Ground-to-Space Transmitter System for Extended Instrument Diagnostics of On-Orbit Operational Radiometric Sensors

Timothy Berkoff, Constantine Lukashin, Trevor Jackson, William Carrion
NASA Langley Research Center, Hampton, Virginia, USA

Steven Brown, Brian Alberding
National Institute of Standards and Technology, Gaithersburg, Maryland, USA

Tom Varghese, Cybioms Inc., Maryland USA

Brendan McAndrew, Jan McGarry, Evan Hoffman, Mark Shappirio, Joel McCorkel
NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

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Motivation & NASA Langley GSLC Project Timeline

2013-2014: Science Innovation Fund concept report (led by Constantine Lukashin)

2014-2015: Patents issued to NASA Langley

2017-2020: NASA Langley internal research and development (IRAD) funding:

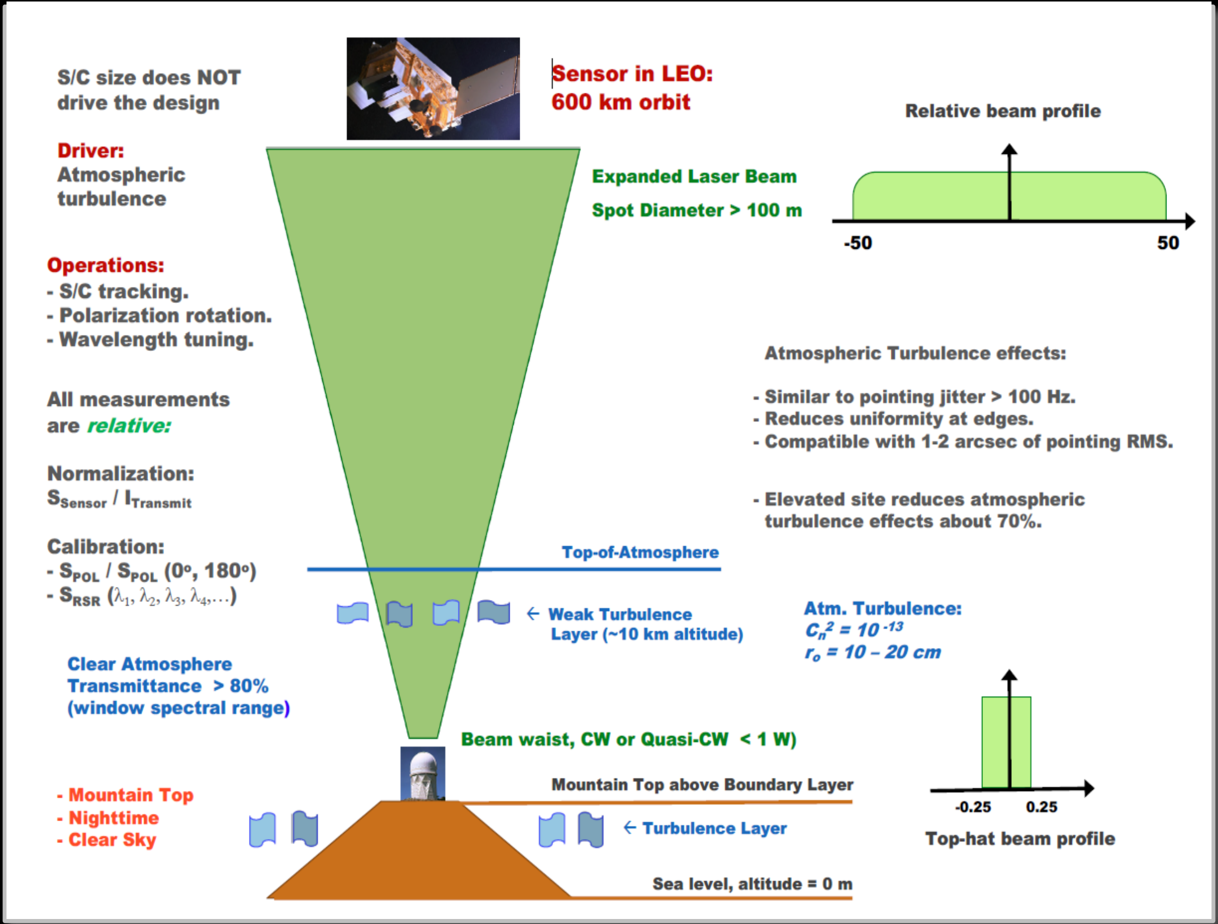
- Inter-agency agreement with NIST to support NASA development work
- Initial tests on GOES-16 with modified GLM beacon
- Design and Build of single-beam test transmitter

2020: COVID!

2021+: Future plans ?!?

