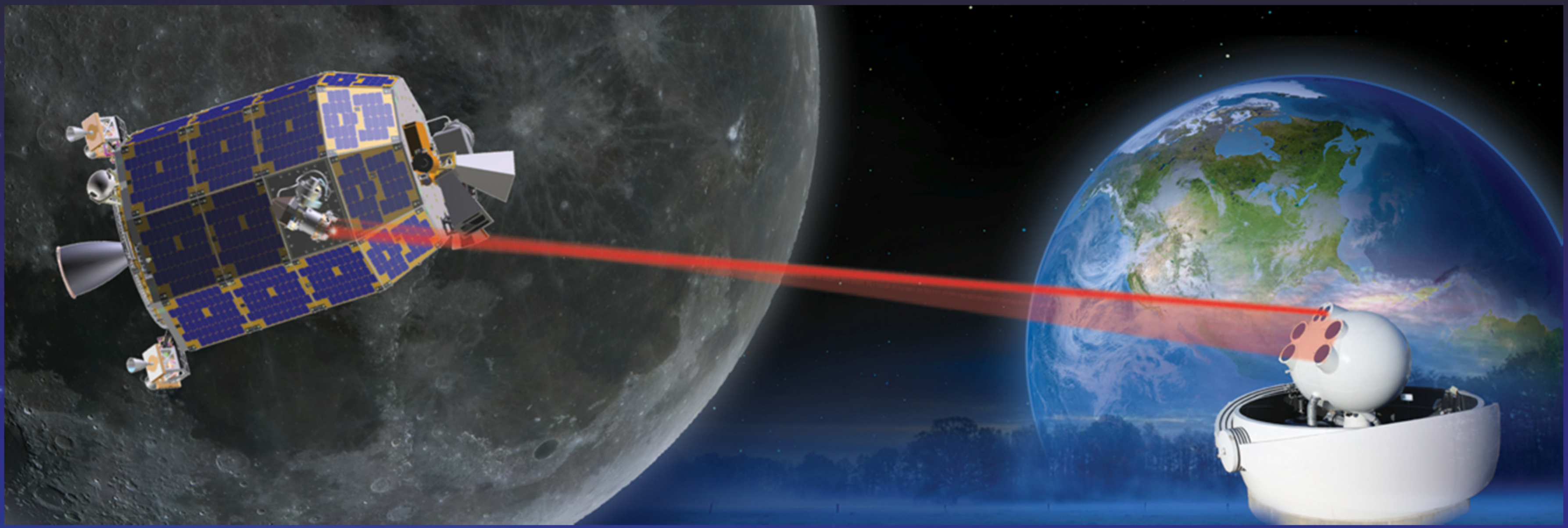
The Lunar Laser Communication Demonstration (LLCD)

NASA's First High-Rate, Two-Way Space Laser Communications Demonstration



Don Cornwell, LLCD Mission Manager, NASA GSFC

Don Boroson, Bryan Robinson, Dennis Burianek, Dan Murphy, Farzana Khatri, all of MIT Lincoln Laboratory

Presentation to the JHU Aerospace Affinity Group

June 11th , 2014

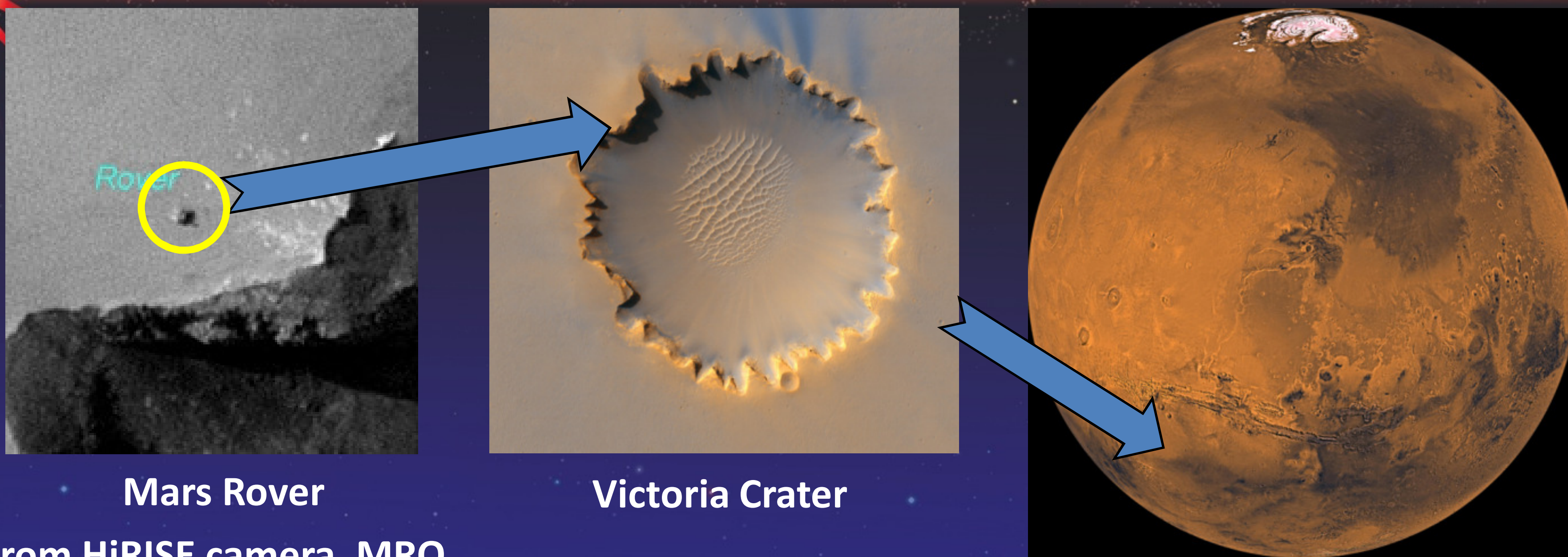
Approved for Public Release

NASA's First High-Data-Rate, Two-Way Space Lasercomm Demonstration

- LLCD was flown to the Moon on the Lunar Atmosphere and Dust Environment Explorer (LADEE)
- Launched on September 6, 2013
- IMMEDIATE LASER CONTACT on October 17, 2013
- Set records for download and upload speeds to the Moon
- Planned operations ended November 22nd

LLCD returned data by laser to Earth at a record 622 Megabits per second (Mbps)
= streaming 30+ HDTV channels simultaneously!

