The Optical Communications Telescope Laboratory (OCTL)

Presentation

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Outline

- OCTL telescope description
  - Location
  - Telescope optical train
  - Multi-port coudé focus
  - (Laser safety System at the OCTL (LASSO)
- History of optical link demonstrations at Table Mountain
  - GOPEX
  - GOLD
  - OTOOLE (OCTL to OICETS Optical Link Experiment)
  - ASTRO (Active Satellite Tracking and ranging from OCTL)
- Future laser communications demonstrations from the OCTL
  - LLOT (Lunar Lasercom OCTL Terminal)
  - OPALS
  - LCRD (Laser Communications Relay Demonstration)
    - Ground station 1 architecture
    - Ground station subsystems
      - Atmospheric monitoring
      - Network integration
      - Integrated optical System
      - Monitor and control
- Summary

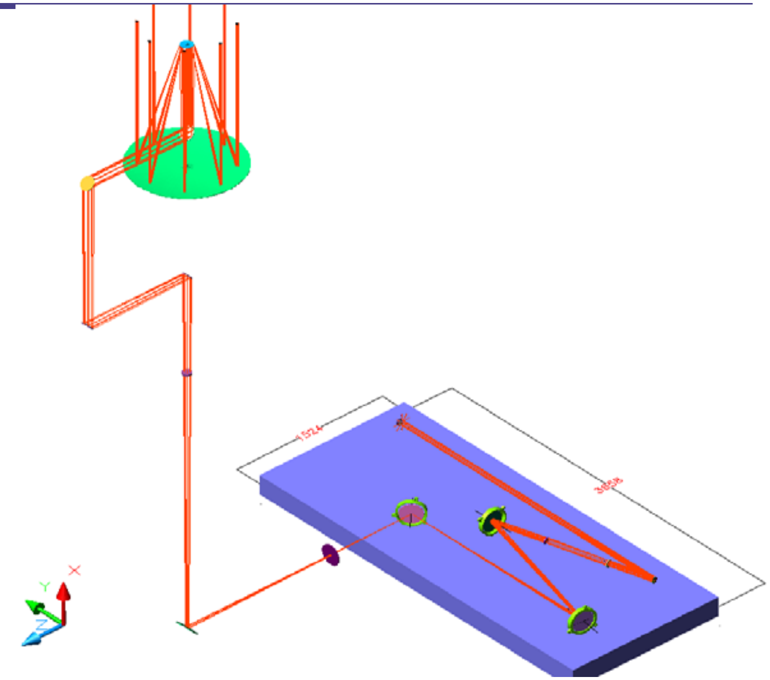
The Optical Communications Telescope Laboratory (OCTL)

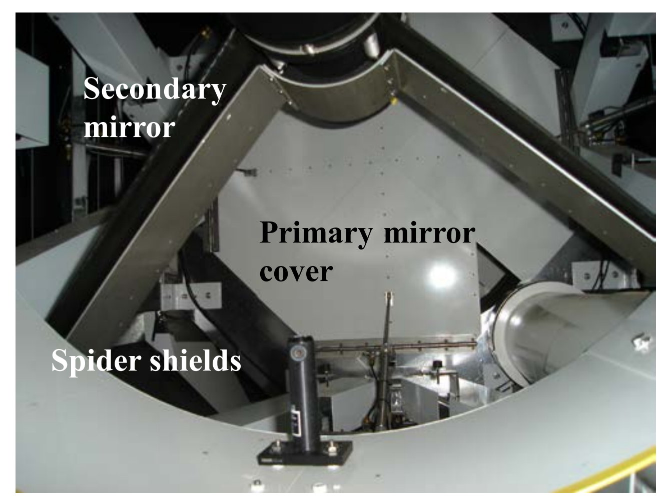
OCTL

- 1-m El/Az telescope located at 2.2km mean sea level altitude
  - Good climatic and atmospheric seeing conditions
- Telescope tracks from LEO to deep space targets; 6 degree keyhole
- Coudé focus supports integration of high power lasers for deep space transmission

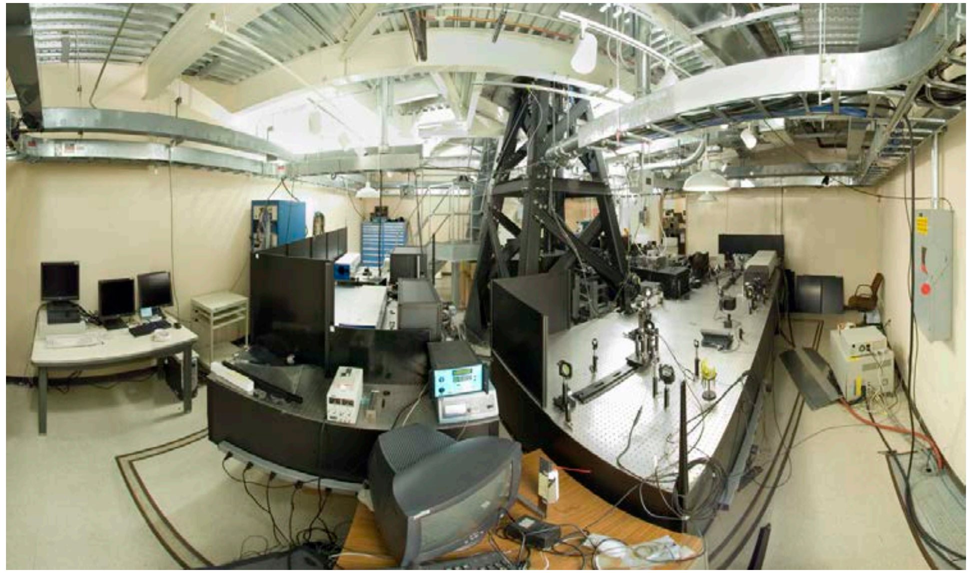
OCTL Telescope Optical Train

- **Optical quality instrument**
  - Primary telescope
    - Surface figure λ/7 wave-front-error (@ 632-nm) across 1-m aperture
    - ~ 50 % optical transmission from 0.5 μm to > 2.2 μm.
    - Seven mirror coudé mount supports high power laser beam transmission
  - Acquisition telescope
    - 20-cm diameter
    - 1.5–m focal length
    - Co-aligned with 1-m telescope
- **Daytime operation**
  - Sun avoidance software supports daytime operation
    - Basic telescope baffle configuration allows pointing to 5° of sun
    - Secondary mirror spider shields prevent solar heating of spiders