GSLC Conceptual Illustrations

Lukashin et al., (2014) Ground-to-Space Laser Calibration System, NASA Langley Research Center Technical Report



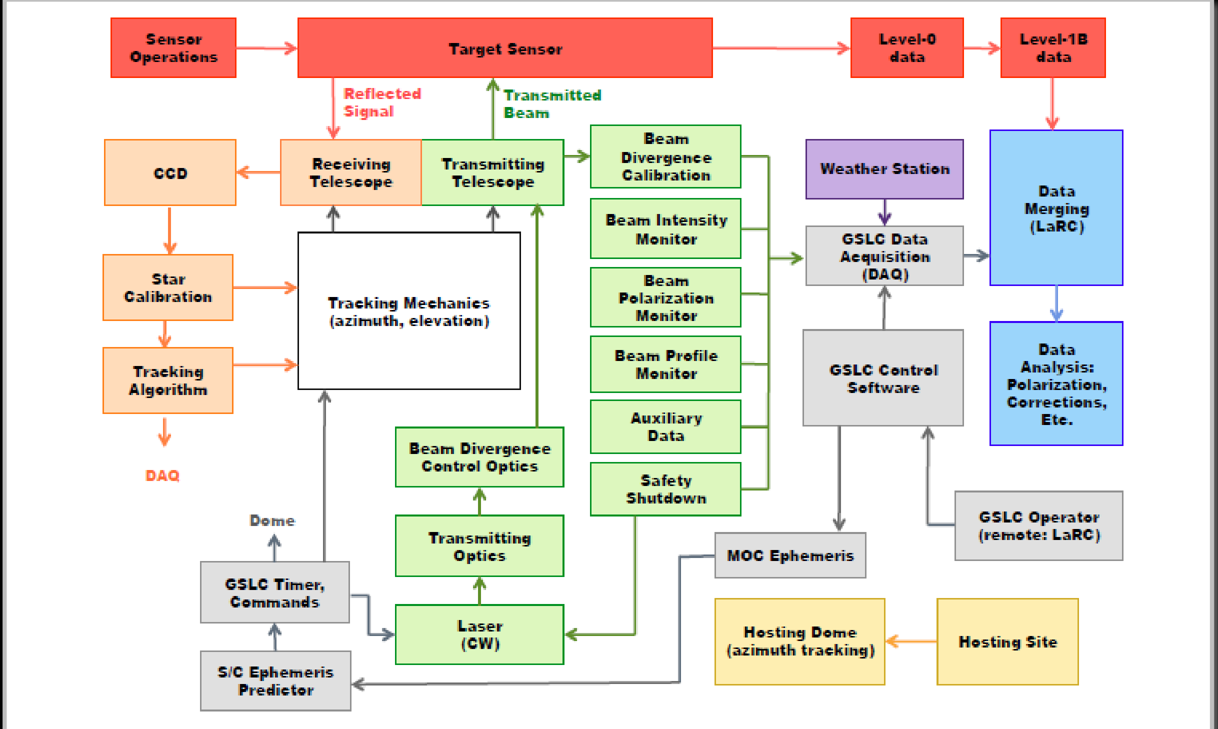


Figure 7: GSCL block diagram, sub-systems are grouped by different color: target on orbit sensor (red), hosting site (yellow), laser, transmitting optics and beam diagnostic (green), tracking mechanics (white), receiving telescope and detectors (orange), weather station (purple), data acquisition electronics and system controls (grey), data system (blue).

[1] Lukashin C. and B. Wielicki, patent US 8767210 B1, "Method for Ground-to-Space Laser Calibration System," July 1, 2014.
[2] Lukashin C. and B. Wielicki, patent US 9052236 B2, "Method for Ground-to-Space Laser Calibration System," June 9, 2015.

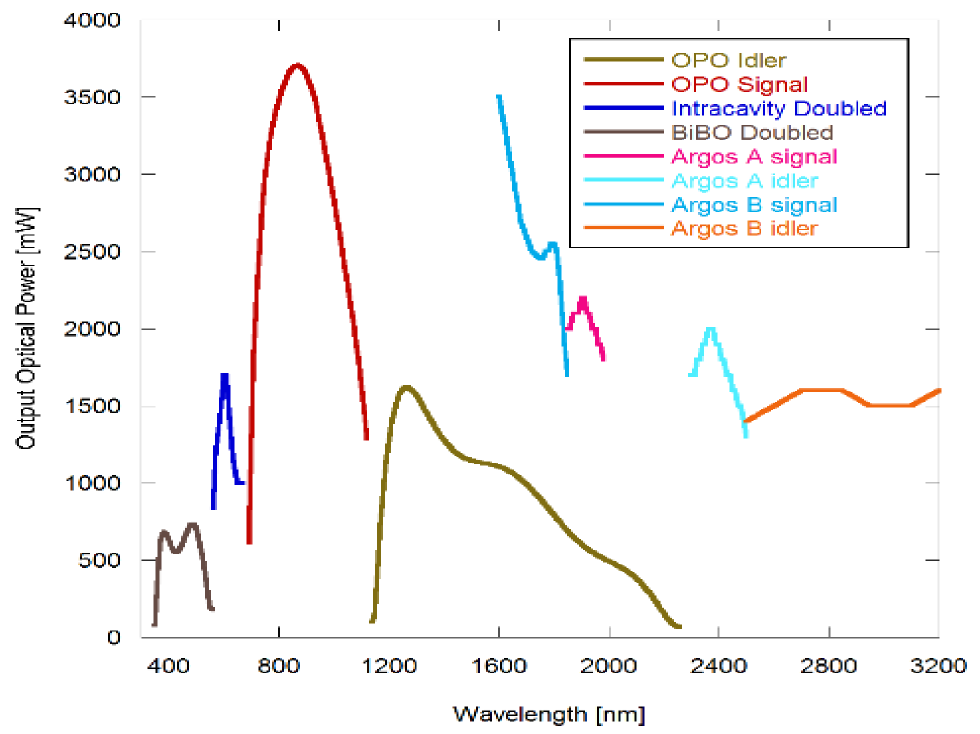
Potential GSLC Diagnostic Measurements & Wavelength Coverage