NASA's science data needs are driving faster download data rates…



Mars Rover

From HiRISE camera, MRO
Approx 1-foot resolution

Victoria Crater

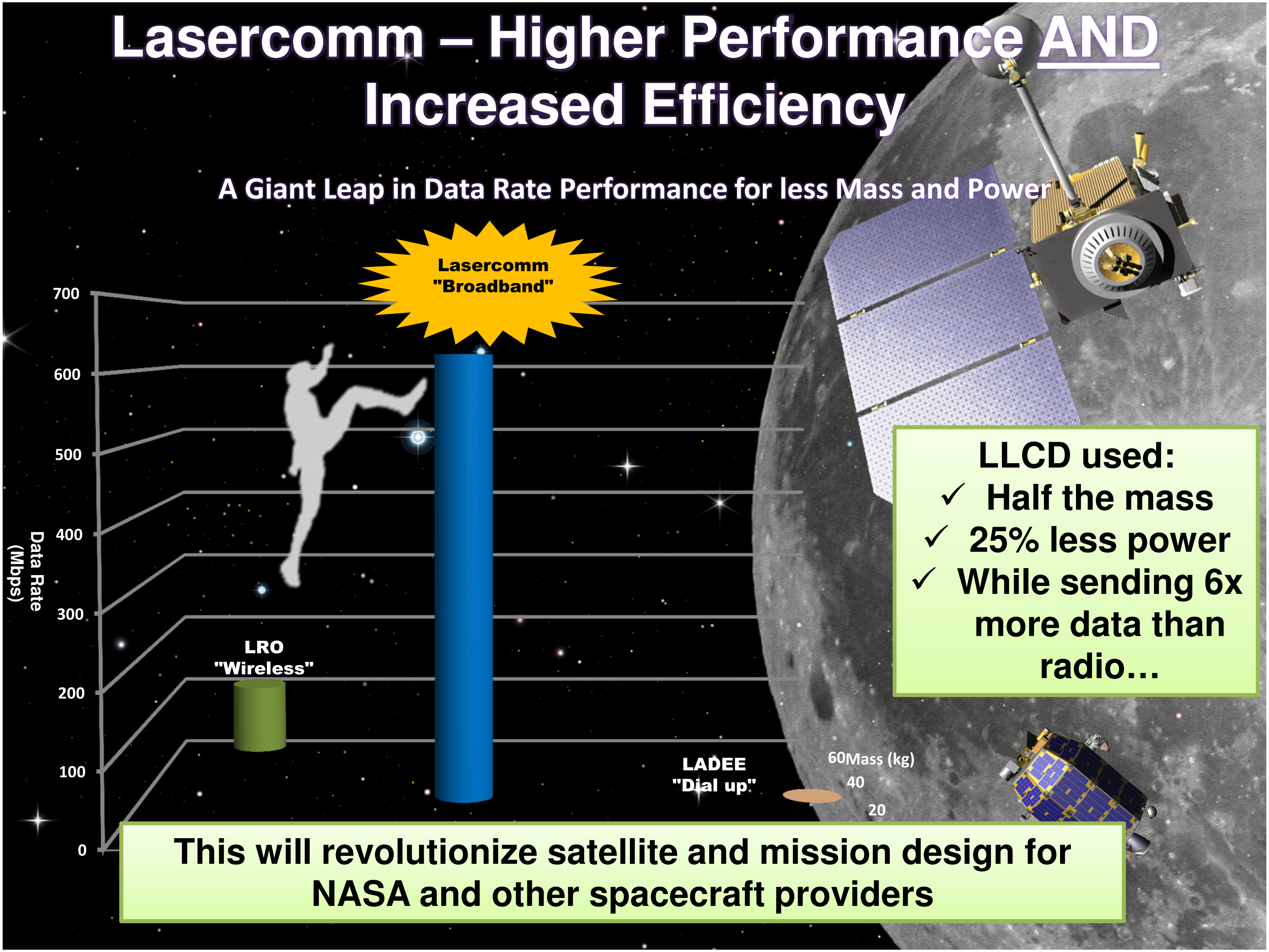
Mars

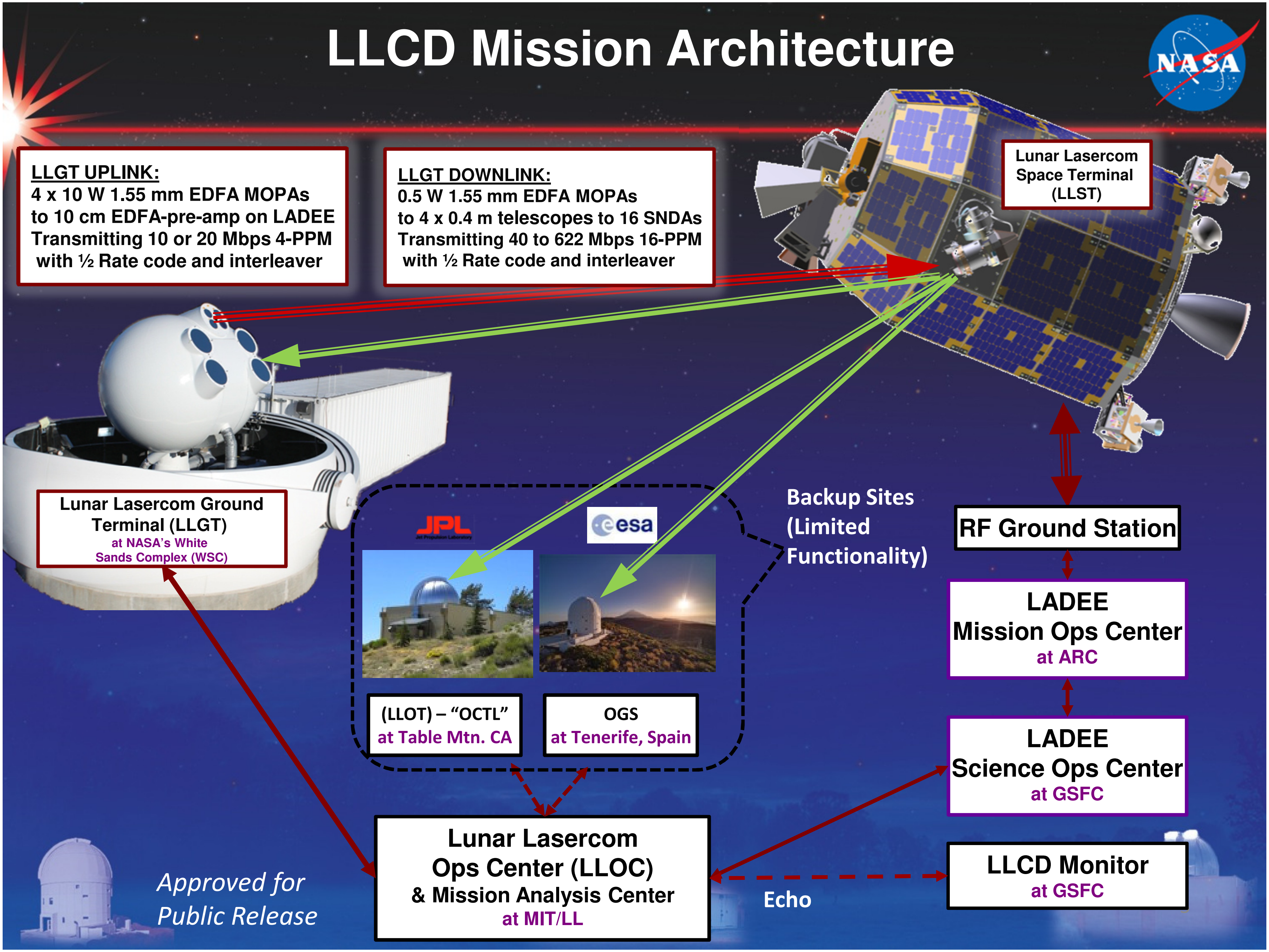
To transmit a 1 foot res map of entire Mars surface (1.6e15 points)

- at 1 bit / pixel:
- 5 Mbps requires 9 years (best Ka-band)
- 250 Mbps requires 9 weeks (JPL's DOT)

Higher data rates will be required to break through the present-day science return bottleneck

Chart courtesy of Don Boroson, MIT Lincoln Laboratory


Lasercomm – Higher Performance AND Increased Efficiency
A Giant Leap in Data Rate Performance for less Mass and Power
Lasercomm "Broadband"
LRO "Wireless"
LADEE "Dial up"
Data Rate (Mbps)
700
600
500
400
300
200
100
0
60Mass (kg)
40
20
LLCD used:
✓ Half the mass
✓ 25% less power
✓ While sending 6x more data than radio…
This will revolutionize satellite and mission design for NASA and other spacecraft providers


