

Enabling precise geo-spatial calibration of the GLM sensor on board the GOES-R satellite using ground-based Laser beacons from NASA Moblas 4 and 7

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International SLR workshop, Oct 9-14, 2016, Potsdam, Germany



Abstract

The Geostationary Lightning Mapper (GLM) is one of the most important capabilities of the next generation NOAA GOES-R series weather satellites, the first of which is scheduled for launch on Nov 4, 2016. These satellites will allow near real-time imaging of severe weather conditions and locations to provide improved weather warnings. The alignment calibration of the on-board GLM sensor is desired for the accurate mapping of the sensor pixels to geo-spatial coordinates. The purpose of the one-way GLM beacon is to create "artificial lightning", to mimic the oxygen triplet emission line around 777.2 nm associated with lightning, for onboard sensor detection. To perform this task, NASA and NOAA plan to locate laser beacons on the East and West coasts of the USA using the precise geodetic locations of MOBLAS 7 (Greenbelt, MD) and MOBLAS 4 (Monument Peak, CA). A semiconductor diode laser in a MOPA scheme will be used to generate the desired 777.2 nm laser beacon output. The CW laser beam will be optically modulated to achieve a 0.1-1 millisecond pulse to generate the electrons needed for accurate position centroiding. An auxiliary refractive optics telescope with a high QE camera payload and image processing capability will be piggybacked to the main telescope for satellite acquisition during night time tracking. A fiber optically-coupled beam expander will be used to transmit the beam to the S/C. The co-alignment of the auxiliary telescope and the beam expander will be completed in the laboratory, and the whole platform will be additionally co-aligned with the MOBLAS primary telescope. The laser will be tied to the SLR station safety interlock similar to that of the SLR laser with the added logic for a single laser firing at any one time. The GLM test will be performed during the Post Launch Test (PLT) window and is expected to begin in Jan 2017. Details are discussed.



GOES-R GLM - Background

- Geostationary Lightning Mapper (GLM) is one of the most important capabilities of the next generation NOAA GOES-R series weather satellites;
- These satellites will allow near real-time imaging of severe weather conditions with locational knowledge to provide significantly improved weather warnings.
- The alignment validation/ calibration of the on-board GLM sensor is desired for the accurate mapping of the sensor pixels to geo-spatial coordinates.
- GLM beacon will create "artificial lightning", to mimic the oxygen triplet emission line around 777.2 nm associated with lightning, for onboard sensor detection.
- First of this series of satellites is scheduled for launch on Nov 4, 2016.
- NASA and NOAA plan to locate laser beacons on the East and West coasts of the USA using the precise geodetic locations of MOBLAS 7 (Greenbelt, MD) and MOBLAS 4 (Monument Peak, CA).



GLM On-orbit Validation - Laser Beacon

- SLR station provides an accurate geo-spatial position as well as a precise platform for optical pointing, acquisition, and tracking; NASA has 2 perfectly located SLR stations;
- GLM's lightning detection must be navigated to $140 \mu\text{rad}$ (3σ) to provide geographically accurate severe weather warnings.
- Primary image navigation, wrto land features in the Earth imagery, possible only during day;
- Thermal gradients can change the boresight between the GLM and the star trackers, which is most severe when the satellite's nadir surface is sunlit during local night.
- GLM's wide-FOV lens assembly has a large number of refractive elements. Misalignments can change boresight, focus & plate scale, while thermal effects can change refractive index;
- Beacon pointing from multiple locations will provide the required spatial references to verify /modify the image navigation algorithm and the GLM optical model;