These diagnostics are not dependent on knowledge of absolute irradiance level arriving at sensor on orbit

Diagnostic Measurements

Diagnostic	Method	Notes
Response Function (RF)	Laser intensity can be adjusted in steps to characterize linearity/responsivity function and also impulse response	With several steps in known intensity changes, a responsivity curve can be determined and check for dynamic range and linear sensor response
Relative Spectral Response (RSR)	Laser source wavelength tuning at multiple steps is used to determine spectral response shape	In regions where atmospheric absorption might affect measurements, radiative transfer model type approach could be used and/or co-located atmospheric data (i.e. ozonesondes for O3 & H2O, lunar Pandora spectrophotometer for other gases)
Polarization (POL)	A linearly polarized beam is rotated rapidly with an active half-wave ferroelectric crystal in the transmitter	Polarization rotation states are self-referenced due to the cyclic nature of the measurements (same expected signal at +/- 180 deg.)
Out of Band Response (OOB)	Large wavelength steps or gated combination of multiple laser sources can be used to investigate spectral in/out of band blocking. Spatial-angular stray light impacts can also be characterized by illuminating with angular offsets to sensor	Important for understanding spectral and spatial cross-talk/leakage issues impacting satellite measurements. Rapid switching between "on" & "off" band removes dependence on absolute radiance
Geolocation (GLR)	Ground-based laser light sources can be used for precise pointing determinations of space-borne sensor systems. NASA has done thisfor the GLM sensor on GOES-16/17 and can be extended to other sensors that need this type of calibration	See Buechler, D., et al., Proc. SPIE 10764 (2018) for geo-calibration of the GLM/GOES sensor. Geo-spatial resolution could also be determined with a pair of spatially separated light sources

NIST laser source wavelength coverage



GSLC measurement strategies

Atmospheric effects

Turbulence: scintillation and beam wandering

- Elevated locations (mountaintop observatories)
- Rapid measurement cycle (2 seconds or less)
- Repeat averaging of measurement cycle
- Spatial-split multi-beam propagation
- Flat-top & overfill of sensor aperture to maintain uniformity
- Guide-star imaging stability measurements

Spectral Absorption

- Select wavelengths that avoid strong spectral features
- Atmospheric modeling
- If needed:
  - Sonde/ozonesondes, H_2O, O_3, T
  - Lunar AERONET/PANDORA measurements: nighttime column spectral absorption measurements

Cloud, aerosol interferences

- Elevated location (mountaintop observatories)
- If needed: cloud & aerosol lidar

Pointing geometry

GEO v. LEO

Point and stare

- Scanner (e.g. TEMPO & others)
- Attitude platform pointing
- Specialized maneuvers for push-broom and 2-D array sensors

If needed, multiple locations to cover field of regard

Lukashin et al., (2014) Ground-to-Space Laser Calibration System, NASA Langley Research Center Technical Report

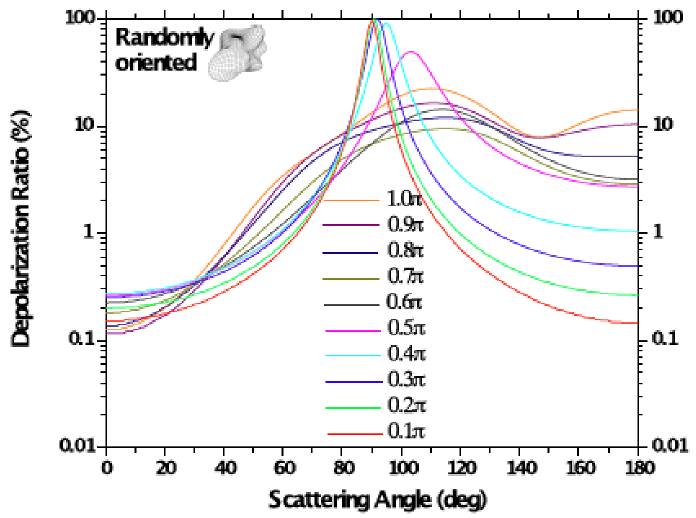


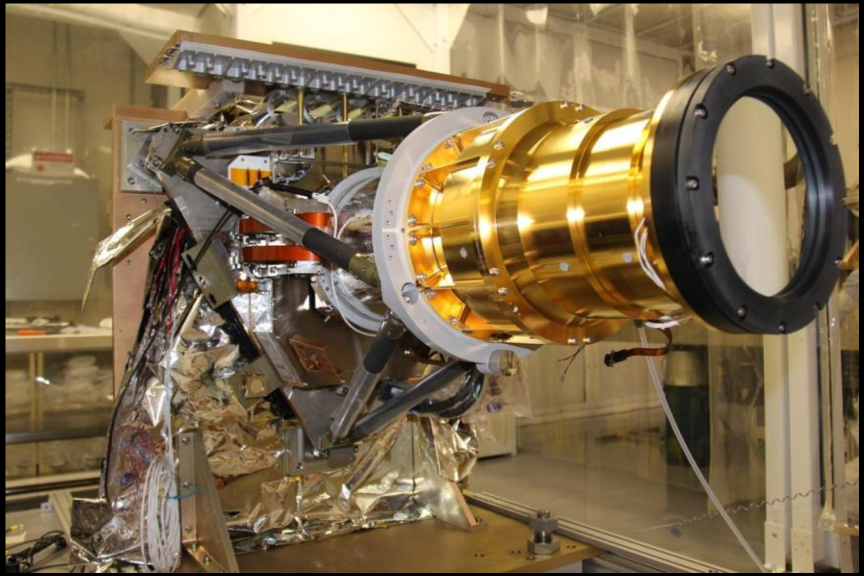
Figure 10: Results from radiative transfer calculations: depolarization ratio at 532 nm as function of scattering angle for Gaussian-shaped aerosol particles of different size. Depolarization in forward scattering direction (laser beam) is below 0.3%.