OCTL Multi-port Coudé Focus



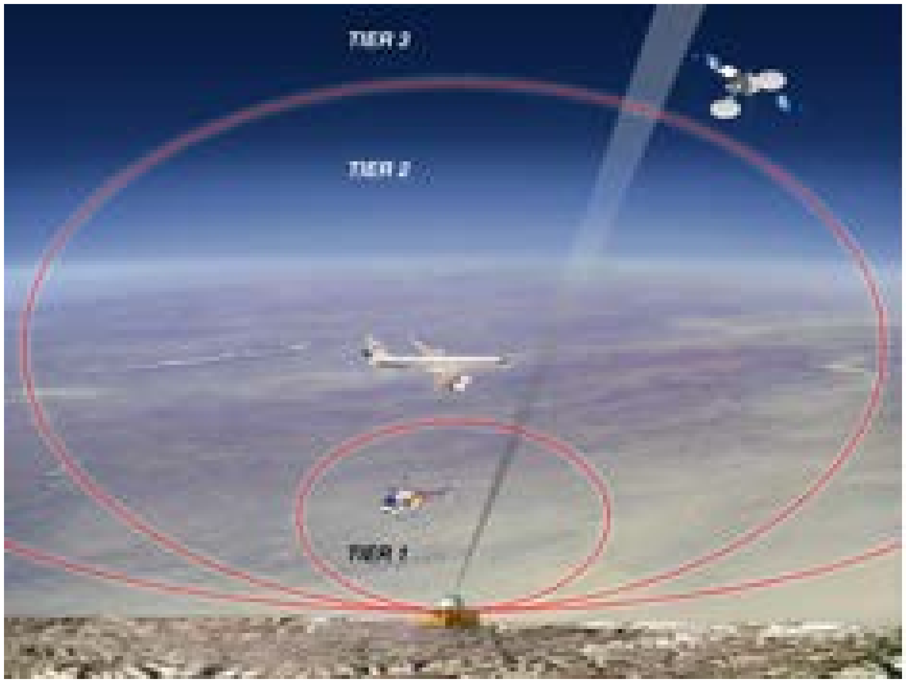
Four-port coudé path

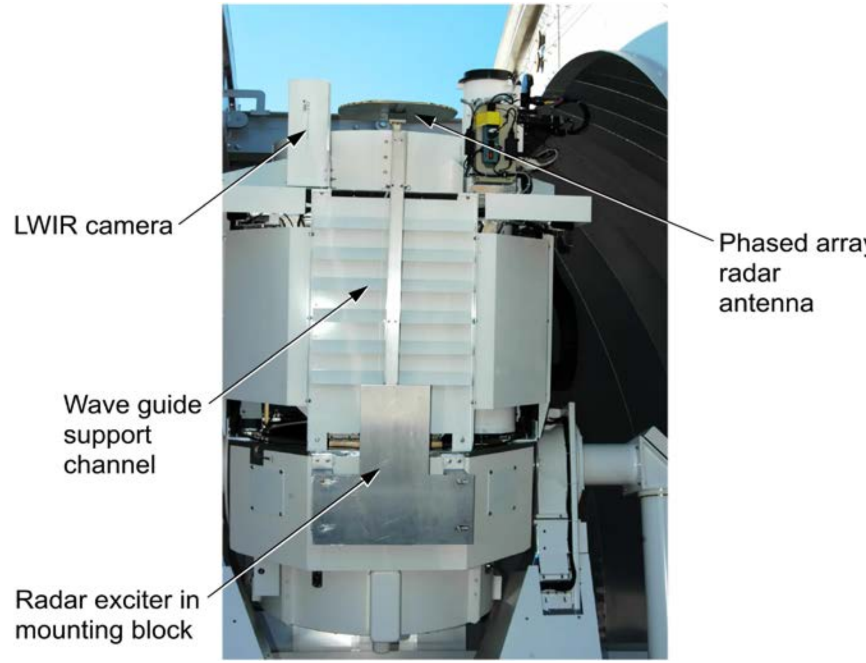
- Ports support (i) Adaptive optics, (ii) Passive satellite tracking and telescope characterization, (iii) Active satellite tracking with laser beam propagation, and (iv) Bidirectional laser communication experiments
- Port-to-port pointing repeatability < 3 arc seconds

Adaptive optics facility instrument

- Current configuration: 97 actuators across 1-m aperture supports daytime operations suppressing sky background at near-sun pointing angles, silicon wavefront sensor

LAser Safety System at OCTL

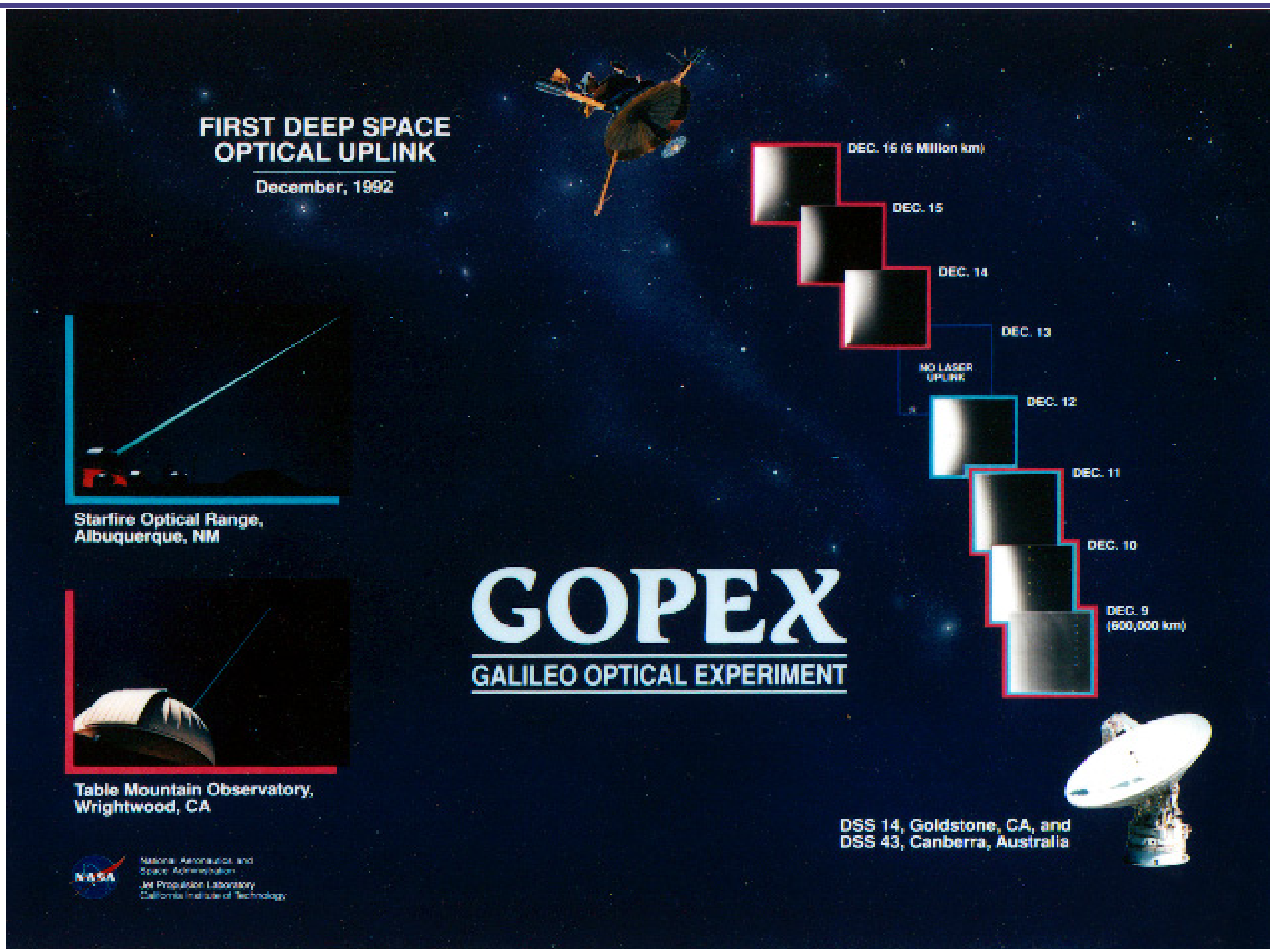




- Facility is instrumented with a three-tier safety system for safe laser beam propagation through navigable air and near-Earth space
  - Tier 1: Two wide field LWIR cameras alert to aircraft at risk of intercepting beam
  - Tier 2: Bore-sighted radar detects and signals alert of aircraft at risk of intercepting laser beam out to 50 km
  - Tier 3: Laser Clearinghouse provides predictive avoidance times to avoid illuminating spacecraft.