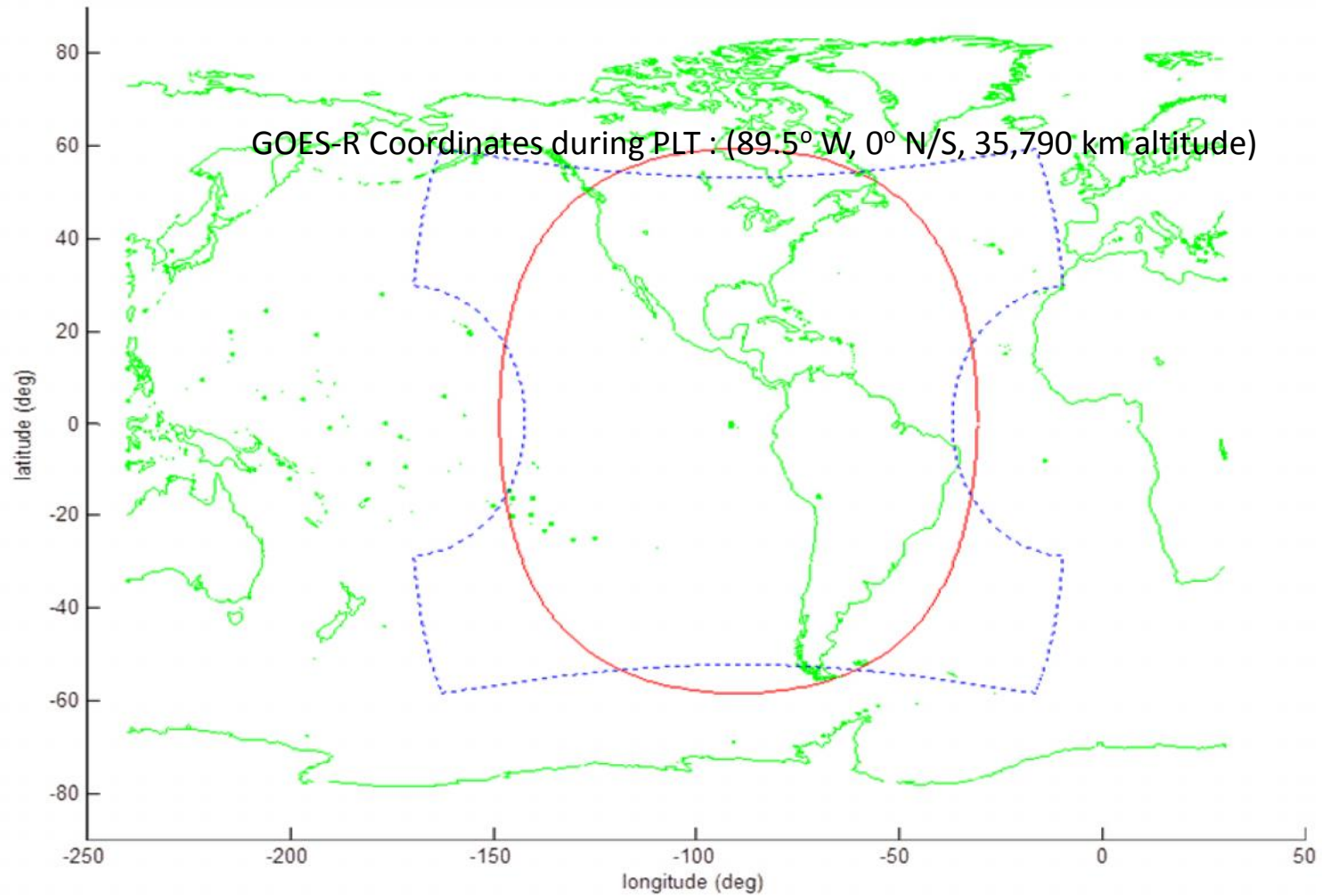


GLM Beacon - Operational Requirements

- Perform laser beacon measurements during **post-launch test (PLT)** when GOES-R is placed in a geostationary orbit at **89.5° W longitude**
- Transmit laser beacon pulses within the **GLM's 1 nm bandpass** to simulate lightning pulses simultaneously from two well-separated sites within the GLM's FOV
- Perform measurements over various periods **during day and night**;
 - On-orbit changes are **thermally driven & slowly-varying**
 - Frequent measurements (hourly) desired, especially **during eclipse**
 - Exact **data requirements being worked** out for CONOPS at this time
- **Co-register beacon navigation with primary daytime image** navigation and assess accuracy of nighttime extrapolation
- **Verify image navigation algorithm and optical models** and modify if necessary
(Previous analysis by Adam Milstein of MIT/Lincoln Labs)



