NASA’s Optical Communications Program for 2017 and Beyond

Dr. Don Cornwell, Director
Advanced Communications and Navigation Division
NASA Headquarters, SCaN Program
2013: NASA’s First, Historic Lasercom Mission

The Lunar Laser Communication Demonstration (LLCD)

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

MIT Lincoln Laboratory, NASA GSFC, NASA Ames, NASA JPL, and ESA

2014 Popular Mechanics Breakthrough Award for Leadership and Innovation for LADEE

2014 R&D 100
Winning Technology in Communications category

Nominated for the National Aeronautic Association’s Robert J. Collier Trophy

Winner of the National Space Club’s Nelson P. Jackson Award for 2015
Geographic site diversity is required to reduce the likelihood that clouds will interrupt the link; it also allowed the opportunity to demonstrate international interoperability while sharing the costs of the system of LLCD.
NASA's Plan Forward for Near-Earth Relay Optical Missions: LCRD in GEO

- **GEO Relay and Ground 2019**
  - Gen-1 GEO Optical Relay Terminal
  - Laser Communications Relay Demonstration (LCRD)
    - 311 Mbps x 2 Return Links on RF
    - 16 Mbps Forward Link on RF
  - Gen-1 Optical User Terminal
    - 1.244 Gbps Optical Return Link
    - 51 Mbps Forward Link
  - Orion EM-2
    - Up to 531 Mbps PPM Return Link
    - 20 Mbps Forward Link
  - SCaN Operated Gen-1 Optical Ground Station
  - Operations Center
  - SCaN Operated Gen-1 OGS
  - Gen-1 Optical Ground Station

- **Deep Space**

- **Near Earth**
Laser Communication Relay Demonstration (LCRD) on STPSat-6 for June 2019 Launch

- Joint SCaN/NASA Space Tech Mission
- Hosted payload with AFRL/STP
- Two to eight years of mission ops
- Flight Payload
  - Two LLCD-heritage Optical Modules and Controller Electronics Modules
  - Two software-defined DPSK Modems with 2.88 Gbps data rate (1.244 Gbps user rate)
  - 622 Mbps Ka-band RF downlink
  - New High Speed Switching Unit to interconnect the three terminals
  - RFI for “Guest Investigators” revealed significant commercial interest
- Key for NASA’s Next-Gen Earth Relay in 2024 timeframe
LCRD Mission Architecture with SCaN-Provided Ground System, Directly Integrated into NASA’s Space Network

Two Terminals at 1550 nm
1.244 Gbps User Rate
Full Duplex (Bi-Directional)

2 x 311 Mbps
Ka-band
Downlink to WSC

Table Mountain, CA
Optical Ground Station 1 (OGS-1)
Remote LCRD Mission Ops Center (R-LMOC)

STPSat-6 Mission Ops Center

LCRD Flight Payload On STPSat-6

White Sands, NM
Optical Ground Station 2 (OGS-2)

LCRD Mission Ops Center (LMOC)

Hawaii

NASA Goddard Space Flight Center

LCRD Developed
OGS-X Developed
Joint LCRD/OGS-X Developed
Space Network Developed
OVERVIEW

- Two GEO Relay Terminals based on LLCD Optical Module flown on LADEE with 2.88 Gbps DPSK Modems
- Connected by NASA’s first frame-layer switch in space (5 Gbps 8 x 8 switch fabric)
- Hosted payload on AFRL’s STPSat-6 for Jun ‘19 LRD

PROGRAM STATUS AND NEXT STEPS

- Passed CDR in December 2016
- Payload I&T began in March 2017

COMMERCIALIZATION

- Major modules (CE, SSU) and sub-components (OM, MRM) now commercially-available under FFP

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**LCRD Technology Components Status**

- Optical Module (multiple vendors on FFP contracts) TRL 8 Complete
- Multi-Rate Modem (vendors, GSFC) TRL6 Complete
- Controller Electronics (Commercial FFP) TRL6 Complete
- Space Switching Unit (Commercial FFP) TRL6 Complete
- System Integration (GSFC) In progress All 2017
LCRD Payload: All Modules now in Environmental Testing; Full Payload I&T Fall 2017