Atmospheric aerosol forward scattering polarization effects are not expected to be a significant factor

Geolocation: NASA's Geostationary Lightning Mapper Beacon

- Geostationary Lightning Mapper (GLM) on GOES-16 & 17
- Operational measurement of lightning events at 777 nm
- GLM was not intended for high precision radiance measurements, but nevertheless radiance values can be obtained from its data
- GLM ground-based beacons were previously implemented for geo-location determinations & already an approved activity at MOBLAS sites, see Buechler et al., 2018
- Provided a pathway for initial POL and RSR testing

The GOES-R Geostationary Lightning Mapper (GLM), Photo Credit: Lockheed Martin



GOES-17 launch 2018

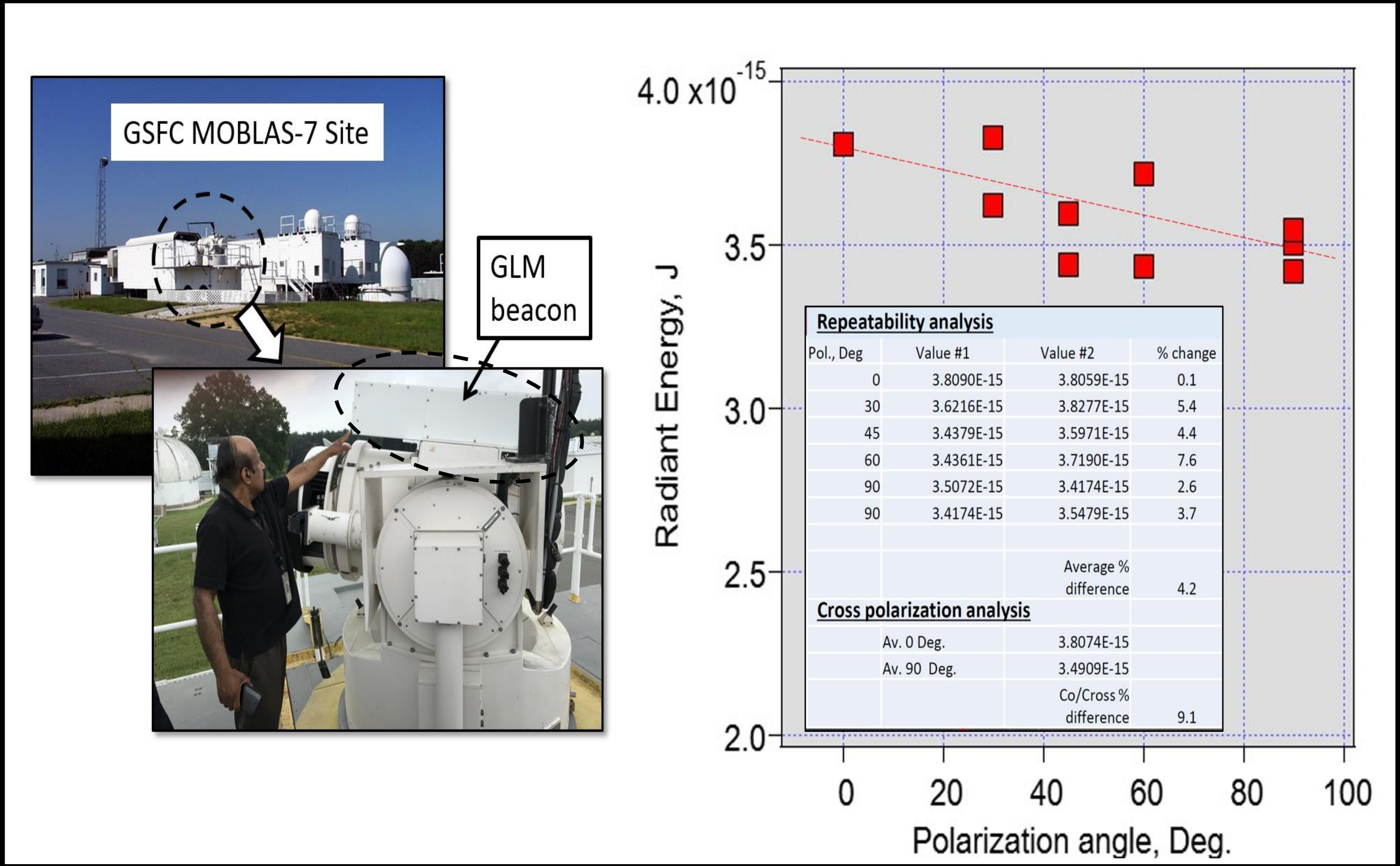
Polarization illumination test of the GOES-16 satellite Geostationary Lightning Mapper (GLM) sensor

- Existing GLM geolocation beacon [Buechler et al., 2018], modified by Cybioms to allow for polarization and RSR tests of GOES 16/17

- Polarization data collected (11 measurements at 2-3 minutes each, 5 states, ~30 minutes to complete a repeat cycle between 0-90 deg) varied on average 4.2% in radiant energy received by GLM.