GLM's FOV from GEO @ 89.5° W





GLM On-orbit Validation - Laser Beacon & Auxiliary optics

- A semiconductor diode laser in a [MOPA](#) scheme to generate the 777.2 nm laser beacon
- [CW laser beam will be optically modulated to achieve a 0.1-1 millisecond pulse](#) to generate the electrons needed for accurate position centroiding.
- An [auxiliary refractive optics telescope](#) with a high QE camera payload and image processing capability to be piggybacked to the main Moblas telescope;
- A [fiber optically-coupled beam expander](#) will transmit the beam to the S/C. The co-alignment of the auxiliary telescope and the beam expander will be completed in the laboratory, and the whole platform will be additionally [co-aligned with the MOBLAS primary telescope](#).
- The laser will be tied to the [SLR station safety interlock](#) similar to that of the SLR laser with the added logic for a single laser firing at any one time.
- GLM test will be performed during the [Post Launch Test \(PLT\) window](#) beginning in Jan 2017.



GLM Laser Beacon – Locations, Approach, & Parameters

Approach

- Transmit beacons from MOBLAS SLR stations
- Pointing & tracking with MOBLAS telescopes
- Co-boresight with radar with shutter (Easier FAA & LCH approval)
- Sites in USA minimize cost & avoid ITAR problems

Greenbelt, MD

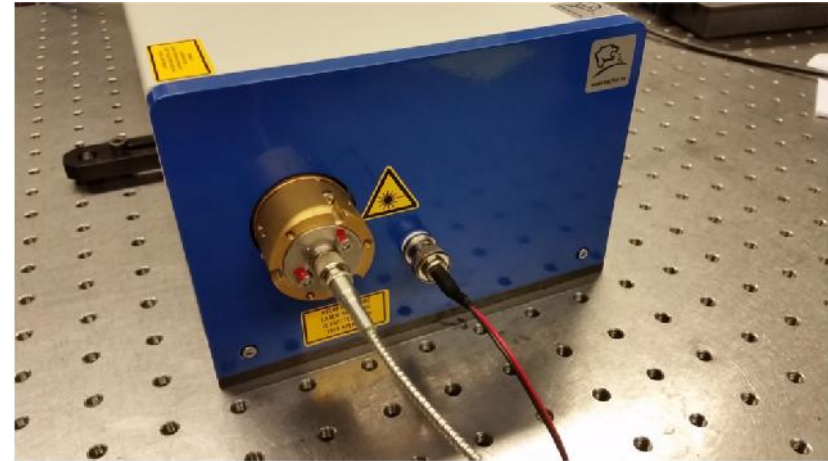
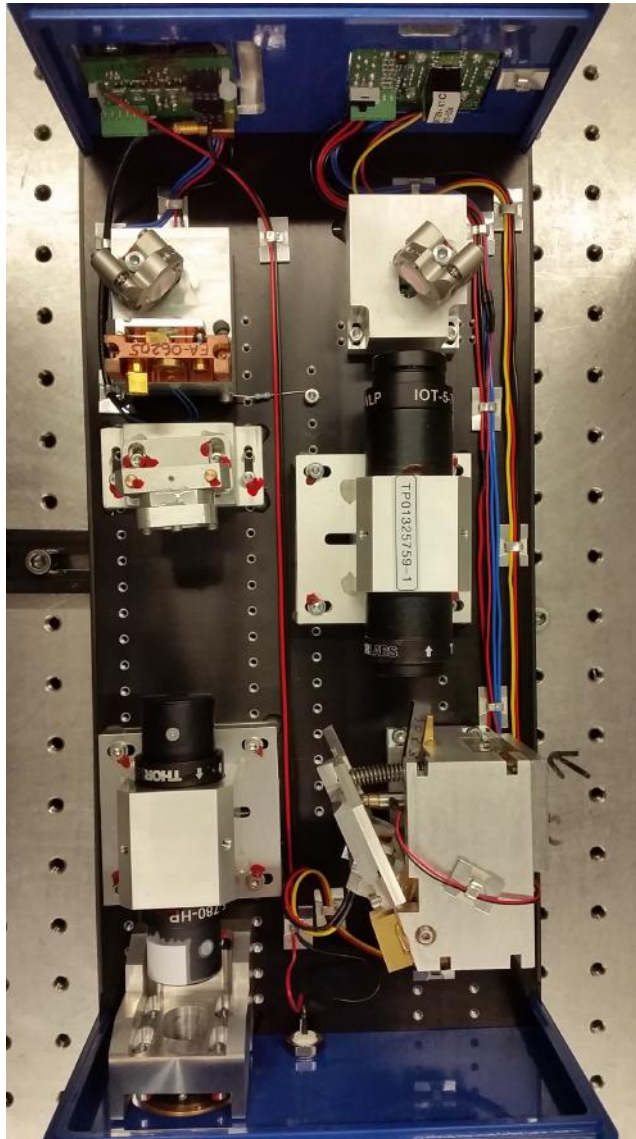
- SLRF Coordinates: (76.5° W, 39.0° N)
- Field angle in GLM 's focal plane: ($\theta_x = 1.67^\circ$ E, $\theta_y = 6.11^\circ$ N)
- Pixel dimensions: ($\Delta_x = 30 \mu\text{m}$, $\Delta_y = 22 \mu\text{m}$)