Past Laser Communications Demonstrations at TMF

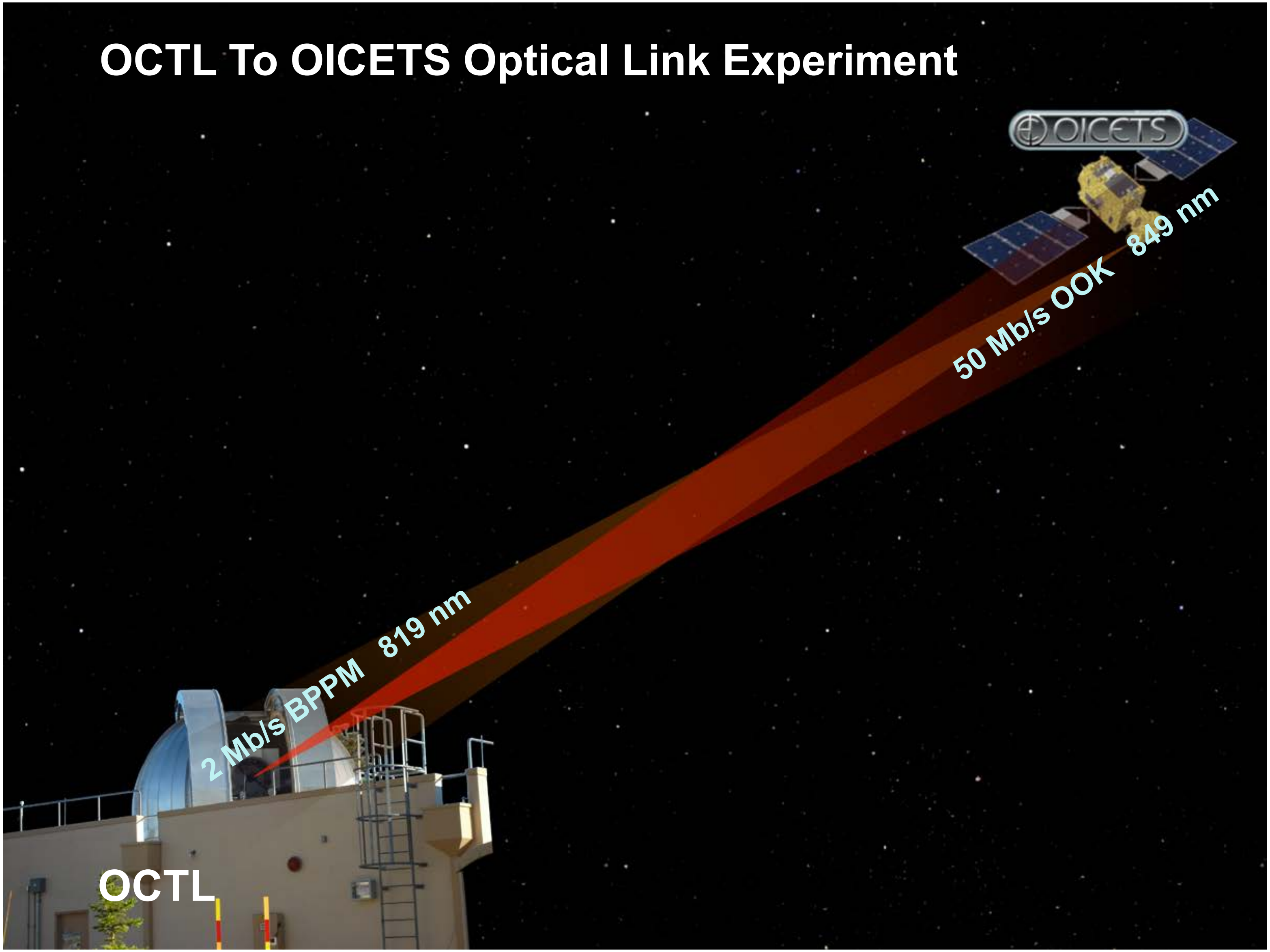
Galileo OPtical Link Experiment Dec. 1992



Experiment demonstrated need for site diversity and uplink scintillation mitigation

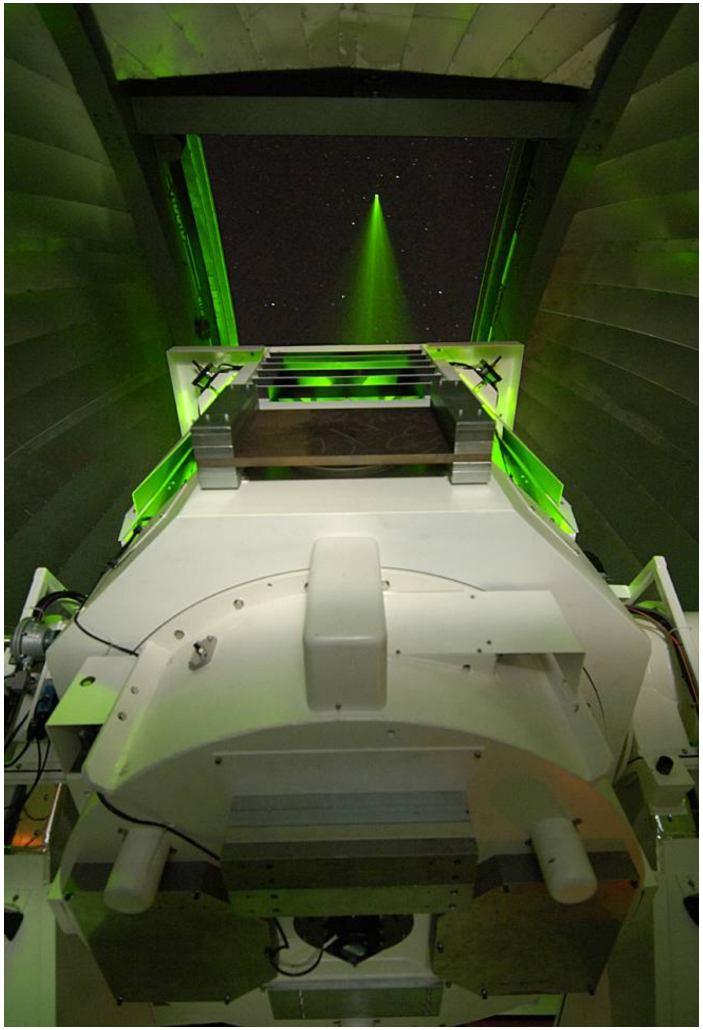
GOLD Nov. 1995- Mar. 1996

Bi-directional optical communications link to ETS-VI spacecraft at GEO ranges
Demonstrated multi-beam mitigation of uplink scintillation


OCTL To OICETS Optical Link Experiment
OICETS
50 Mb/s OOK 849 nm
2 Mb/s BPPM 819 nm
OCTL

Active Satellite Tracking OCTL

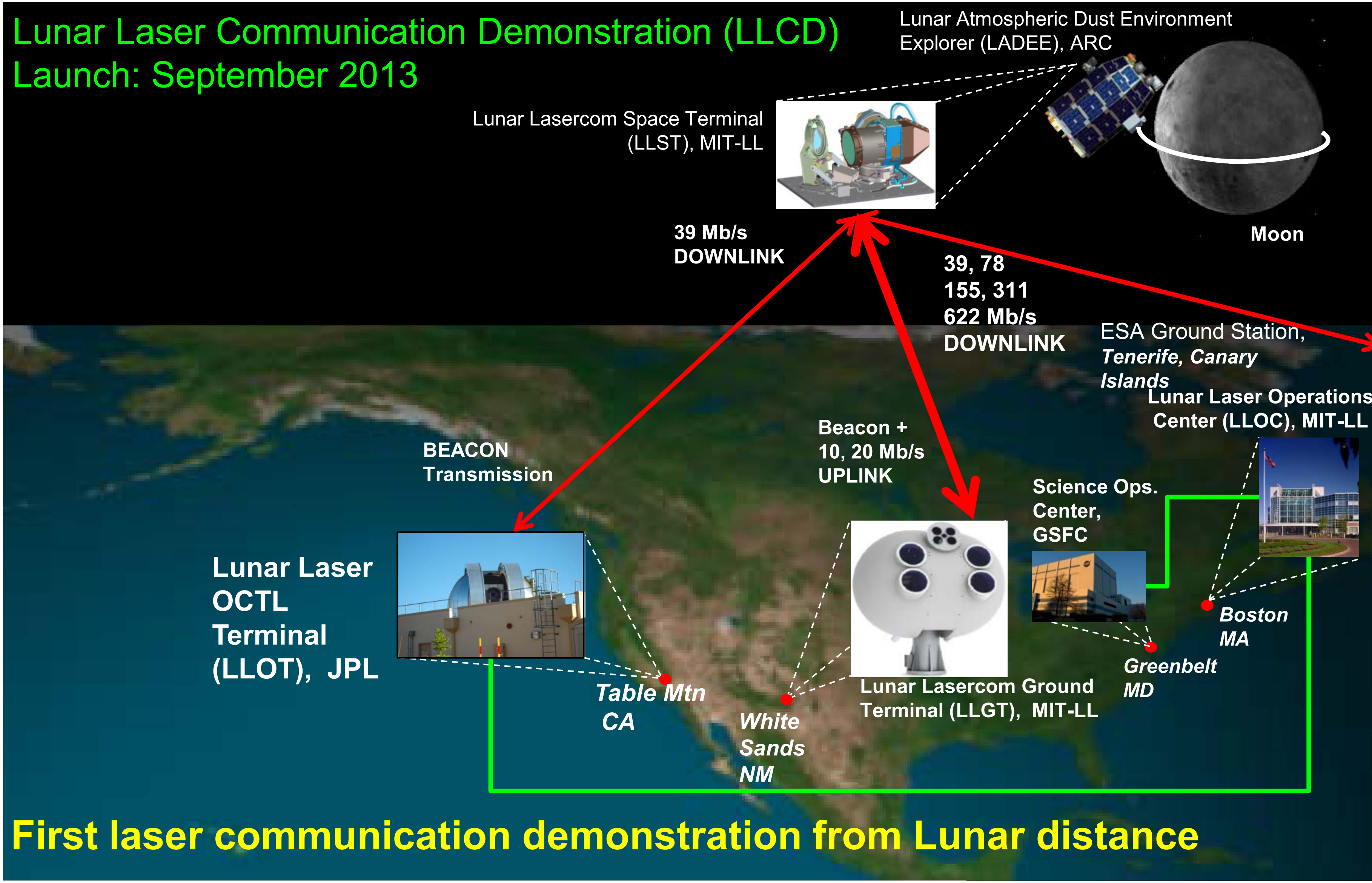
- OCTL is approved to propagate lasers to more than 20 U.S. and international satellites
- Experiments validate beam propagation models and develop ground-to-space laser communications operational strategies
- Initial visible wavelength operations have been replaced by near-IR propagation
- Demonstrated first range-resolved Doppler imaging of spacecraft