LLCD Mission Architecture
NASA
LLGT UPLINK:
4 x 10 W 1.55 mm EDFA MOPAs
to 10 cm EDFA-pre-amp on LADEE
Transmitting 10 or 20 Mbps 4-PPM
with ½ Rate code and interleaver
LLGT DOWNLINK:
0.5 W 1.55 mm EDFA MOPAs
to 4 x 0.4 m telescopes to 16 SNDAs
Transmitting 40 to 622 Mbps 16-PPM
with ½ Rate code and interleaver
Lunar Lasercom Space Terminal (LLST)
Lunar Lasercom Ground Terminal (LLGT)
at NASA's White Sands Complex (WSC)
JPL
esa
Backup Sites (Limited Functionality)
(LLOT) – "OCTL"
at Table Mtn. CA
OGS
at Tenerife, Spain
RF Ground Station
LADEE Mission Ops Center
at ARC
LADEE Science Ops Center
at GSFC
Lunar Lasercom Ops Center (LLOC) & Mission Analysis Center
at MIT/LL
Echo
LLCD Monitor
at GSFC
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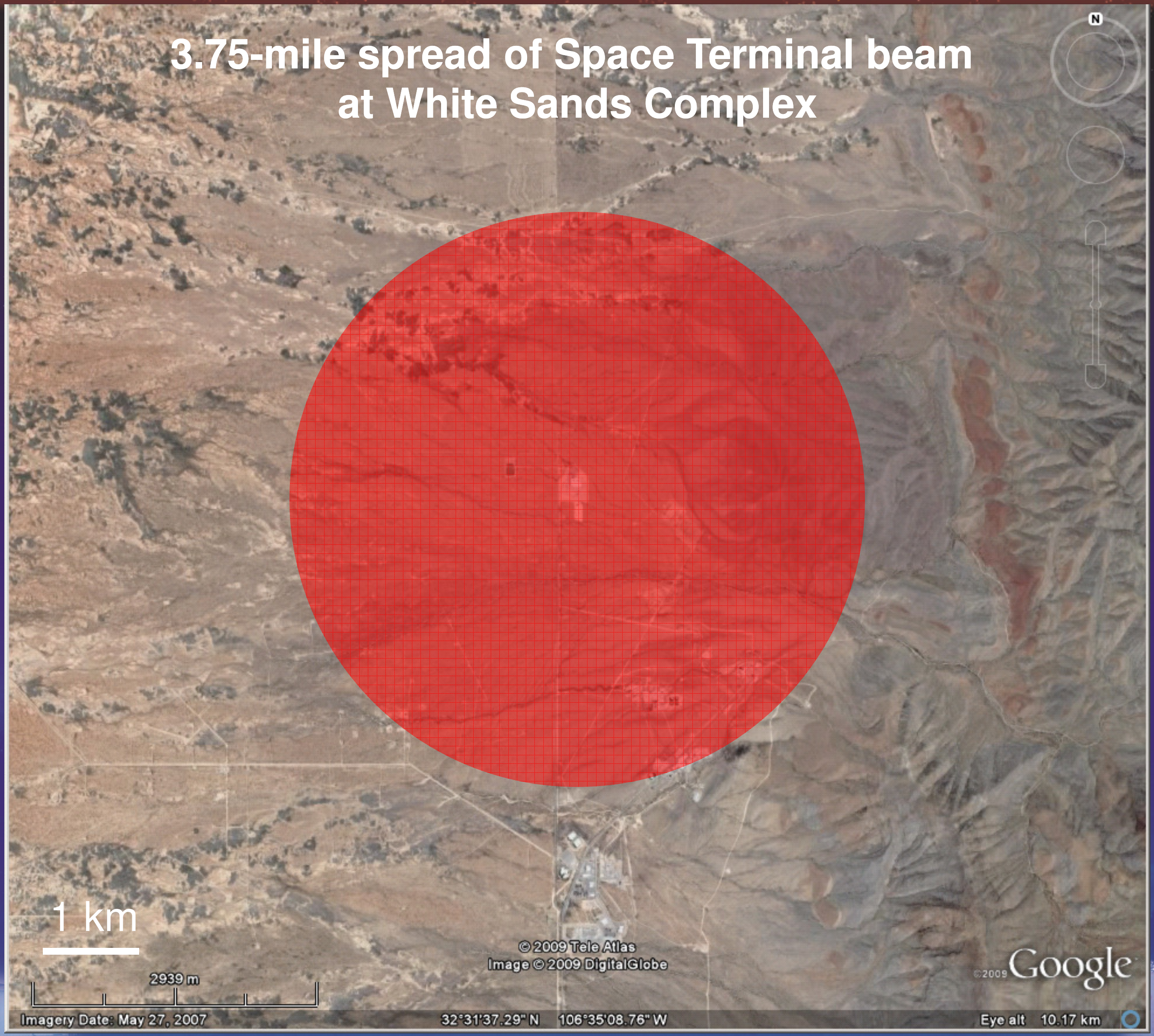
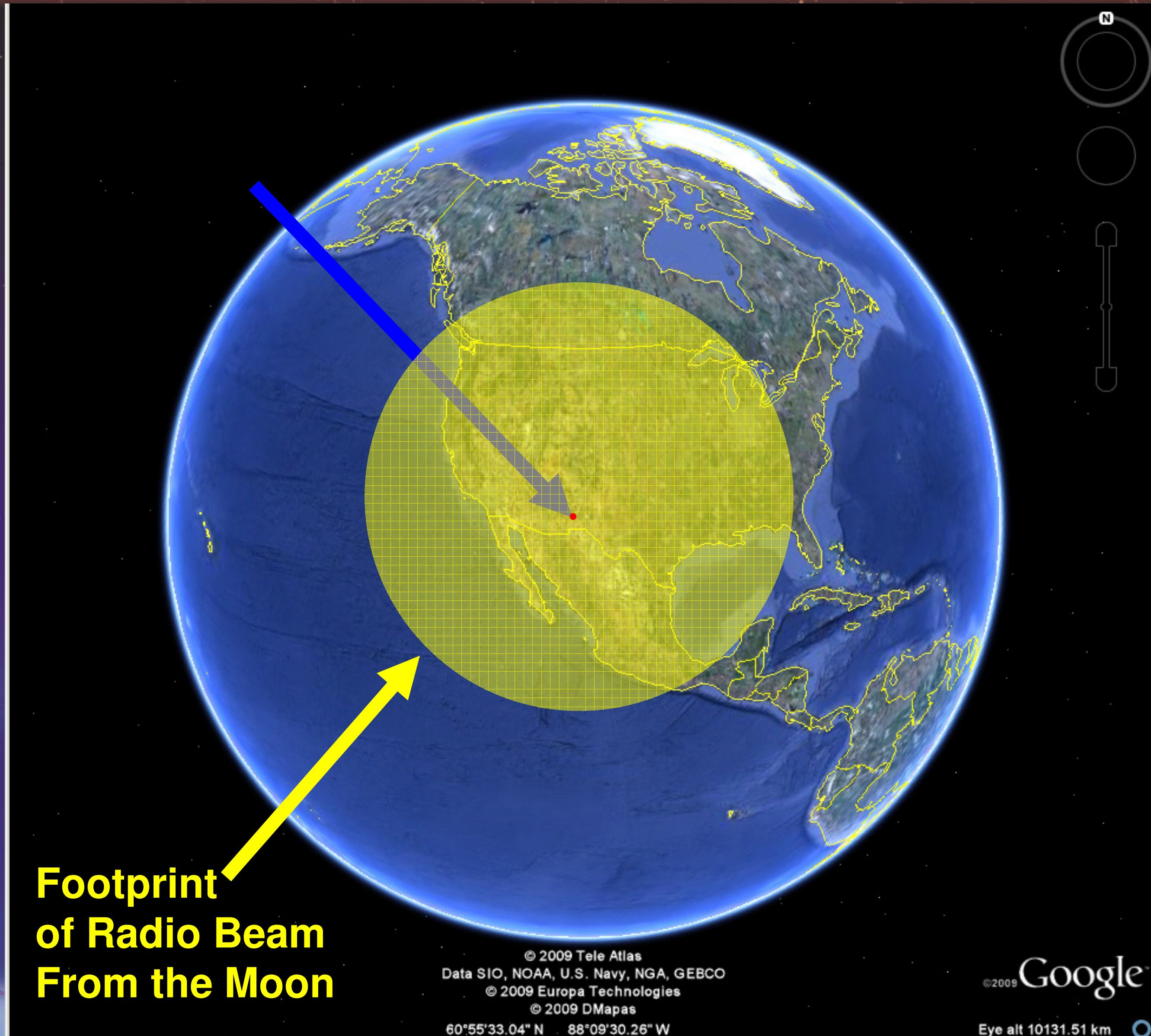
LLCD's Biggest Challenge: Pointing LLCD's Narrow Beam from the Moon