Monument Peak, CA

- SLRF Coordinates: (116.4° W, 32.8° N)
- Field angle in GLM 's focal plane: ($\theta_x = 3.72^\circ$ W, $\theta_y = 5.26^\circ$ N)
- Pixel dimensions: ($\Delta_x = 28 \text{ mm}$, $\Delta_y = 24 \text{ mm}$)
- Baseline = 3561 km (straight line through earth)



GLM Laser Beacon – MOPA layout



1. Wavelength: **777.2 - 777.4 nm**;
wavelength **fixed at 777.2nm** desired;
2. Spectral width: **~ 0.1nm**;
3. Wavelength Stability: **100MHz / K**
4. Pulse width: **~ 1ms**
5. Laser Peak Power = **1.8W**;
6. Raw beam Divergence <M2>: **~1.5 mrad**



GLM Laser Beacon - Telescope Mounting





GLM Beacon -Laser Requirements

| Parameter | Requirement | Rationale |
|----------------------------------|---|--|
| Wavelength (λ) | 777.2 \pm 0.3 nm | 1. GLM's central λ at \sim 6.4 $^\circ$ field angle |
| Pulse Repetition Frequency (PRF) | One station @ 50 Hz One station @ 60 Hz | 1. Min PRF > 3 Hz Coherency filter 2. Max \sim 100-200 Hz for threshold relaxation 3. Avoid subharmonics of 503 Hz to prevent synchronization of pulses with frame readout |
| Pulse Duration (τ) | Variable; Min $\tau \approx$ 0.1 msec Max $\tau \approx$ 1.0 msec | 1. Min: Modulation efficiency 2. Max: Minimize frame splitting |
| Received energy/pulse* | > 50,000 pe < 1,500,000 pe | 1. Exceed threshold by \sim 10x to permit centroiding 2. Prevent saturation |
| Mode/polarization | TEM00; Polarization not critical | 1. Maximize received energy |