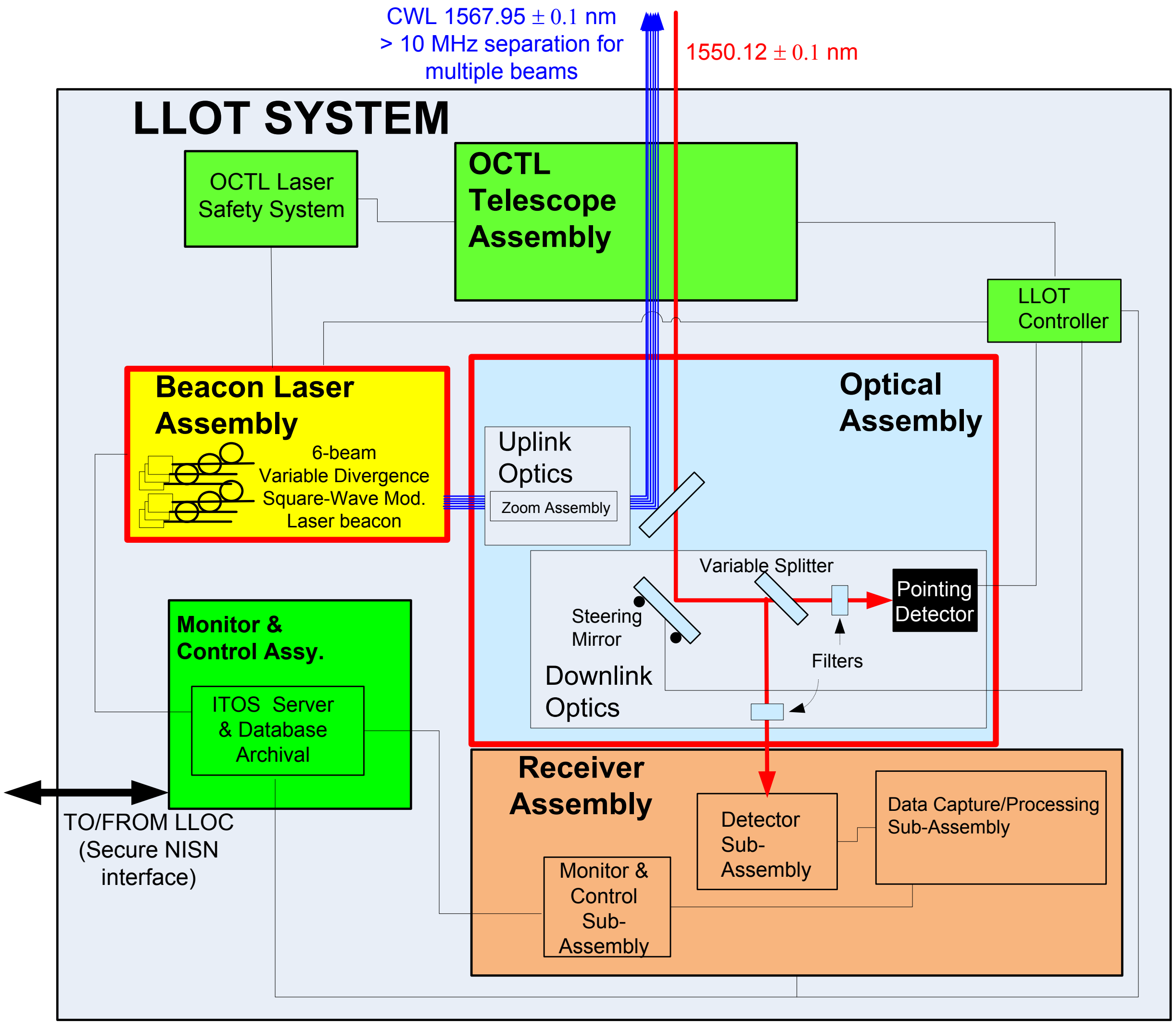
Future Demonstrations from the OCTL

LLCD Architectural Overview

Jet Propulsion Laboratory
California Institute of Technology



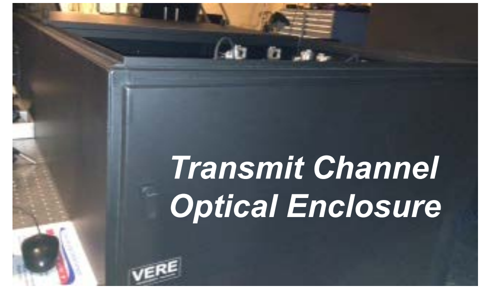
LLOT Ground Station System Block Diagram

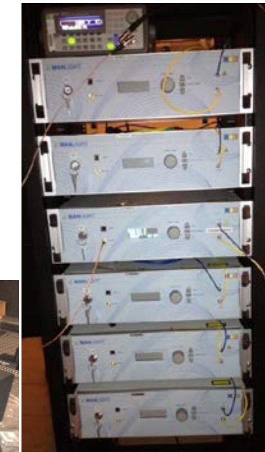


OCTL Telescope

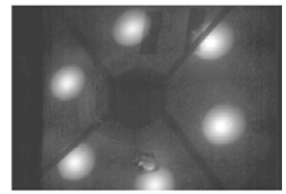
LLOT Status

- **Optics and laser assembly integration with OCTL telescope and testing underway**
  – Multi-beam (6 x 10 W) 1568 nm beacon to LLST
  – Receive optical train for 1550 nm downlink
  – Provide filtering and transmit/receive isolation for day and night time links