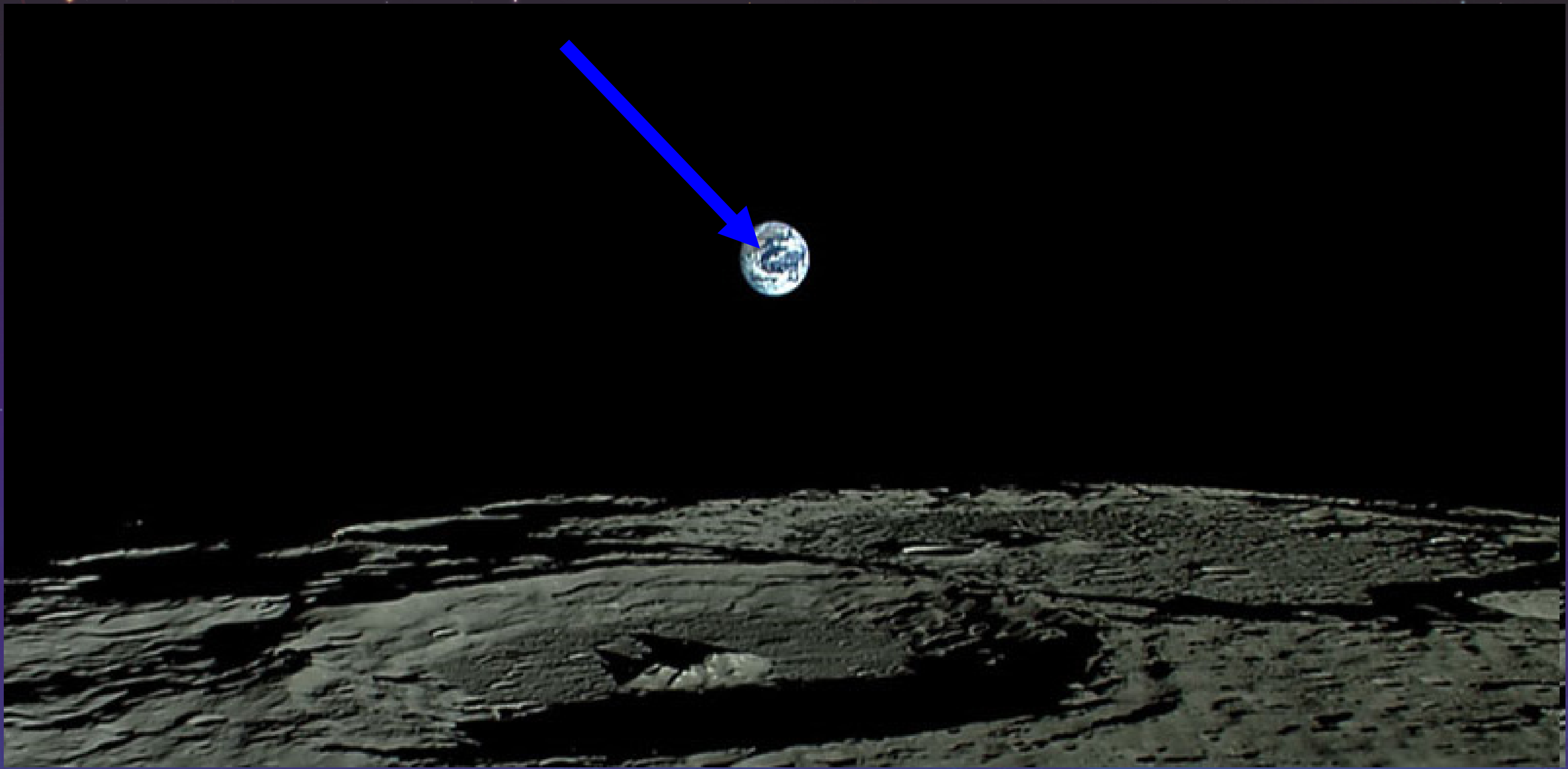
LLCD's Biggest Challenge: Pointing LLCD's Narrow Beam from the Moon

LLCD's Biggest Challenge:
Pointing LLCD's Narrow Beam from the Moon

LLCD's Biggest Challenge: Pointing LLCD's Narrow Beam from the Moon



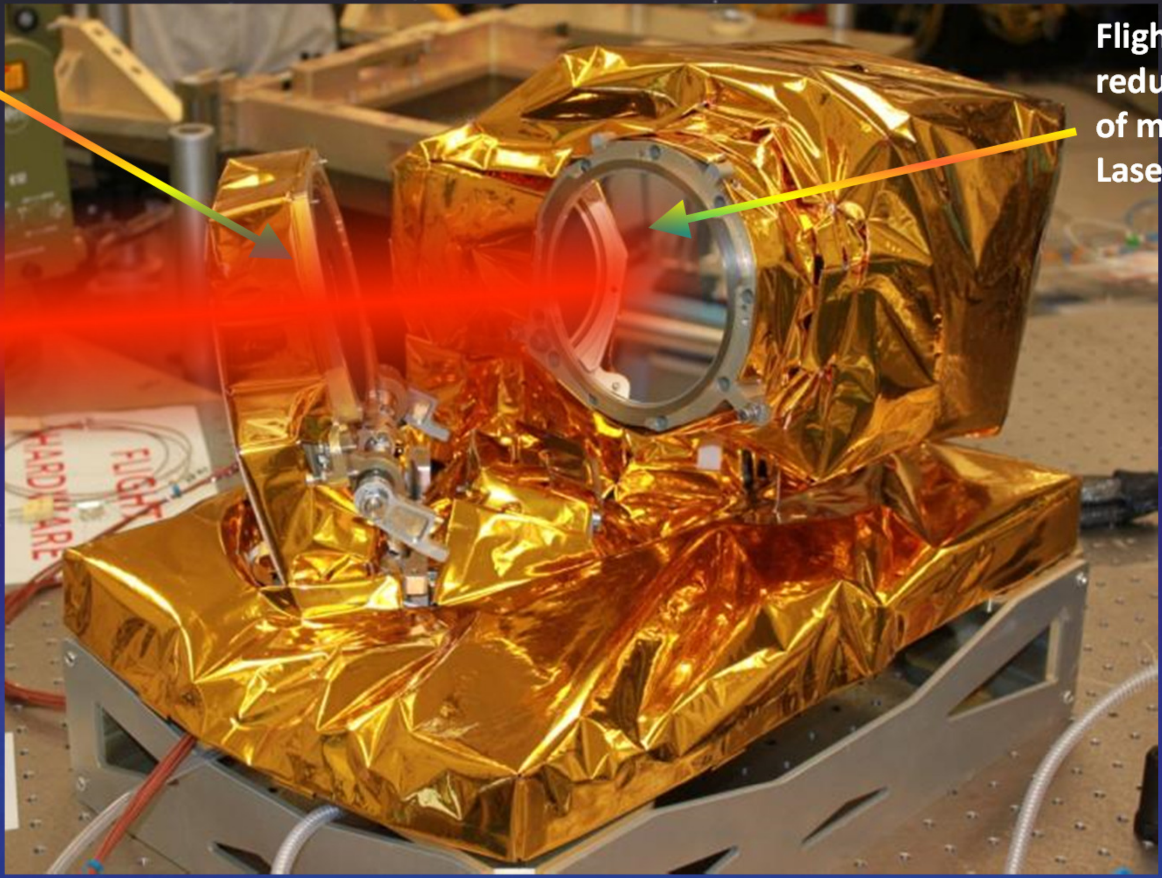
LLCD's Biggest Challenge: Pointing LLCD's Beam from the Moon



Hitting a 3.75-mile target from 250,000-miles away is HARD!

LADEE Space Terminal Laser

Latch to protect and hold telescope during launch



Flight aperture size reduced by an order of magnitude (4” Laser Window)

Innovative stabilization design enabled a leap forward in fine pointing accuracy

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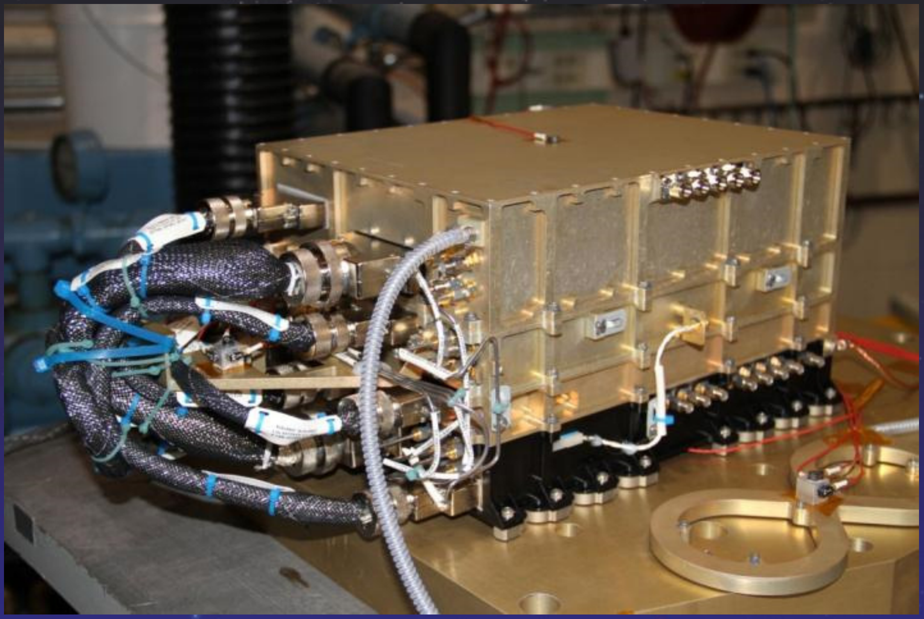
Built by MIT/Lincoln Laboratory