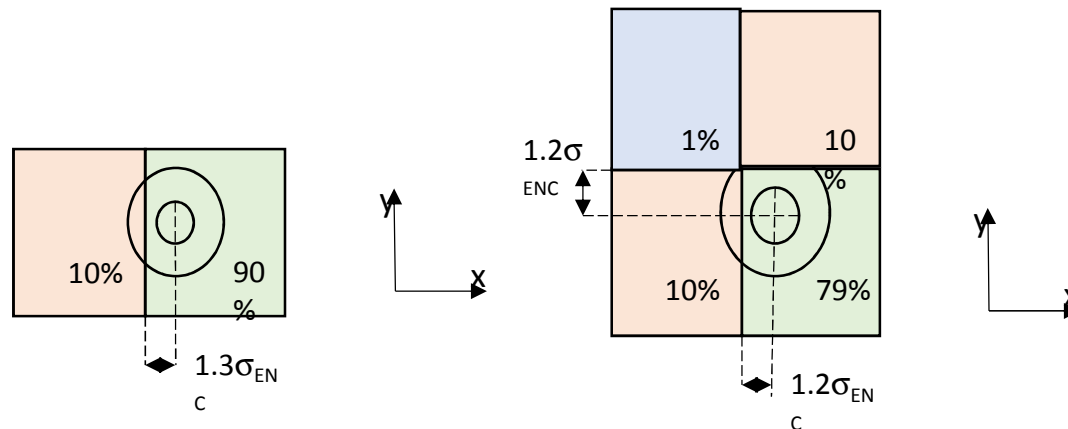
GOES-R - Velocity Aberration

1. GOES-R satellite and the beacon are fixed in the rotating Earth-referenced frame, but not in an inertial reference frame
2. Satellite moves eastward at 3.07 km/sec
3. Beacon at Equator moves eastward at 0.47 km/sec
4. Aim $2\Delta v/c$ east of apparent position of satellite
5. $2\Delta v/c = [(3.07 - 0.47) \text{ km/sec}] / 3 \times 10^5 \text{ km/sec} = 17.4 \text{ } \mu\text{rad}$ for beacon at nadir (3.6 arcsec); slightly higher values for GSFC & Monument Peak



Centroiding to Reduce Angle of Arrival(AOA) Uncertainty

1. Typical parameters: Signal at least $10X >$ threshold, PSF diameter 20-25 μm , pixels range from $30 \times 30 \mu\text{m}$ at nadir to $26 \times 20 \mu\text{m}$ & $24 \times 22 \mu\text{m}$ at max field angles
2. High probability of detecting beacon in > 1 pixel: centroid determines angle of arrival (AOA) very accurately;
3. Signal \gg threshold in one pixel with no signals in adjacent pixels reduces uncertainty in AOA estimate at pixel's center (Estimate: $6.6 \mu\text{m}$ from boundary)





GLM laser Beacon - Safety Requirements

- NOHD Range is <1km;
- laser enabling/disabling tied to the SLR radar system to invoke the full safety features of the NASA SLR system;
- Requirements for laser beacon operations
 - NASA GSFC safety approval
 - GOES-R mission assurance approval for PLT
 - Coordination with U.S. authorities (FAA, LCH)
- If laser beacon campaign extends after handover to NOAA, then NOAA's permission is needed.

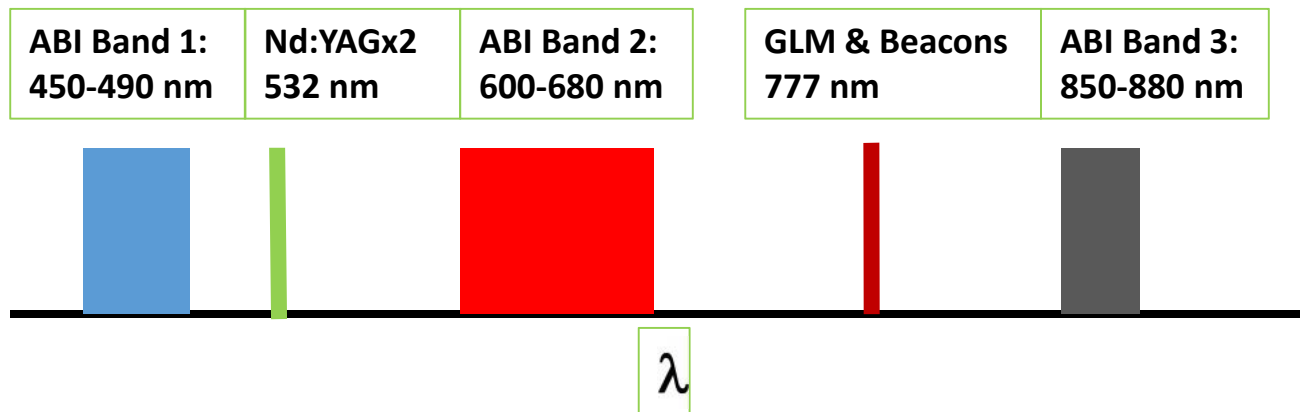


No potential for Laser damage to GLM or ABI

Both GLM and ABI are required to survive the Sun in the FOV
(> 2 min duration for the GLM)