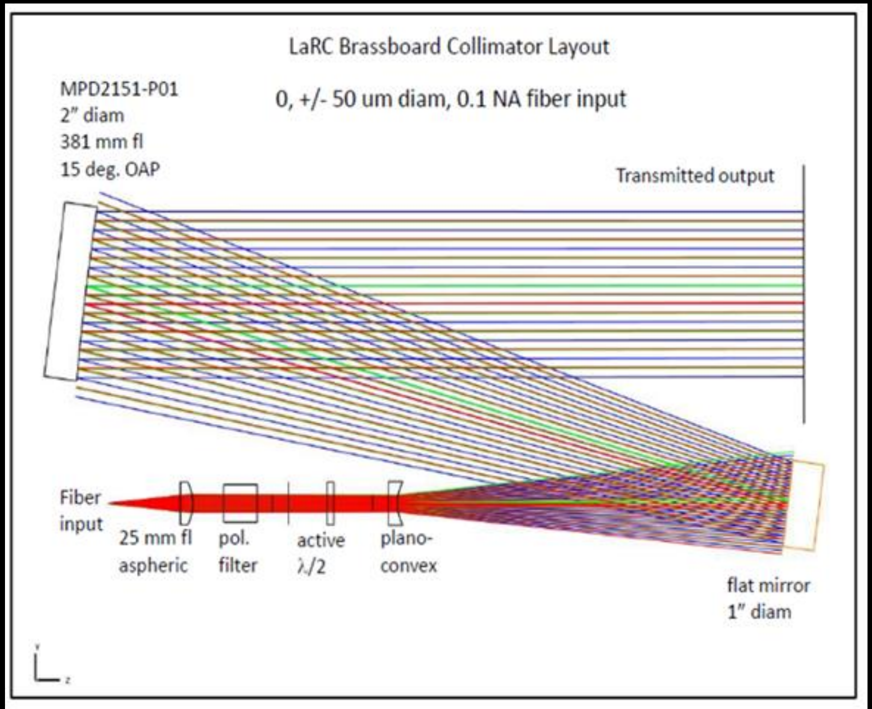
- A trend was observed suggesting a slight dependence on GLM polarization between 0 and 90 deg. transmitter orientation, corresponding to 9.1% change in radiant energy.

- RSR measurements not possible due to government shutdown



NASA Langley Transmitter Design

- Utilize existing GSFC & NIST laser sources
- Transportable/field deployable
- 2” diam off-axis parabola (no central obscuration)
- Active polarization control with contrast at least 500:1, >10 Hz switching rep rate
- Divergence control: 20 to 500 micro-radians
- To the extent possible achromatic
- “Top Hat” beam
- Mechanical interface compatible with NIST and other future tracking systems we may need
- Can operate at diffraction limit with SM fiber



Key:
Blue = 550 nm
Green = 750 nm
Red = 950 nm

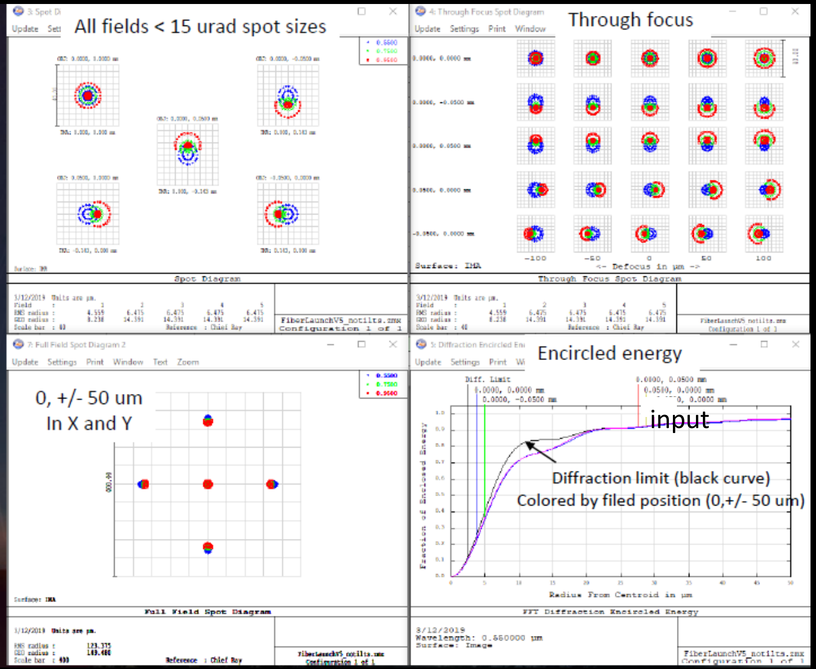
Simulated auto-collimator spot size performance using a paraxial 1 m fl lens placed in the transmitted beam