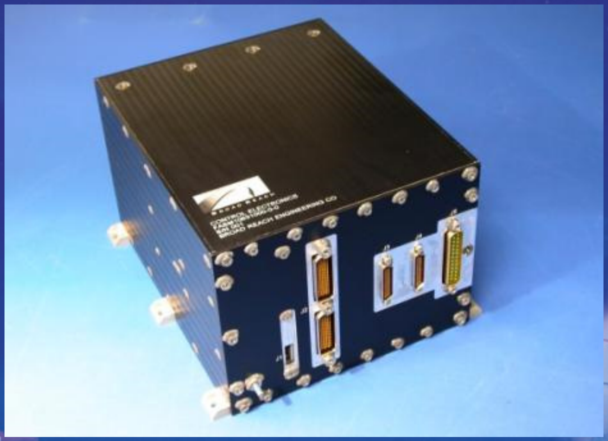
Space Terminal Internal Modules

- Uplink functions
  - *Selectable 10, 20 Mbps*
  - *Command, data, and test pattern demux*
- Downlink functions
  - *Selectable 40-620 Mbps*
  - *Mux terminal telemetry, looped-back uplink, spacecraft data, test patterns*
- Enables time-of-flight



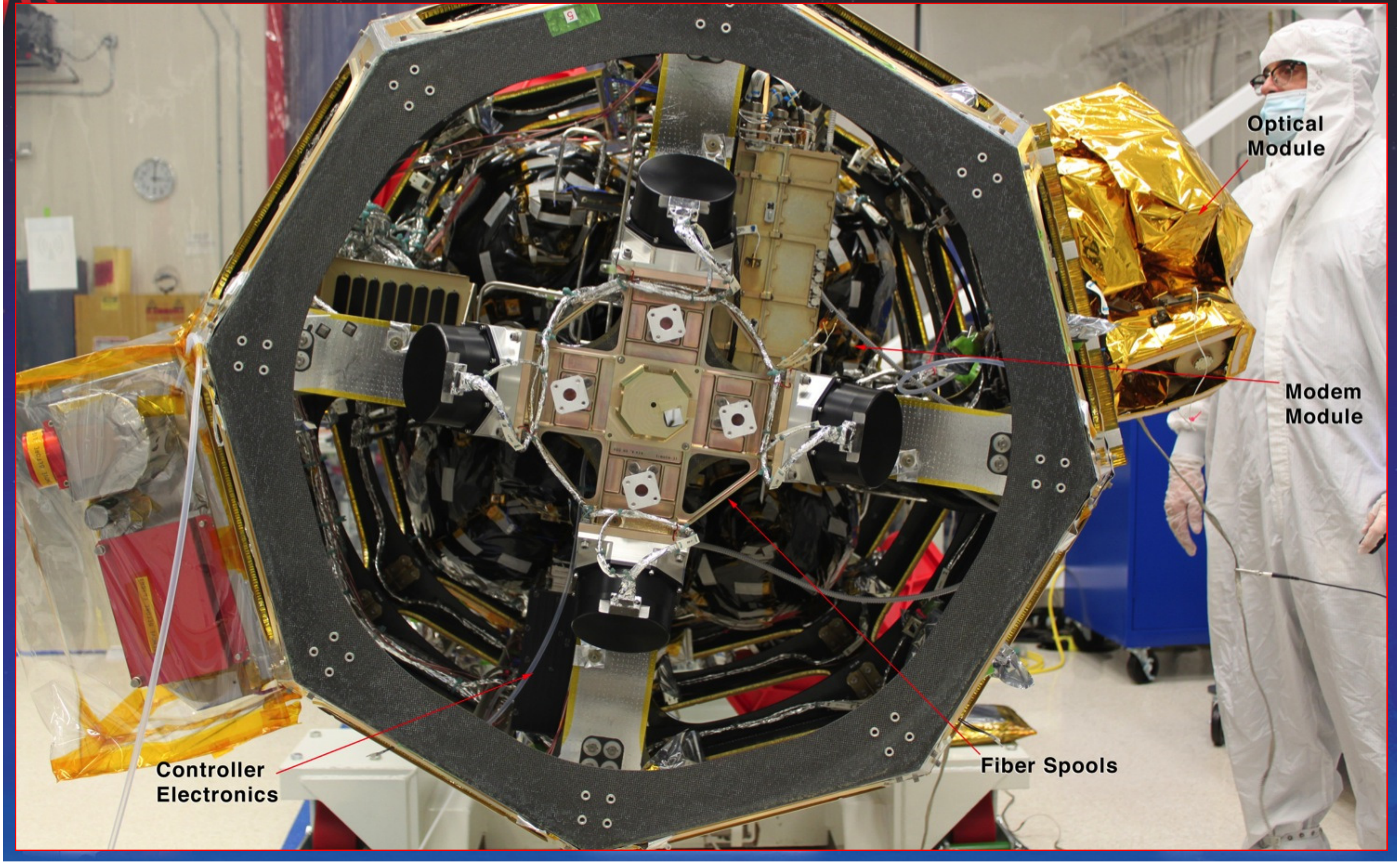
Modem Module

Controller Electronics Module



- Controller functions
  - *Spacecraft controls interface*
  - *Space terminal configuration*
  - *Digital controls for PAT*

LLCD Fully Integrated on LADEE



The LADEE Launch from Wallops

11/8/2013

LLGT

Lunar Lasercom Ground Terminal

Located at NASA's White Sands Complex
White Sands, New Mexico

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Scale-able Ground System LLGT Telescope for PPM (Spatially-Incoherent Detection)

- **Lunar Laser Ground Terminal (LLGT)**
  - 2-axis gimbal
  - 4@15 cm uplink telescopes
    - Fiber-coupled to 4 10-W EDFAs
  - 4@40 cm downlink telescopes
    - Each multi-mode fiber-coupled to four-array of SNDAs
  - Four Superconducting Nanowire Photon Counting (SNDA) arrays all in one cryostat
  - Telescopes housed in temperature-controlled mini-dome

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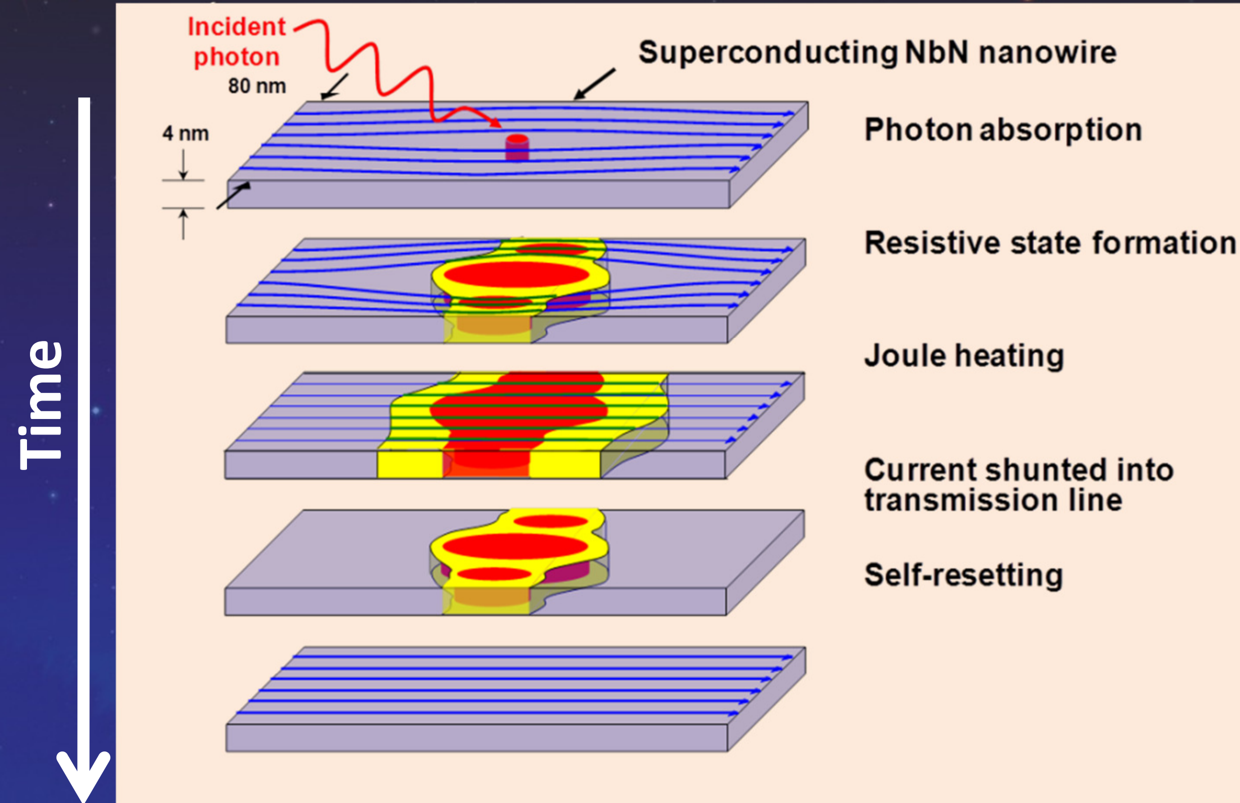
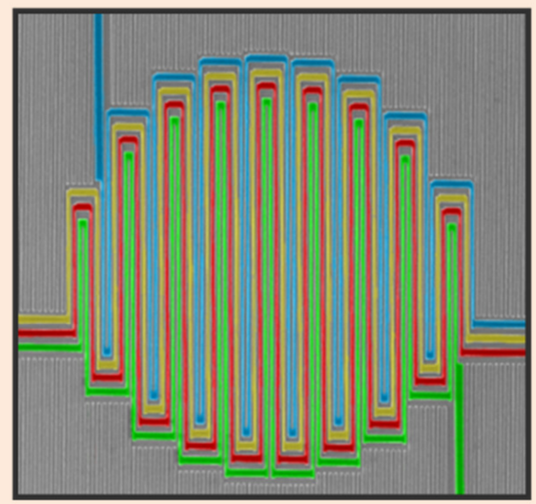
Technology Breakthrough: Super-Sensitive Photon Counting Detectors