Rack Mounted Lasers

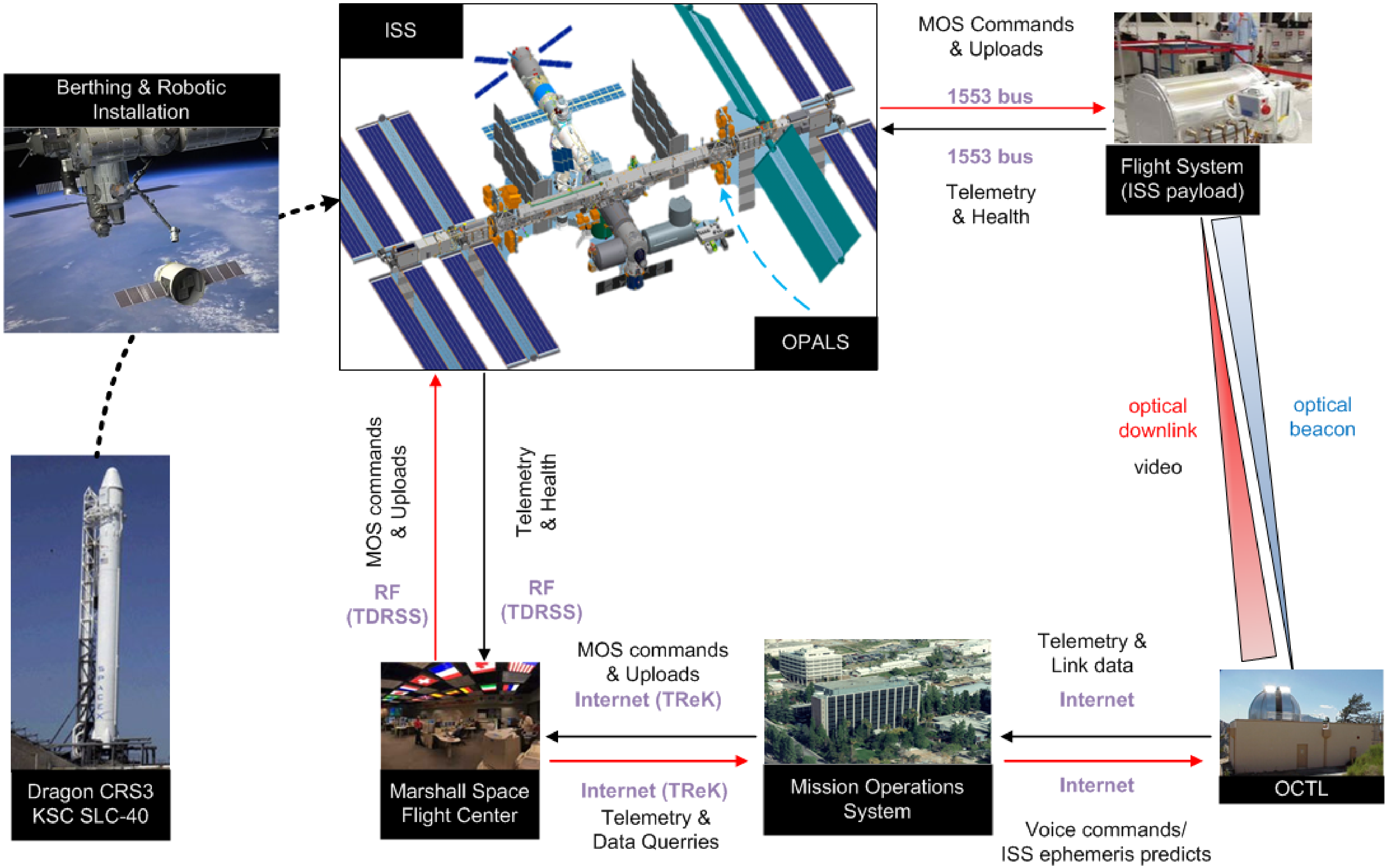


Beacon Spot Pattern on OCTL dome

- **Integrating 12-pixel superconducting nanowire detector array with closed-cycle 1K fridge for deployment at OCTL telescope**
  – Multi-mode fiber coupling of signal received through telescope to detector array
  – Detector output recorded for post-processing by software receiver

- **Compatibility tests with LL-MIT planned for June with operations in October-November 2013**

OPALS Architectural Overview



OPALS Facets

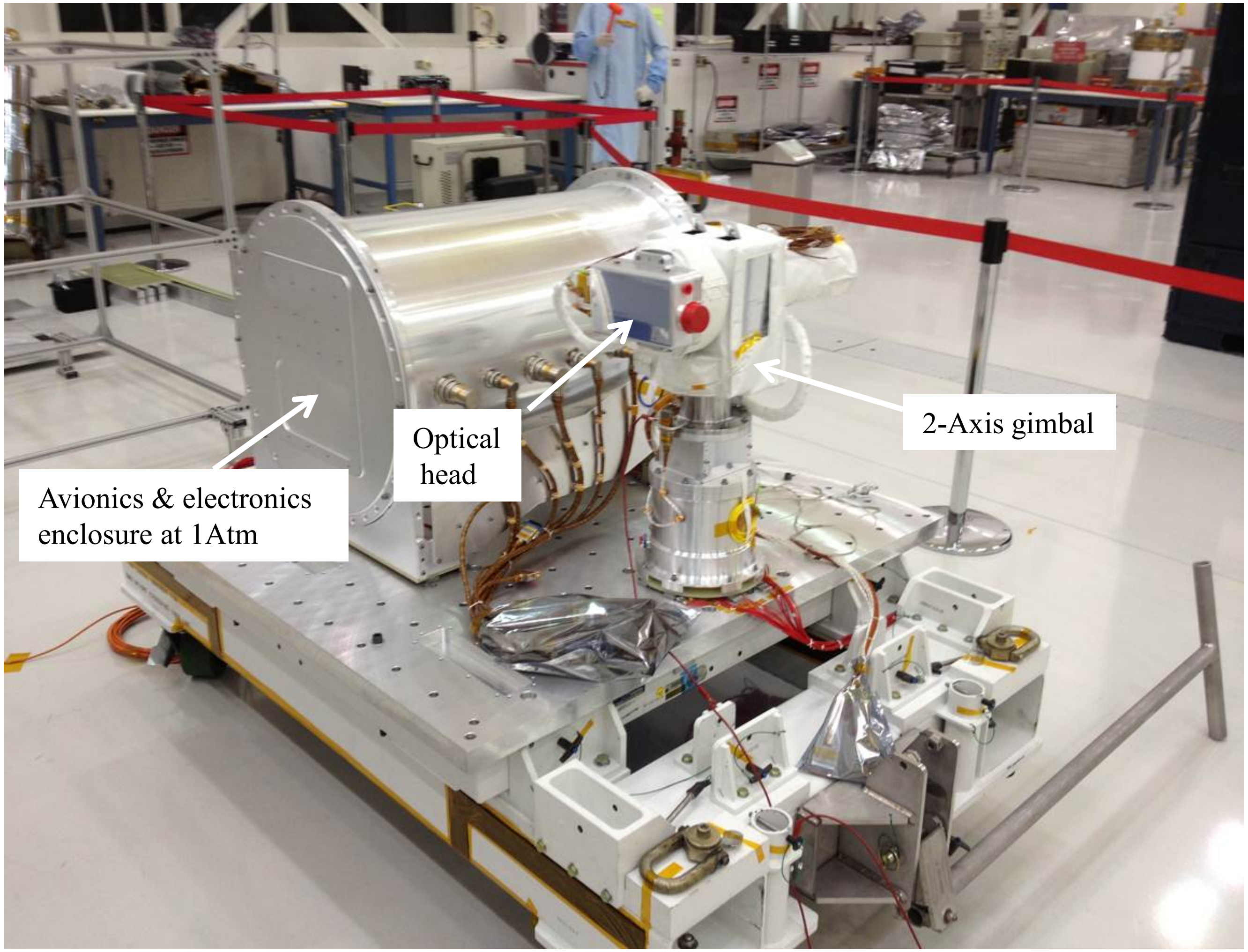
- **Optical link performance characterization & validation**
- **Atmospheric turbulence characterization**
  - **Obtain downlink aperture-averaged fading statistics by recording received power**
  - **Obtain uplink scintillation statistics by recording beacon power on flight system**
- **Link availability studies**
  - **Geometry, atmospheric & environmental, day vs. night**
- **Pointing performance**
  - **OCTL Open loop tracking**
  - **Flight System acquisition, tracking, stability**


High-rate Downlink Ground Transceiver (1-m Diameter)

DOWNLINK CHARACTERISTICS		
SIGNALING		
Modulation	OOK	-
Uncoded BER	1.00E-04	-
ECC	Reed-Solomon	-
Modulation Rate	30-50	Mb/s
TRANSMITTER		
Downlink wavelength	1550	nm
Beam Divergence (1/e^2)	1.35	mrad
Average laser power	2.5	W
Power transmitted from FS	>0.833	W
POINTING		
Pointing Bias	150.0	µrad
Pointing Jitter (RMS)	125.0	µrad
LINK GEOMETRY		
Max Zenith Angle	65	deg
Max Range	700	km