Fiber input object: NA= 0.1, fields at 0 and +/-50 um in X and Y

Close to diffraction limited performance for all wavelengths

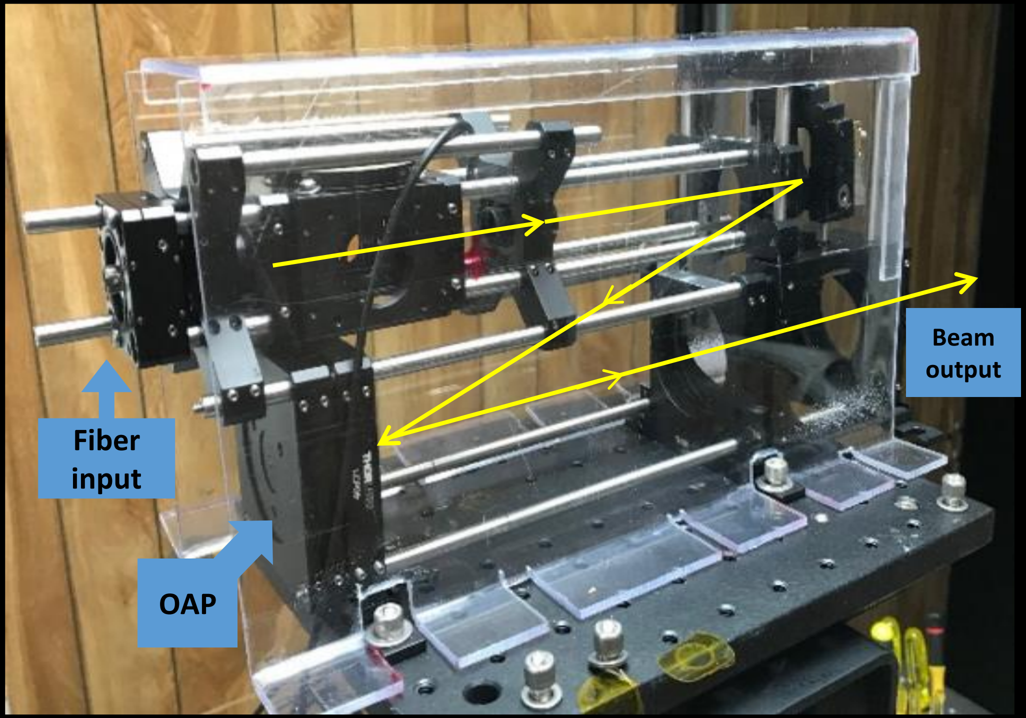
Minimal/no focus shift with wavelength

50 micron fiber = ~130 urad full angel divergence



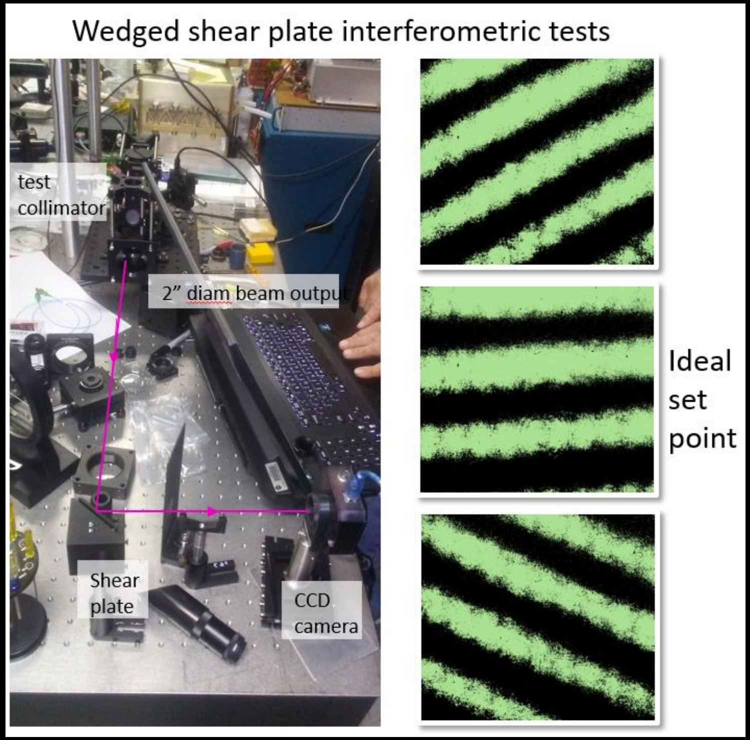
NASA Langley Transmitter Construction & Characterization