….the most sensitive detectors ever made for the infrared…

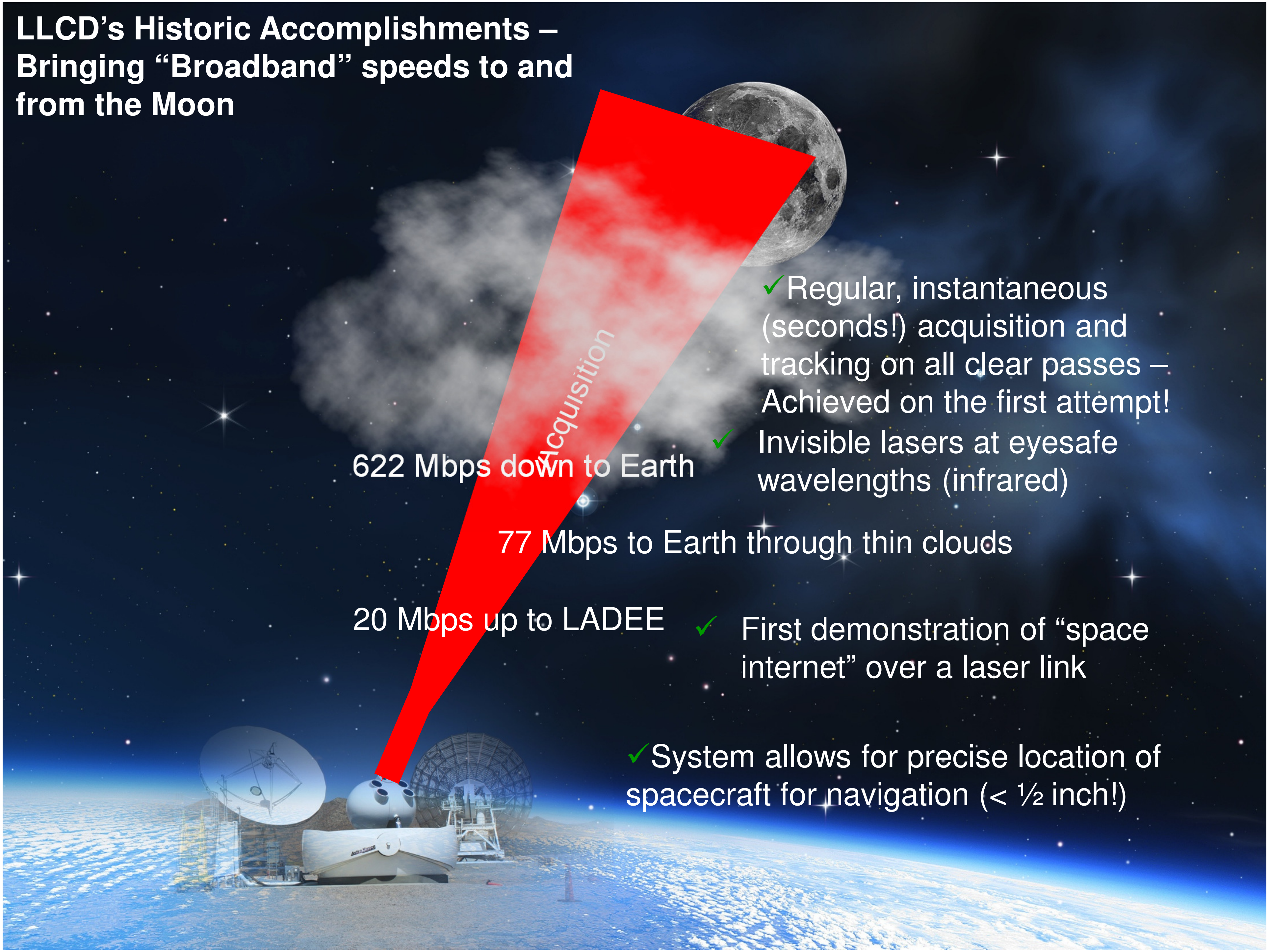


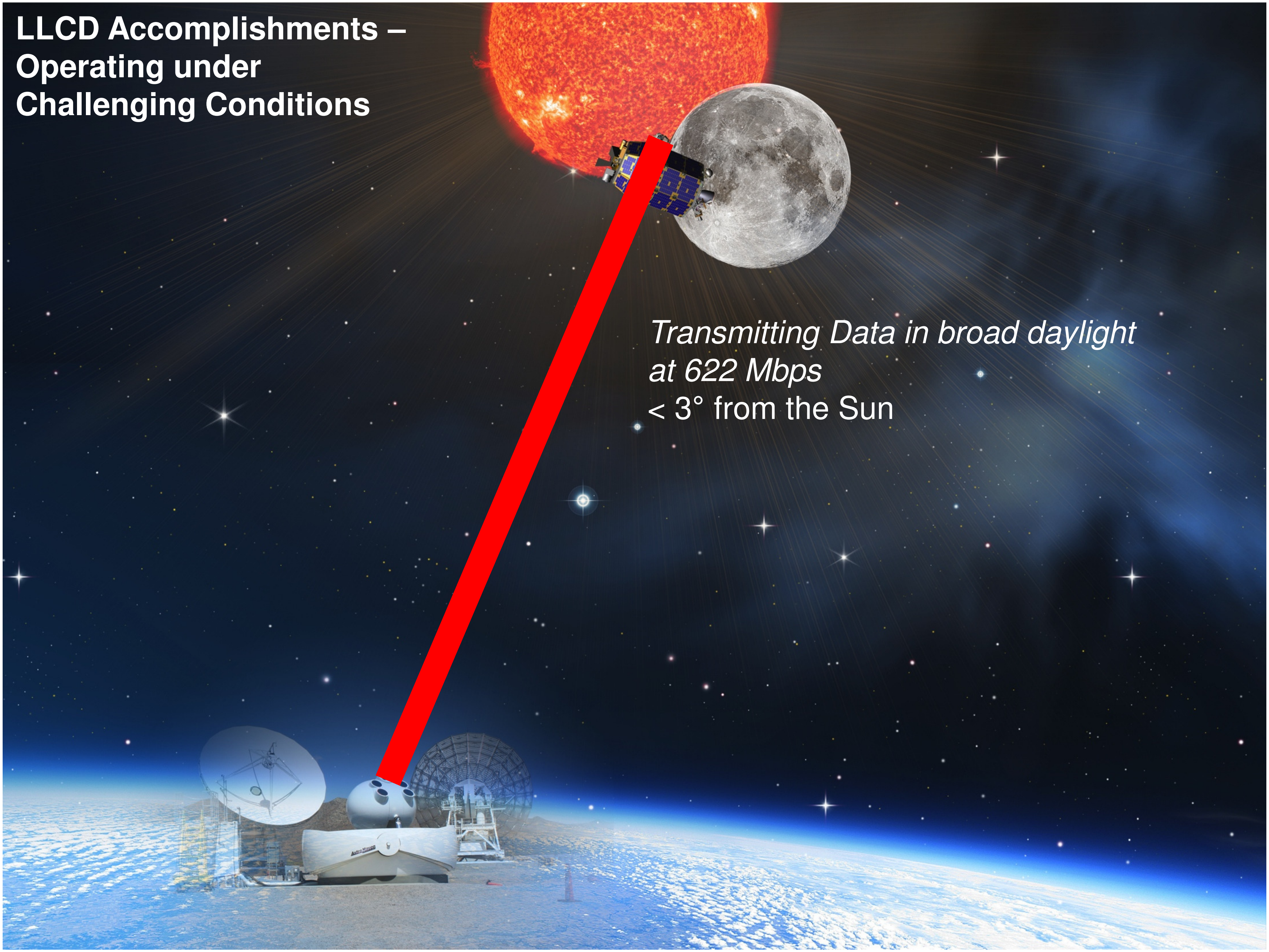
4-element detector array
1/6 width of a human hair