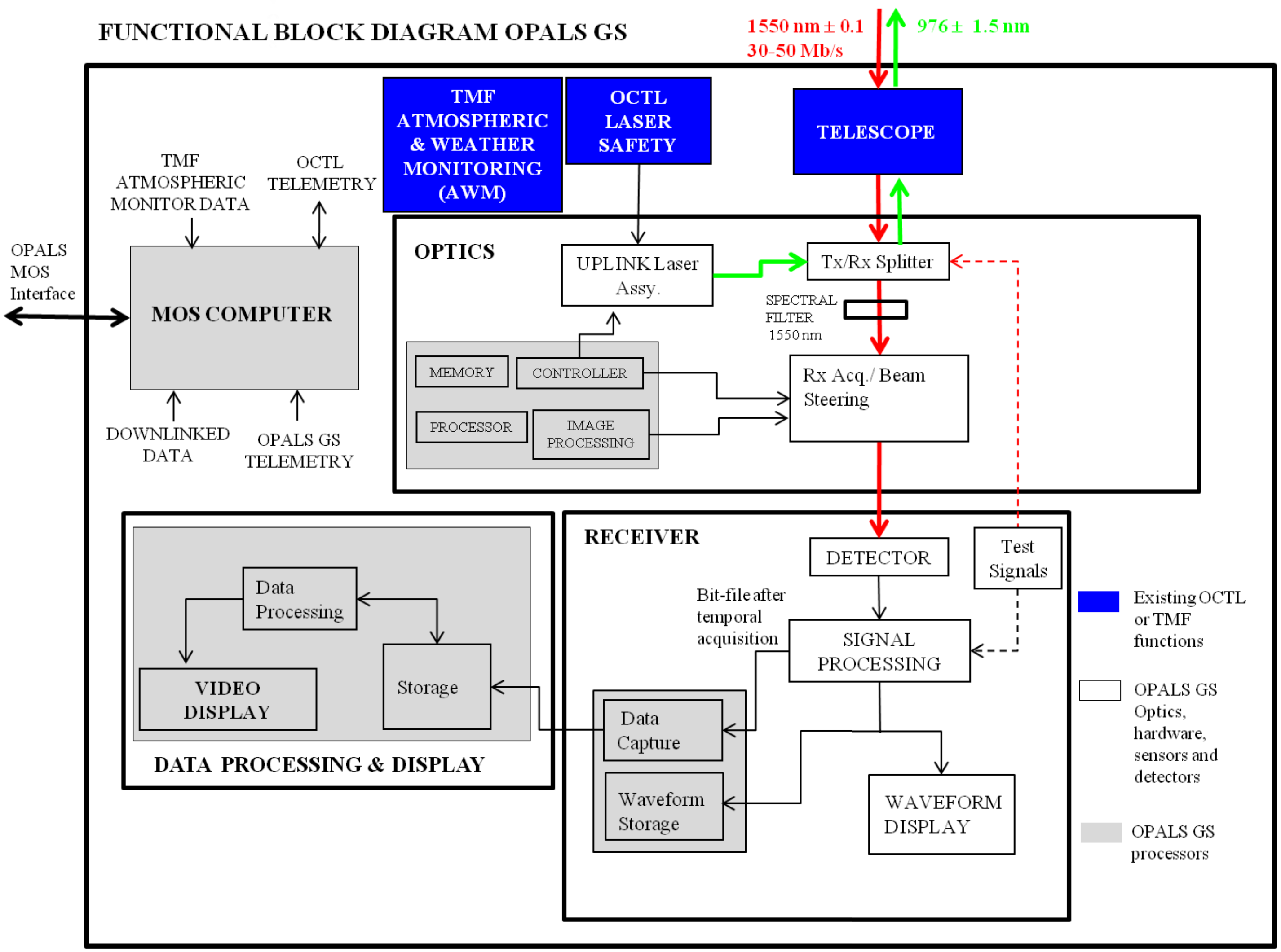
BEACON CHARACTERISTICS		
Uplink wavelength	976	nm
Average Laser power	5	W
Beam divergence	1.7	mrad
Power transmitted from OCTL	1.26	W

OPALS Flight Hardware



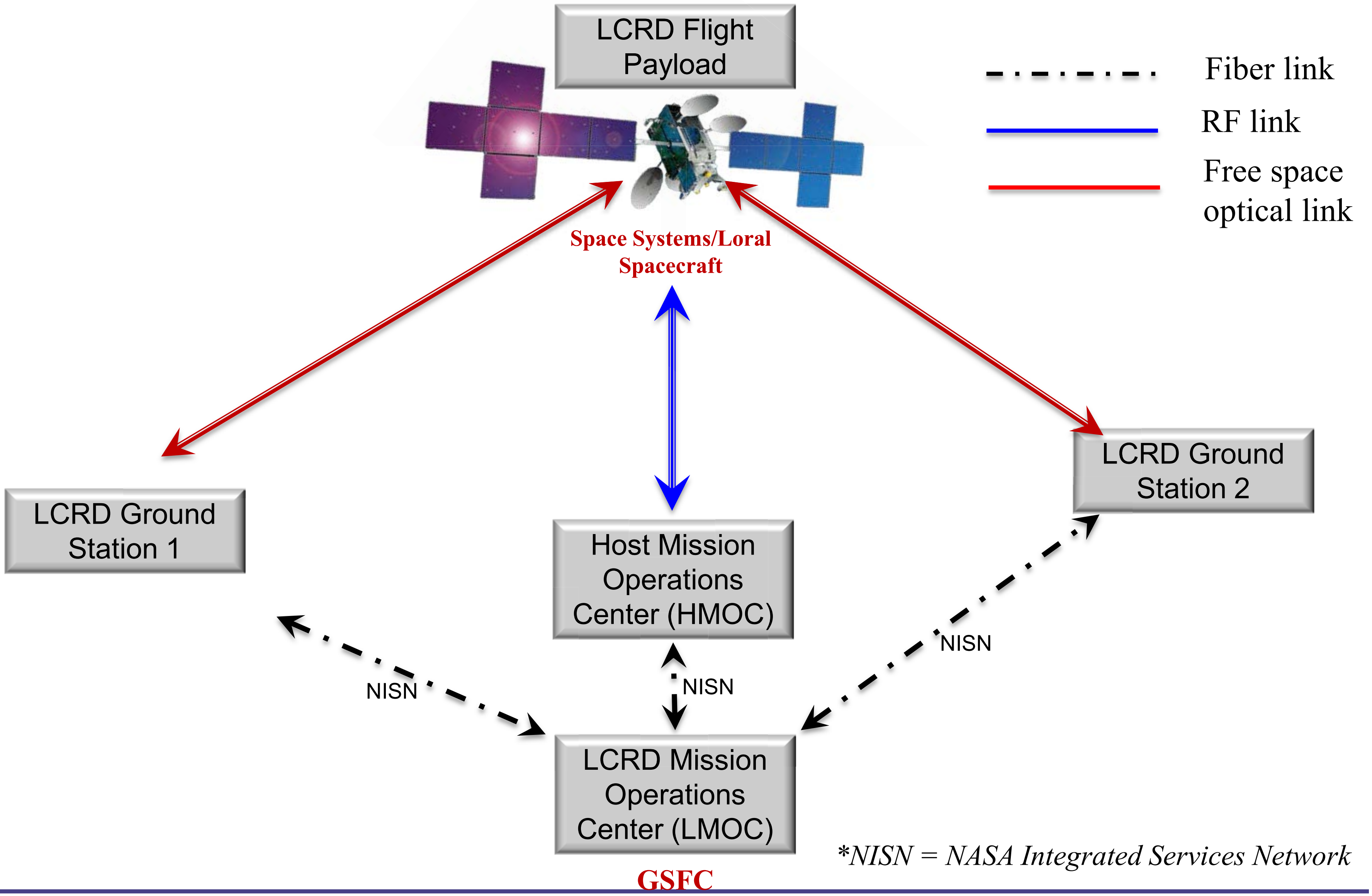
OPALS Flight system (without FRAM) prepared for dynamics testing.

