In May 2022, it was launched into orbit 482 km above Earth's surface.
- TBIRD has delivered terabytes of data at record-breaking rates of up to 100 gigabits per second.

- 100 times faster than the fastest internet speeds in most cities.

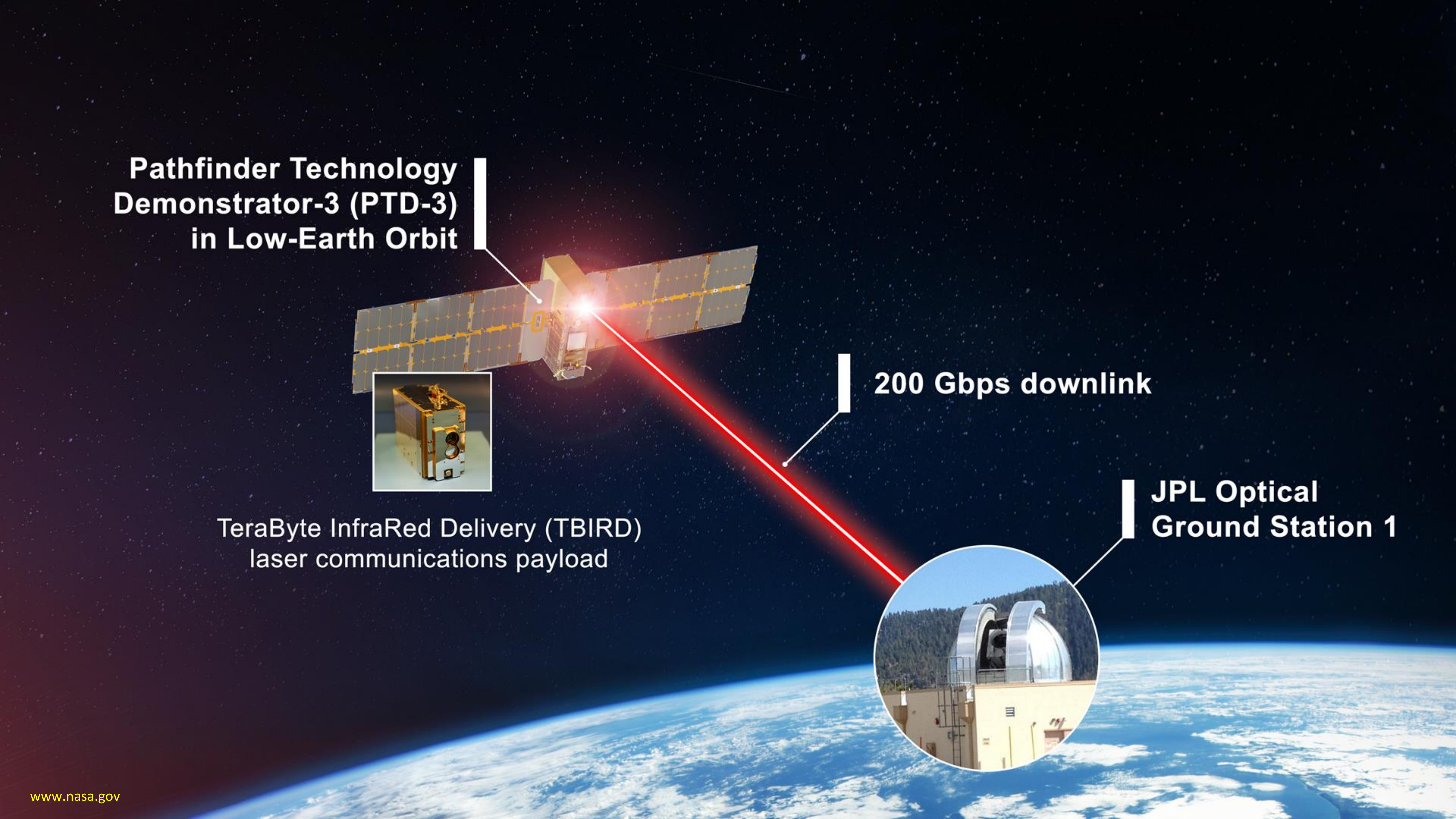
- 1000 times faster than traditional RF communication.

- December 1,2022: NASA confirmed that TBIRD downlinked 1.4 terabytes of data over laser communications links in a single pass that lasted about five minutes.





Fun fact: TBIRD is the size of a tissue box and,
PTD-3 of the size of two stacked-cereal boxes.


Pathfinder Technology Demonstrator-3 (PTD-3) in Low-Earth Orbit
200 Gbps downlink
TeraByte InfraRed Delivery (TBIRD) laser communications payload
JPL Optical Ground Station 1

Summary

- Use of optical links for space communication was first demonstrated by LLCD in 2013.
- It is proven that laser-based communication provides higher data transmission at lower mass and power of the system.
- It will allow for more science data.
- Astronauts go through a lot of psychological issues in space, the new high transmission could allow them to have a video call with family and friends, or Netflix and chill.


Thank you