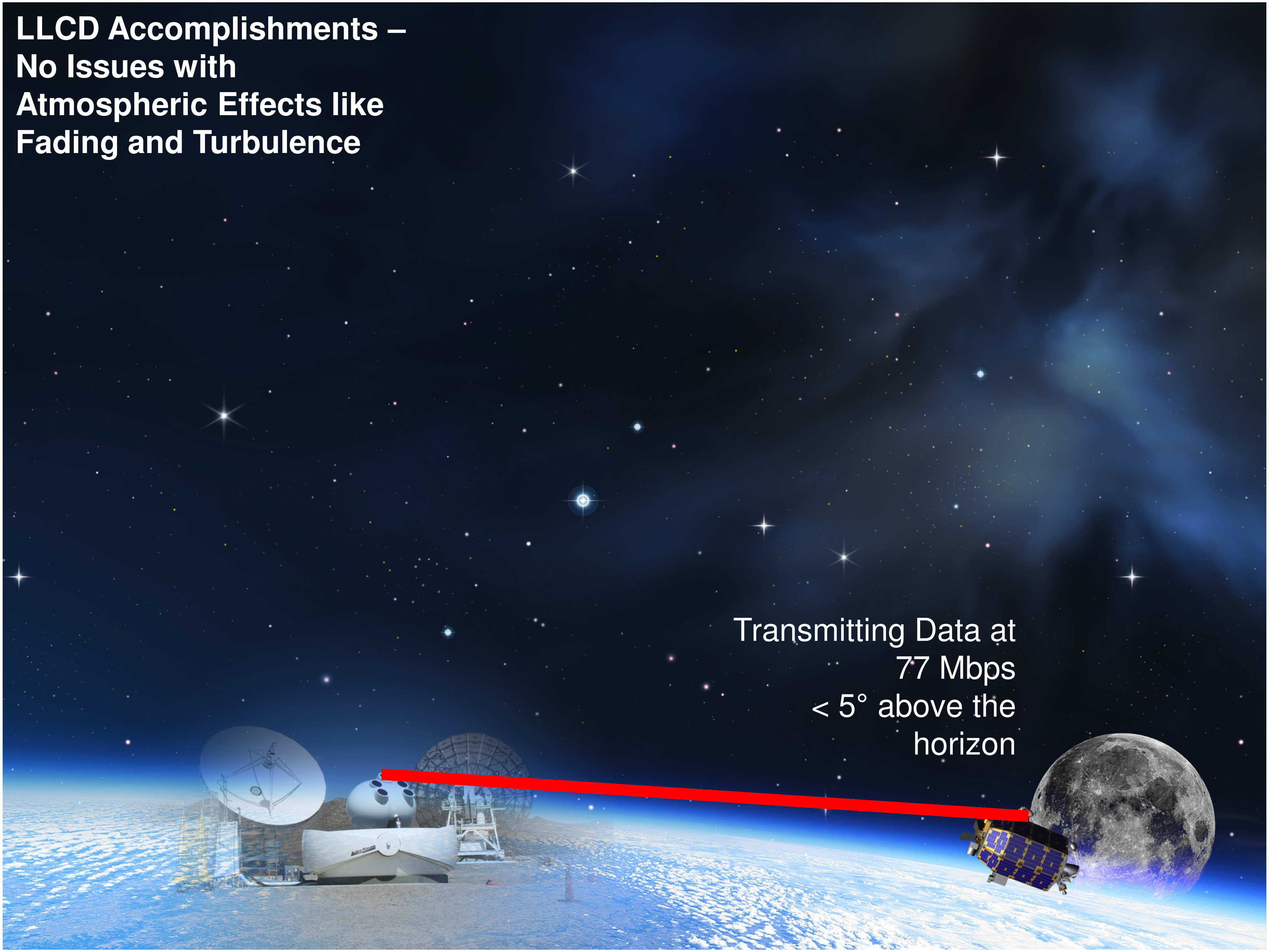


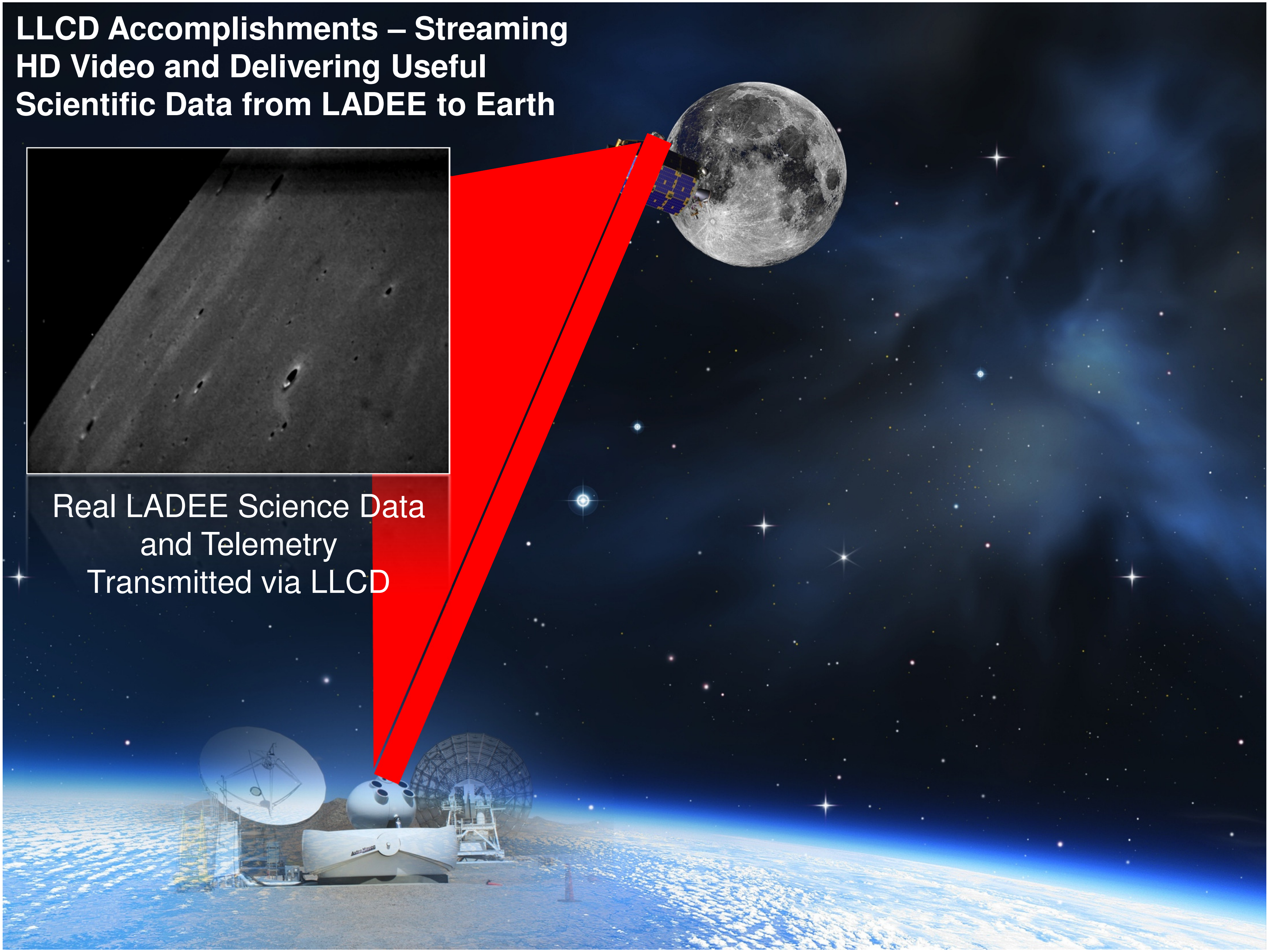
ctors

Enabled 2 bits of information per photon and the new broadband level data rates


LLCD's Historic Accomplishments – Bringing "Broadband" speeds to and from the Moon
Acquisition
✓Regular, instantaneous (seconds!) acquisition and tracking on all clear passes – Achieved on the first attempt!
✓ Invisible lasers at eyesafe wavelengths (infrared)
622 Mbps down to Earth
77 Mbps to Earth through thin clouds
20 Mbps up to LADEE
✓ First demonstration of "space internet" over a laser link
✓System allows for precise location of spacecraft for navigation (< ½ inch!)