OPALS Ground Station Block Diagram



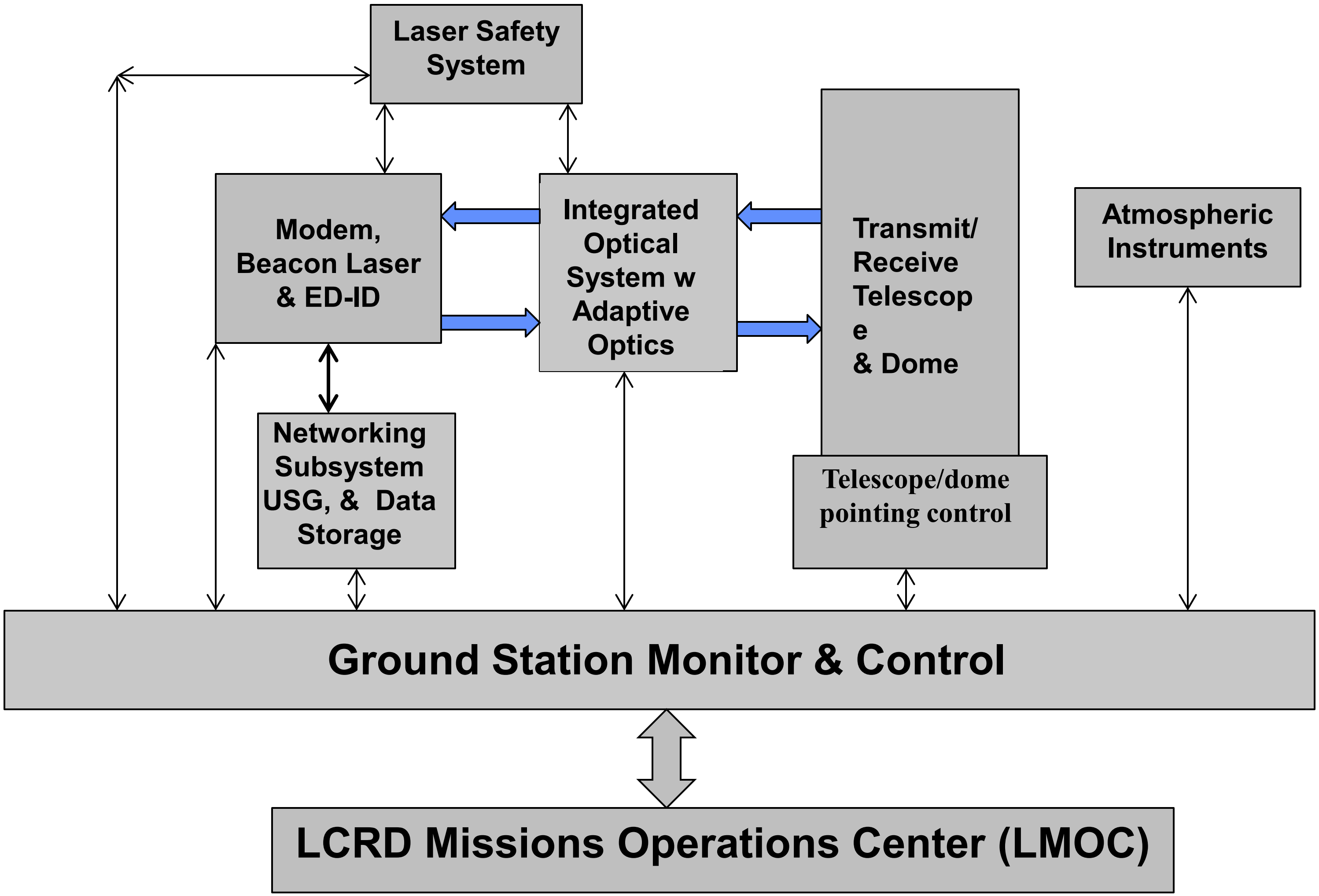
OCTL Telescope

LCRD System Architecture Overview



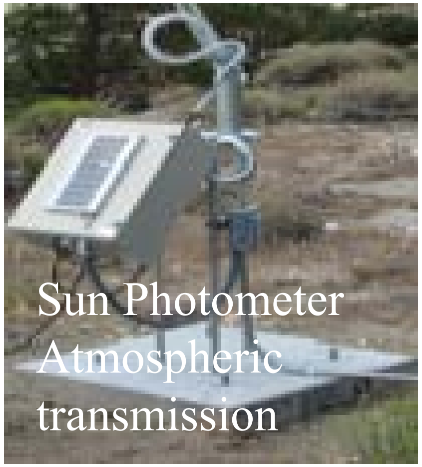
**NISN = NASA Integrated Services Network*

LCRD GS1 Ground Station-1 Architecture (OCTL)