Optical Module #2
Vibration Testing

SHIM EDU
Electrical Integration to Surrogate Plate

Optical Module #1
Thermal Vacuum Testing

Modem #1
Vibration Testing
NASA’s Optical Plan Forward: Optical Ground Station Expansion

OVERVIEW
- Initially two SCaN-managed facilities at TMF and HI for Gen-1 GEO relay demo in June 2019 (LCRD)
- Slewed at LEO rates with Adaptive Optic (AO) correction for single-mode fiber coupling; initially deployed with LCRD-compatible modem
- OGS-1 (TMF) requires upgrade to support CCSDS High Photon Efficiency standard for Orion EM-2
- OGS-1A (TMF 2), OGS-3 (WSC) and OGS-4 (Livermore) baselined as 60 cm “Hawaii” design with CCSDS HPE support

PROGRAM STATUS AND NEXT STEPS
- OGS-1 and OGS-2 in final development for site I&T in 2018 to support flight demo in 2019
- Upgrades required to TMF for Orion EM-2 support, currently unfunded

COMMERCIALIZATION
- Will leverage existing HW in addition to commercial Gen-1 User Modem (ILLUMA) for Gen-1 GEO relay support
NASA’s Optical Plan Forward: User Terminals for LEO and the Moon

**LEO User Terminal on ISS in 2021**

- Gen-1 GEO Optical Relay Terminal
- Laser Communications Relay Demonstration (LCRD)
  - 311 Mbps x 2 Return Links on RF
  - 16 Mbps Forward Link on RF
- Gen-1 Optical User Terminal
  - 1.244 Gbps Optical Return Link
  - 51 Mbps Forward Link

**Orion EM-2**
- Up to 531 Mbps PPM Return Link
- 20 Mbps Forward Link

**SCaN Operated Gen-1 OGS**
- Gen-1 Optical Ground Station

**Operations Center**

1.244 Gbps Optical Forward And Return Link
ILLUMA-T Next Gen Optical Module: MIT-LL Design, Commercial Manufacture

- 2-axis gimbal with brushless torque motors
- Hemispherical field of regard
  - +/- 175 degrees Azimuth
  - +/- 120 degrees Elevation
- Slew rates of >10 degrees per second
- Off-axis telescope coupled to fixed small-optics bench via Coudé path
- Includes optional wide-angle beacon for acquisition and pseudostar MIRU for inertial stabilization
- ~13 kg total mass for 10 cm model
- Would develop 20 cm model for GEO terminals, including GEO crosslinks
OVERVIEW
• Lower cost and SWaP User Terminal for LCRD (10.7 cm) with new 2.88 Gbps uncoded DPSK Modem and high power amplifier (3 W)
• Launch to JEM-EFU3 on ISS in April 2021
• Photon-counting modem required for Orion EM-2

PROGRAM STATUS AND NEXT STEPS
• Begin I&T of EDU w/flight materials April 2017
• SRR for ISS mission, Orion EM-2 in August 2017

COMMERCIALIZATION
• Major modules (CE, Modem) and sub-components (OM, MRM) to be commercially-developed under FFP
• Full terminal to be competed in 2020 for commercial build of Qty. 5

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ILLUMA-T on ISS

- LEO user terminal for Laser Communication Relay Demonstration based on
  - NGT optical module
  - Commercial modem (procured by GSFC)
- Protoflight terminal to be demonstrated on International Space Station
- Development effort started in FY17
- Delivery Q3, FY20

Lemnos DTO on Orion EM-2 or EM-3

- Lasercom link for NASA manned exploration missions
  - NGT optical module
  - Commercial PPM modem
- Demo proposed for Orion EM-2 mission (launch 2021)
- Development effort started January 2017
- Space terminal delivery for integration with Orion Q2, FY20
NASA’s Plan for Optical Infusion: ...to “GFE” User Terminals to Missions

**THE PLAN**

- Apply STMD & SCaN optical communication technology investment to Science & Exploration missions to transition optical communications to operations
- SCaN provides GFE terminals to NASA missions for direct or relayed services
- STMD & SCaN provide optical relay & ground stations to return mission data to mission users