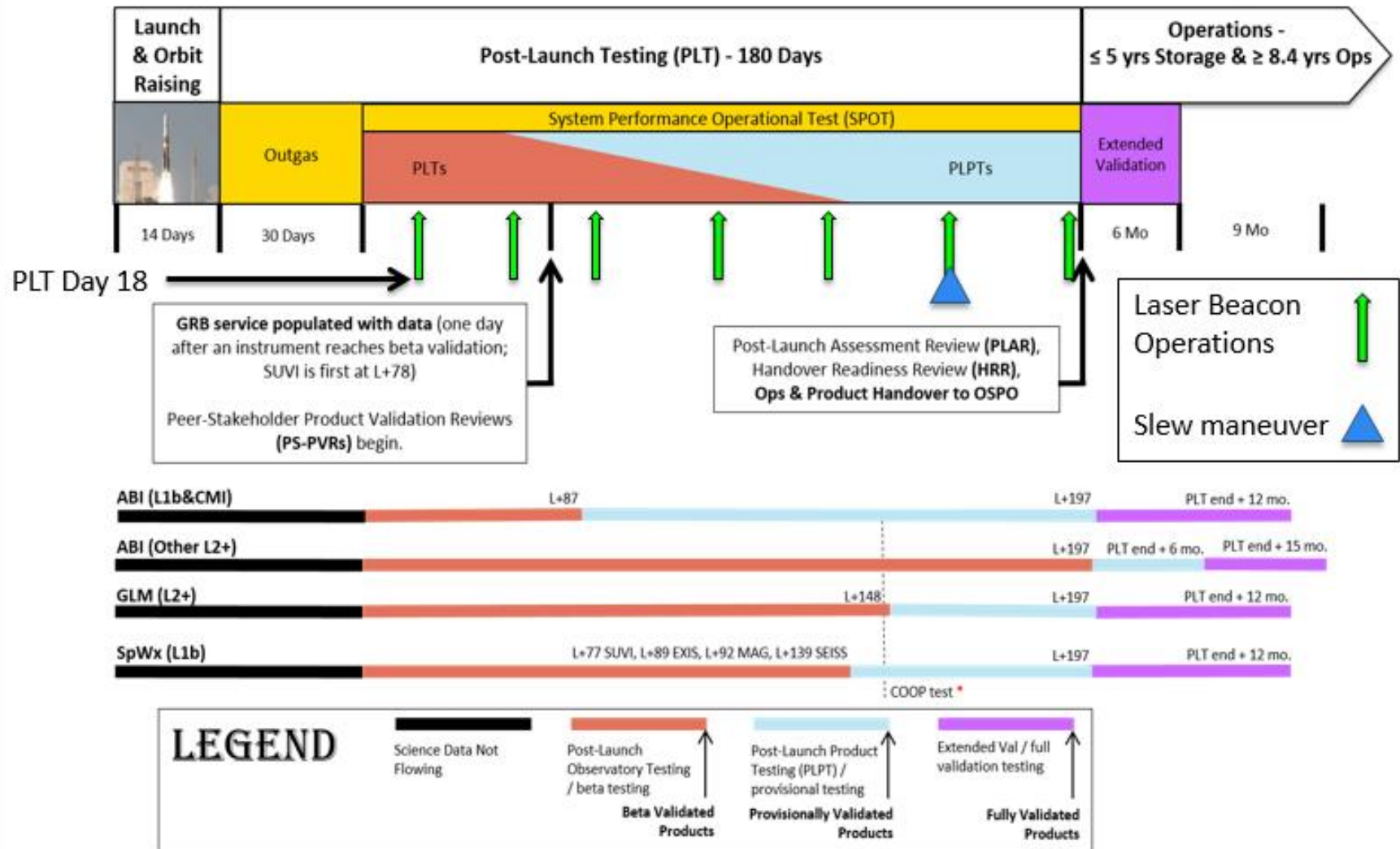
Worst-case laser illumination of GOES-R (requiring major errors by beacon operator) won't damage the GLM or the ABI

1. GLM laser beacon operated in CW mode
2. Wrong laser: Nd:YAGx2 @ 532 nm





Mission Modes & Schedule (tentative)



* Two-day data blackout during this period due to COOP test.