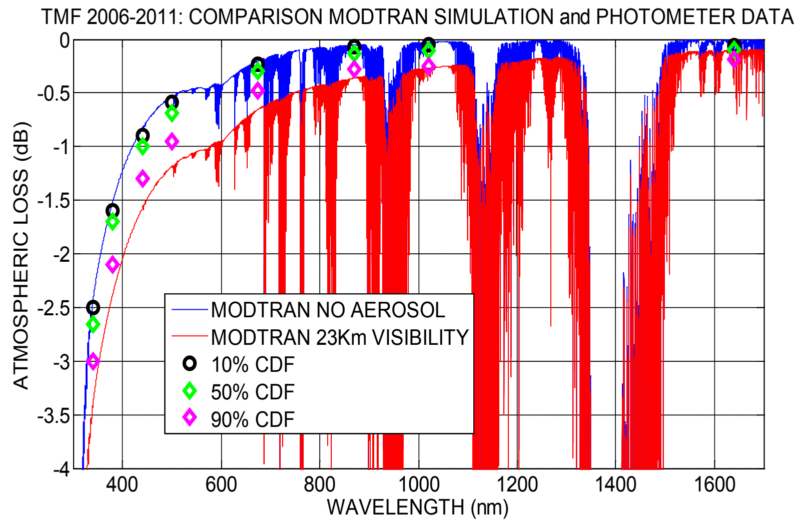


Atmospheric Monitoring Instruments


Cloud cover Monitor


Sun Photometer Atmospheric transmission

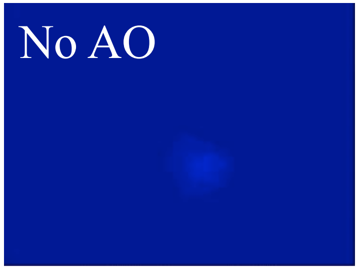
Atmospheric attenuation

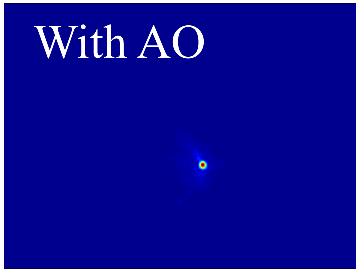



Solar scintillometer

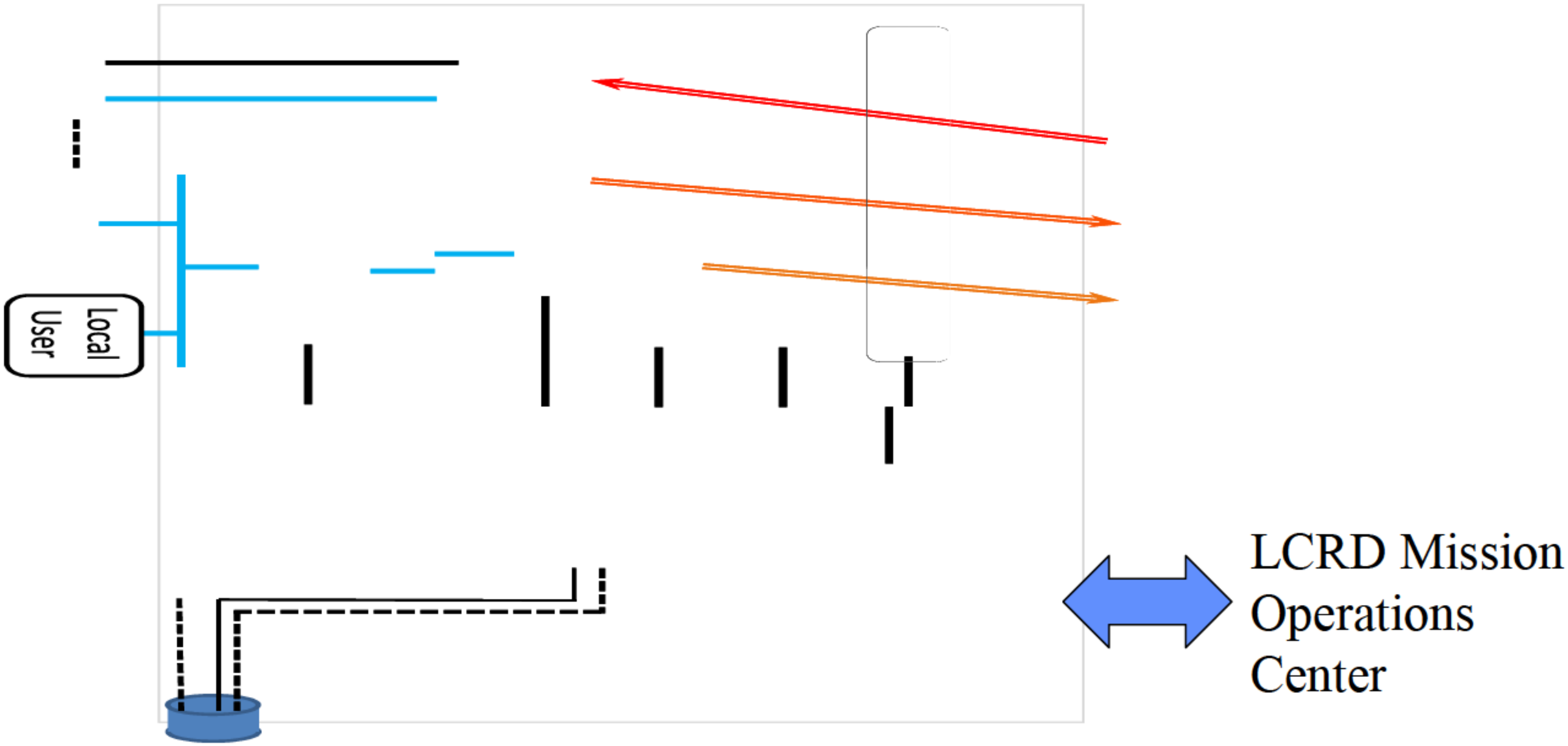

Ground scintillometer

Adaptive Optics
Downlink measurement of r_0


No AO


With AO

LCRD Integrated User Services Gateway

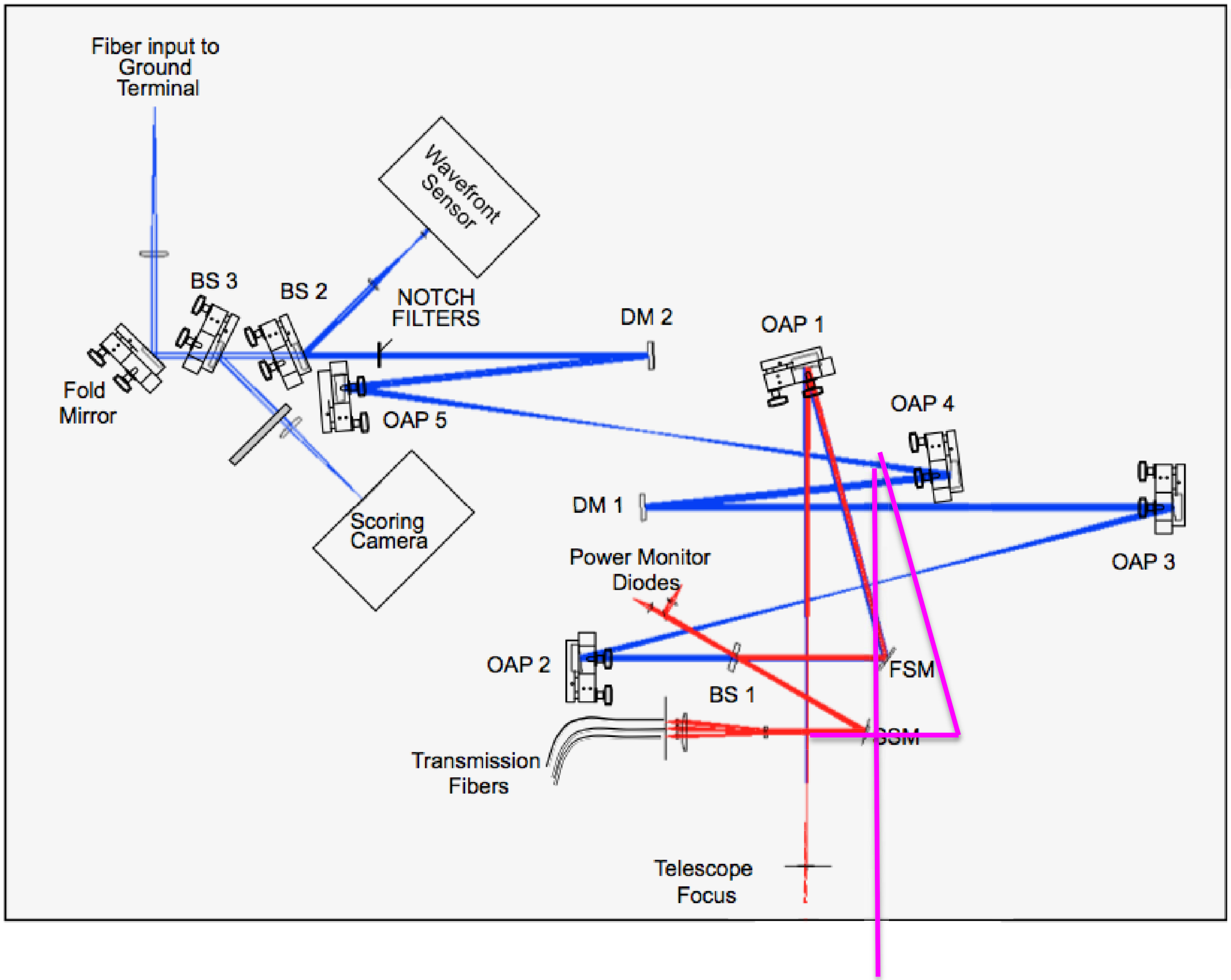


Integrated Optical System with Adaptive Optics System Layout

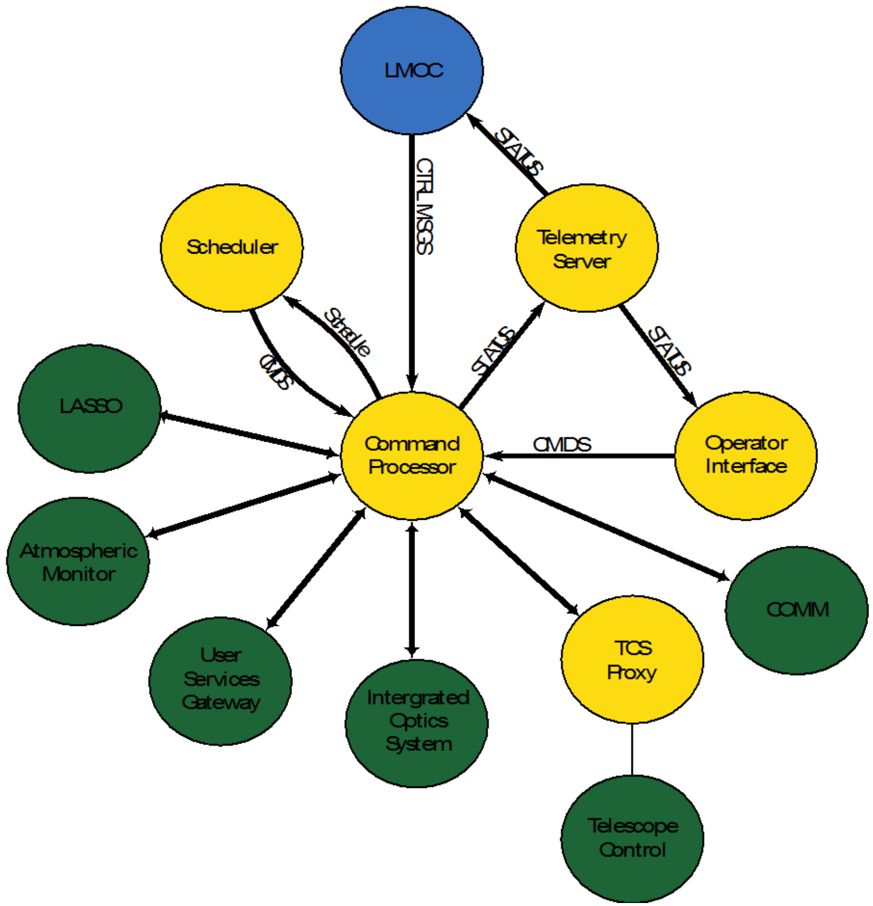
Red line is uplink beam

Blue line is downlink beam

Purple is both beams



Monitor and Control Software Architecture



- Monitor and Control System (MCS) is the software interface between the LMOC and the ground station
- MCS accepts commands from the LMOC to be executed by the ground stations and returns data from the ground station subsystems

Summary

- The OCTL is NASA's first optical communications ground station. It is designed to operate both night and day at sun angles as close as 5 degrees. It is the the out growth of successful JPL laser propagation demonstration projects conducted with JPL deep space and NASDA & JAXA near-Earth spacecraft
- The three-tier LASSO has enabled safe high power laser beam transmission through air and near-Earth space without incident
- OCTL's coudé focus configuration has enabled
  - Active satellite tracking experiments with high power laser beams transmitted through the telescope
  - Demonstration of atmospheric scintillation mitigation by multi-beam propagation
  - Development of adaptive optics to correct atmospheric turbulence-induced wavefront aberrations in a controlled laboratory environment
- Past OCTL demonstrations include the first demonstration of range resolved Doppler imaging of a satellite and support of a high bandwidth bi-directional optical link with the OICETS
- Future demonstrations from the OCTL include LLCD, OPALS and LCRD