Single beam test assembly with active polarization control



First test assembly

Beam interferometric results

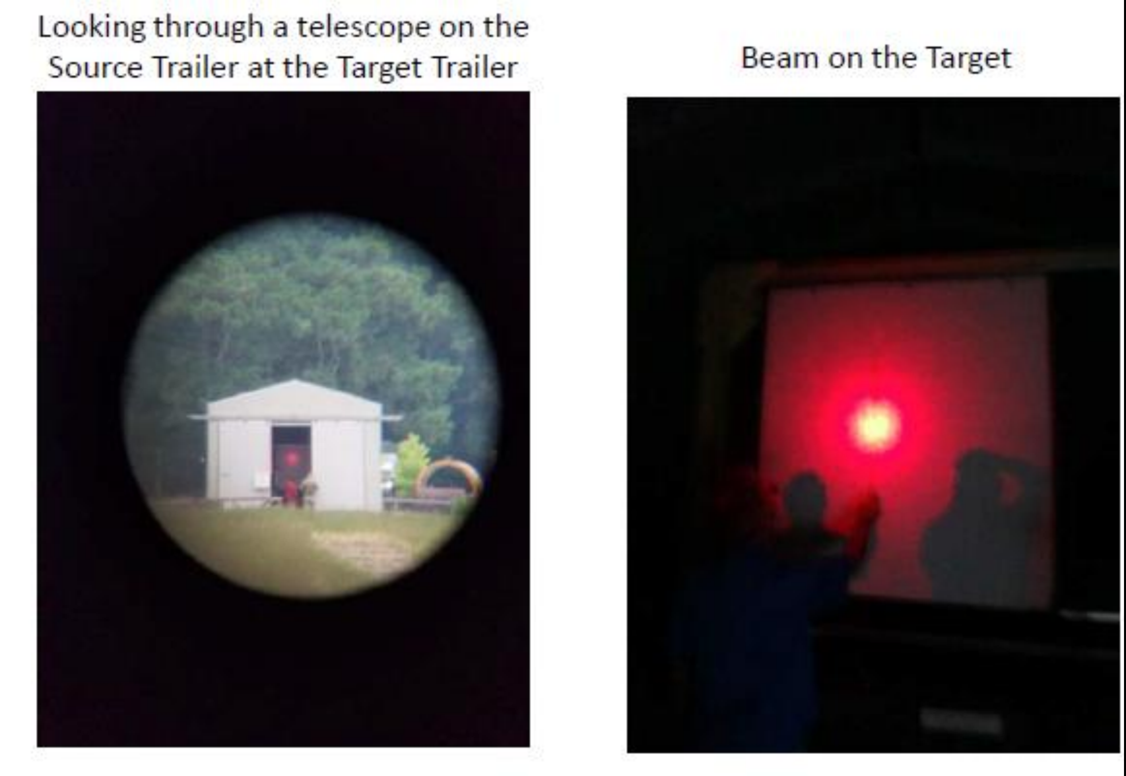


Beam aberration and collimation quality assessment

Polarization contrast tests

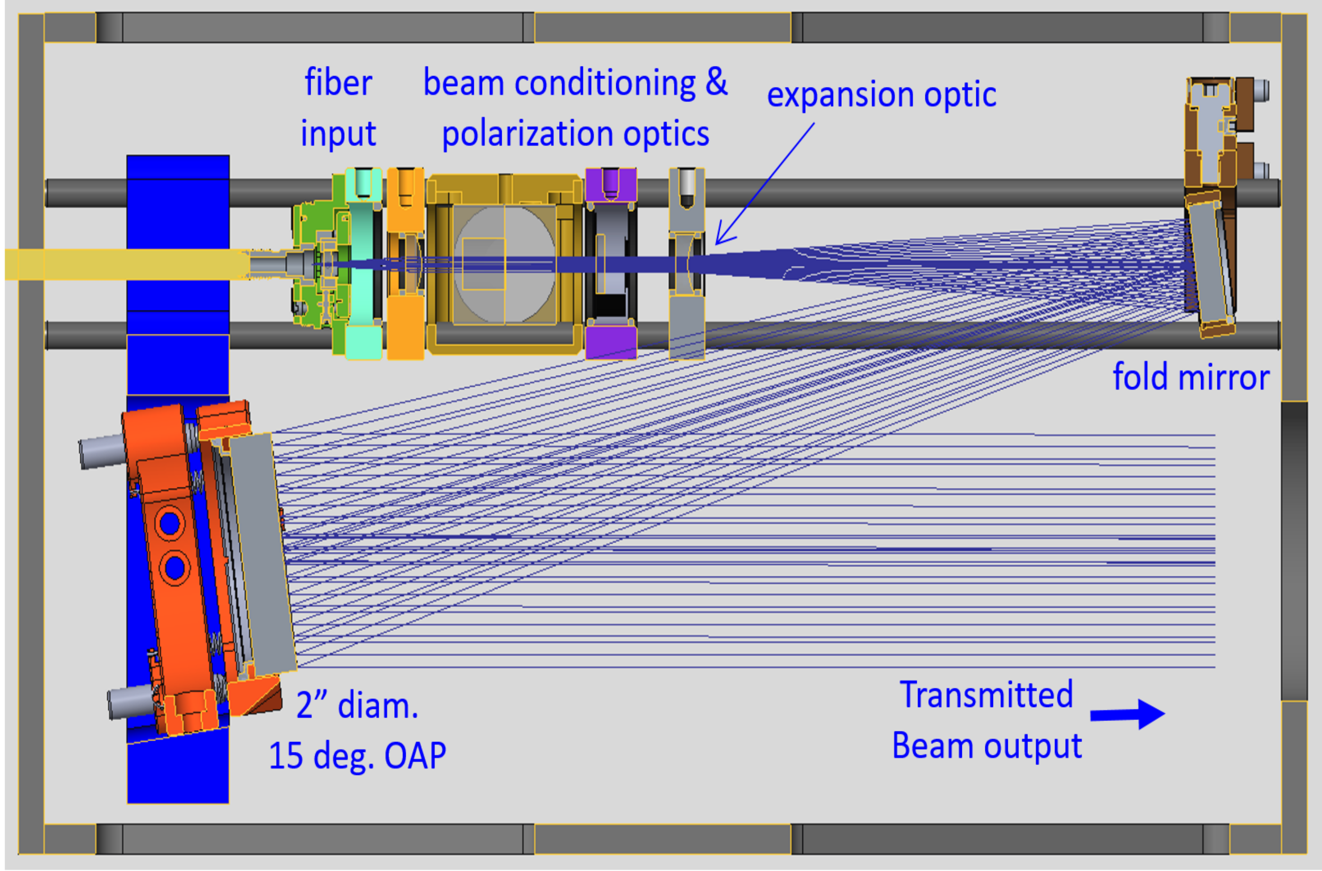
> 500:1 contrast

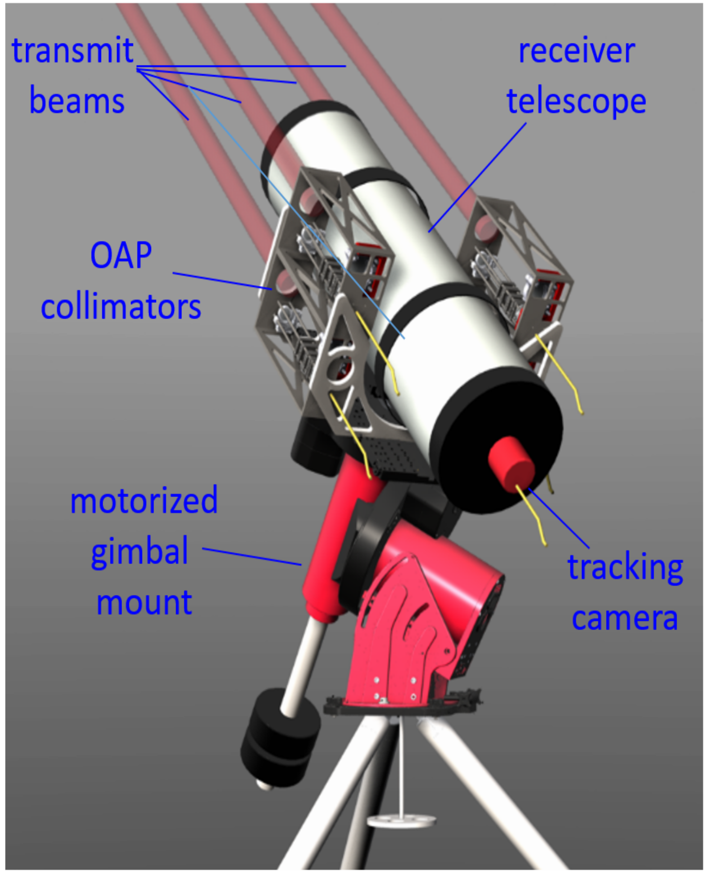
Horizontal Range Testing at NASA Langley



UAS drone ops facility in the same area

Opto-mechanical design and multi-beam application of the NASA Langley transmitter





EOS sensors that could potentially benefit from GSLC diagnostics

Table 1. Candidate EOS sensors for the GSLC technique.

Platform name	Launch Date	Orbit	Sensor name	Footprint	Wavelengths
GEO candidates					
GOES-16 , GOES-S, GOES-T, GOES-U	On-orbit, more expected in series	GEO (~35 Mm) North America	Advanced Baseline Imager (ABI)	0.5 to 2 km footprint, scanner	16 spectral bands, vis nir: .45-.49, .59-.69, .846-.885, 1.371-1.386, 1.58-1.64, 2.225-2.275
TEMPO	2022	GEO (~35 Mm) North America	TEMPO	2.1 to 4.7 km	290 – 490nm, 540-740 nm
GEMS	2019	GEO (~35 Mm) over Asia	GEMS	similar to TEMPO	300 to 500 nm
Sentinel-4	2019	GEO Europe/N. Africa	UVN	8 km	305-400, 400-500, 750-775 nm bands
LEO candidates					
Sentinel 5P (ESA)	2018	824 km	TROPOMI	7 x 3.6 km	270-495, 710-775, 2305-2385 nm
CubeSat HARP	2019	400 km	HARP	2.5 to 4 km	440, 550, 670, and 870 nm
CLARREO Pathfinder	2023	ISS	CLARREO	500m IFOV	320 nm to 2300 nm
PACE	2022	675 km orbit	OCI, HARP-2	1 -3 km	OCI: 350-890, 940, 1240, 1380, 1640, 2130 & 2250 nm