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<th><strong>TARGET FUTURE MISSIONS</strong></th>
<th>Science</th>
<th>Exploration</th>
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<td><strong>FY2017</strong></td>
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<td>Near-Earth DTE</td>
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<td>Deep Space DTE</td>
<td>Technology Demo</td>
<td>GFE’d 200G DTE Optical User Terminal</td>
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<th><strong>GFE starting in 2021</strong></th>
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<th><strong>Gen-1 Optical User Terminal</strong></th>
<th><strong>GFE starting in 2023</strong></th>
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**Technical Specifications**

- **200G DTE User Terminal**
  - Build Quantity: 5
  - **GFE starting in 2021**

- **Gen-1 Optical User Terminal**
  - Build Quantity: 5
  - **GFE starting in 2023**
NASA’s Optical Plan Forward: Deep Space Optical Communications

DSOC Gen-1 Optical User Terminal
DSOC on Psyche Asteroid Mission 2023
125 Mbps from 40M km

DSOC Gen-1 Optical Ground Station
## Deep Space DTE Technologies

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<th>Technology</th>
<th>Overview</th>
<th>Commercialization</th>
<th>Next Steps</th>
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</table>
| **DSOC Gen-1 Optical Ground Station** | • Lease of 5 meter Palomar telescope with photon-counting SNDA detectors  
• CCSDS “High Photon Efficiency” standard compliant system for International cross support                                                  | Major modules (controller electronics, space switch unit) and sub-components (optical module, multi-rate modem) now commercially available under FFP | **CCSDS HPE-standard compliant DSOC Gen-1 OGS funded by HEOMD/SCaN for 2023 ORR**                                                                            |
| **DSOC Gen-1 Optical User Terminal** | • 22 cm aperture terminal, ~ 36 kg 100W, Max 531 Mbps  
• CCSDS “High Photon Efficiency” standard compliant system for International cross support                                                   | **DSOC Gen-1 user terminal funded by STMD/TDM for launch on Discovery 2023 to asteroid Psyche**                                             |                                                                                                                                                                |

### DEEP SPACE DTE TECHNOLOGY DEMONSTRATIONS

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- **DSOC Gen-1 User Terminal**
- **DSOC Gen-1 OGS**
NASA’s Next Gen Relay (2024) with 10G Users and 100G Crosslinks

Gen-2 GEO Optical Relay
- 100 Gbps Crosslinks
- 10 Gbps User Links

Gen-2 User Terminal
- 10 Gbps User Link

SCaN Operators: Gen-1 OGS
- Gen-1 Optical Ground Station

Operations Center

1.2 Gbps Ka-band Downlink
- 99.99% Available

100 Gbps Downlink
- 97% Available
NASA is partnered with JAXA and CNES to develop a “High-Data Throughput” Standard for Near-Earth Relays.

1 Gbps RF GEO to Earth

Lasercomm Links

EDRS A in GEO (ESA 2015)

AlphaSat in GEO (ESA 2014)

LEO-GEO 600 Mbps Lasercomm Links

Sentinel 1 in LEO (ESA 2014)

UAV (General Atomics 2016)

Deep Space “High Photon Efficiency” Standard Recently Accepted by CCSDS Optical Comm Working Group

Draft Recommendation for Space Data System Standards

HIGH PHOTON EFFICIENCY

PROPOSED DRAFT RECOMMENDED STANDARD
CCSDS 000.0-B-0

BLUE BOOK
January 2019
Commercial workshop attendees:

- Facebook Connectivity Lab
- Google X (Loon)
- AT&T
- BridgeSat
- LaserLight Communications
- L-3 CSW
- Fibertek
- And 20 other companies....

Interoperability Issues for Consideration:
- Link scenarios/applications
- Leveraging of Existing standards (e.g., OTN, DVB-S2)
- Wavelength(s)
- Acquisition
- Modulation
- Channel clock
- Channel rate variation
- Data link layer interface
- Channel coding, interleaving, and Q-repetition
- Physical layer framing
- Interface Control Documents (ICDs)
- Interoperability agreements
Questions?

Please feel free to contact me at:

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