LLCD Accomplishments –
Operating under
Challenging Conditions
Transmitting Data in broad daylight
at 622 Mbps
< 3° from the Sun


LLCD Accomplishments – No Issues with Atmospheric Effects like Fading and Turbulence
Transmitting Data at 77 Mbps < 5° above the horizon


LLCD Accomplishments – Streaming
HD Video and Delivering Useful
Scientific Data from LADEE to Earth
Real LADEE Science Data
and Telemetry
Transmitted via LLCD

Project Accomplishments – JPL OCTL and ESA OGS Ground Terminals

JPL's LLOT Ground Terminal (OCTL)

- ✓ Regular, instantaneous (seconds!) all-optical acquisition and tracking between LLST and OCTL
- ✓ Properly-framed, error-free D/L to JPL's OCTL at 40, 80 Mbps
- ✓ Operation at low elevation angles of the Moon (8 degrees at JPL's Table Mountain/LLOT)
- ✓ **"Hand-off" from WSC to JPL during pass in < 2 min!**

JPL's OCTL Facility in Southern CA

ESA's LL-OGS Ground Terminal

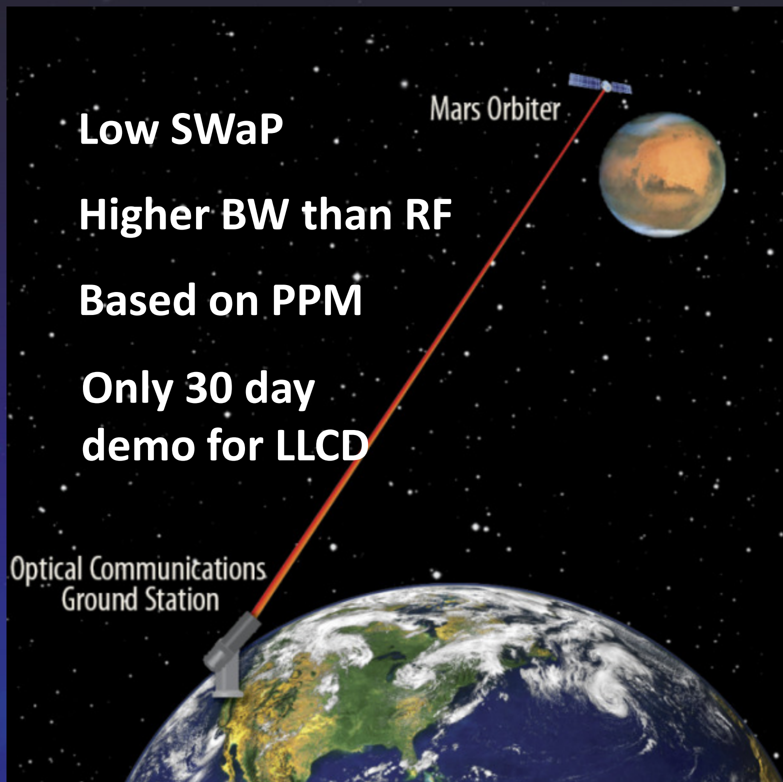
- ✓ Received communication D/L to ESA's OGS at 40 Mbps (new station)
- ○ Fine-tracking on U/L sometimes achieved at LLST, but signal level is 5 dB too low to permit U/L comm
- ○ Final week of passes will try to exercise improved OGS U/L beam pointing

ESA Image of the LLST Beam

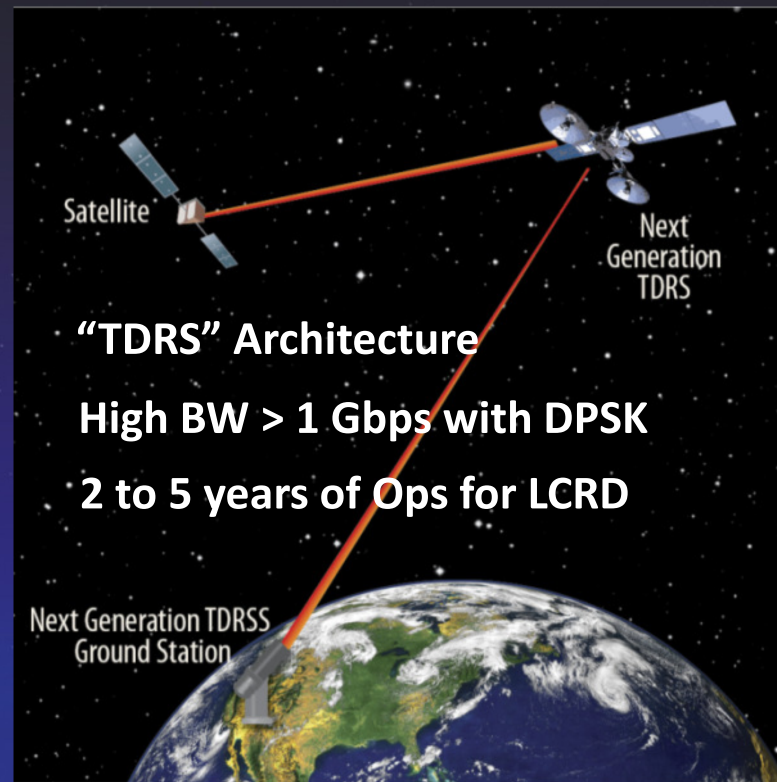
ESA's LL-OGS on Tenerife, Spain

NASA Lasercom Scenarios

Deep Space to Earth (LLCD Demo)



Near-Earth Relay (LCRD Demo)



Additional Scenarios:

- Very high data rate (> 10 Gbps) direct LEO-to-Ground
- Very low SWaP for small spacecraft (e.g., Cubesats)

All scenarios benefit from Disruption-Tolerant Networking (DTN)

Laser Communication Relay Demonstration (LCRD) Mission Architecture

- **STMD/SCaN Mission**
- **Commercial Spacecraft Host**
- **Flight Payload**
  - Two LLCD-based Optical Modules and Controller Electronics Modules
  - **Two Differential Phase Shift Keying (DPSK) Modems with BW > 1.25 Gbps**
  - **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**
  - 2 to 5 years of operational network experiments

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Connect with LLCD!

National Aeronautics and Space Administration

LLCD

Lunar Laser Communication Demonstration

NASA's First Space Laser Communication System

Lunar Laser Communication Demonstration
Goddard Space Flight Center, Code 450.2
Greenbelt, MD 20771

Connect with LLCD

http://llcd.gsfc.nasa.gov

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NP-2013-05-028-GSFC

BACKUP

A Comparison of Downlink Speeds *from the Moon*

Downlink speed comparison	File Size	LLCD @ 622 Mbps	LRO Ka-band @ 100 Mbps	LADEE S-band @ 128 Kbps
How High the Moon **(mp3)**	2 MB	0.013 sec	0.16 sec	125 sec
Dark Side of the Moon **(CD)**	451.5 MB	5.8 sec	36.1 sec	28,219 sec (~8 hr)
Apollo 13 **(Blu-Ray)**	36,800 MB	7.9 min	49.1 min	38,333 min (~639 hr)
U.S. Library of Congress	208,000,000 MB	743 hr	4,622 hr	3,611,111 hr (~412 years)

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