Future platform TBD (previos GLORY mission)	TBD	705 km	APS-2	scanner, 8 mrad IFOV	413, 444, 555, 674, 866, 911, 1376, 1603, and 2260 nm
CubeSat ARCSTONE	TBD	TBD	ARCSTONE		350 nm to 2300 nm
Sentinel-5 (ESA)	TBD	824 km		8-50 km	270-300, 300-370, 370-500, 685-710, 755-773, 1590-1675 and 2305-2385 nm
CubeSat LMPC	TBD		LMPC	.1 deg FOV	1.06, 1.55 and 2.06 um
TRUTHS (UK)	TBD	600 km		40m	320 - 2450 nm

SUMMARY

- Development of Ground-to-Space Laser Characterization (GSLC) would enable a new benefit for enhanced diagnostics for post-launch EOS satellite radiometric sensors while in orbit
- GSLC capabilities include intensity response function (RF), Polarization (POL), Relative Spectral Response (RSR), Out of Band response (OOB), and Geo-location/registration (GLR)
- This approach is expected to result in <3% radiant flux random (not absolute) uncertainties for a single measurement cycle, and with multiple averaging bring random uncertainties < 1%
- Beam transmitter is undergoing horizontal range tests at the NASA LaRC; Once performance is validated, this collimator could be replicated to form a complete multi-beam system interfaced providing a dedicated system for satellite illumination tests by NASA
- Anticipate first single beam satellite illumination tests to be possible in the near-term (~ 1 year), NASA dedicated multi-beam system dependent on further funding

Graphic credit: Tim Marvel

NASA POC: Tim Berkoff, timothy.a.berkoff@nasa.gov, 757-864-3684