CLARREO Reflected Solar Spectrometer: Reference Inter-Calibration Activities

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Presentation Outline

1. **Update on CLARREO RS Inter-calibration:**

   - Paper on the Radiometric Uncertainty due to Polarization (TGRS).
   - Paper on CLARREO RS sampling from the ISS.
   - Current and planned studies and papers.

2. **Update on the Ground-to-Space Laser Calibration (GSLC) approach:**

   - The GSLC concept at conclusion of LaRC SIF project (September 2012).
   - Roadmap forward.

Update on CLARREO RS Inter-calibration

1. **Submitted & revised papers:**

   - C. Roithmayr et al., "Opportunities to Intercalibrate Radiometric Sensors from International Space Station", to be published at J. of the Astronautical Sciences (consistent with B. Dunn's CLARREO/ISS concept).

   - C. Lukashin et al., "Uncertainty Estimates for Imager Reference Inter-calibration with CLARREO Reflected Solar Spectrometer", TGRS Special issue, revised manuscript is re-submitted. Editor Comments (quote):
   "An excellent paper on a challenging topic (CL - polarization) with major implications to the EO community particularly for climate quality observations."

2. **Current and planned papers and studies:**

   - Finish paper on the CLARREO RS Inter-calibration sampling from P90 orbit.

   - Write paper on the CLARREO RS requirement for sensitivity to polarization.

   - Validation of CERES-derived surface BRDF over Dome-C using SCIAMACHY observations and RT modeling (S. Kato, C. Lukashin, A. Radkevich).

   - Implementation of CLARREO RS inter-calibration algorithms into the MIIC (C. Currey, C. Lukashin, D. Doelling, and C. Roithmayr).

   - Long term: Build empirical PDM database as a product or plug-in into MIIC.

Ground-to-Space Laser Calibration (GSLC): Feasibility Study

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1 - NASA LaRC, Hampton, VA; 2 - Vigyan, Hampton, VA; 3 - SSAI, Hampton, VA

What is GSLC ?

- The GSLC is an accurate ground-to-space laser calibration system, with CW tunable laser, 3 W transmit power, expanded beam with top-hat profile, 100% linear polarization.
- Transmitting laser light to instrument on orbit during nighttime clear-sky conditions, from a mountain top. Tracking the S/C in LEO and GEO.
- To minimize atmospheric contribution to the calibration uncertainty the calibration cycles should be performed in short time periods - a few seconds.
- All measurements are designed to be relative.
- The short-timed calibration cycles involve ground operations with laser beam – changing its polarization and wavelength.

1. Motivation: Improvement in the EOS data products

1.1 RS Instrument Calibration Function includes (not limited to):

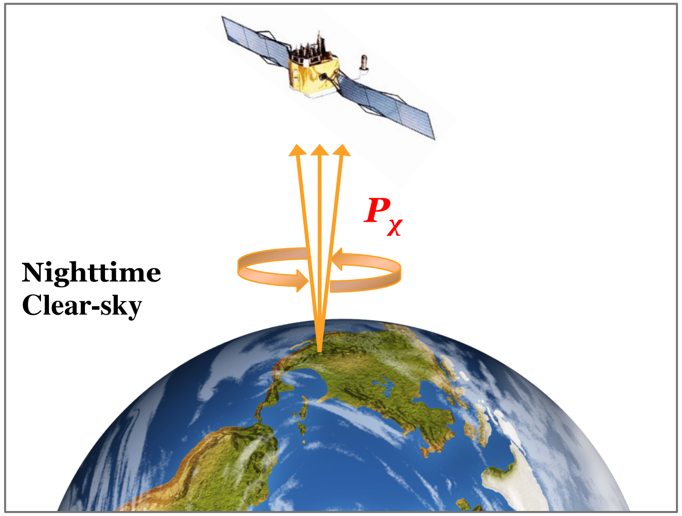
- Offset (temperature dependence);
- Offset & gain (solar diffuser degradation);
- Gain (temperature dependence);
- Gain (scan angle dependence);
- Gain (polarization dependence);
- Gain (optics degradation, wavelength dependence);
- Stray light response function (both offset & gain).
- Geolocation of observations.

1.2 High accuracy requires calibration for all these factors ON ORBIT !

- Comprehensive onboard calibration system does not exist.
- Comprehensive onboard calibration system would have very high costs $\times$ $N_{sensors}$

All this leads to increasing uncertainty in Earth Science data products

2. GSLC Operations & Measurements



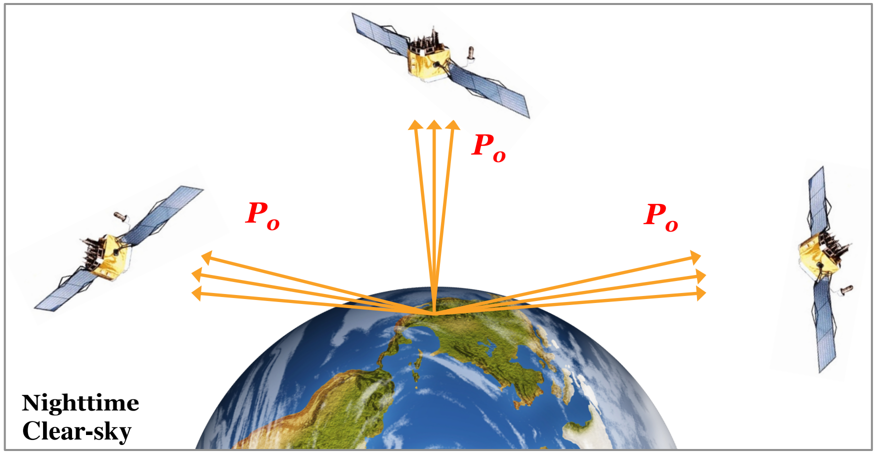
2.1 Sensitivity to Polarization:

- **Polarized laser beam transmitted to Target sensor on orbit.**
- **Beam polarization rotated from 0º to 360º within seconds.**
- ***Relative:* normalization to intensity at 0º, 180º, 360º.**

2.2 Optics Degradation:

- **Non-polarized laser beam transmitted to Target sensor on orbit. Wavelengths changes from blue to red within short duration (seconds).**
- ***Relative:* ratio instrument response in blue to response in red (correction for atmosphere).**
- **Tune laser wavelength (20 – 50 nm change) within seconds (narrowband Spectral Response mapping).**

2.3 Response to Stray Light:



- **Target sensor in nominal mode (e.g. cross-track).**
- **Laser beam transmitted to Target sensor on orbit.**
- ***Relative:* normalize to response in direct view.**
- **Special operations by sensor (imaging the GSLC site) are feasible.**

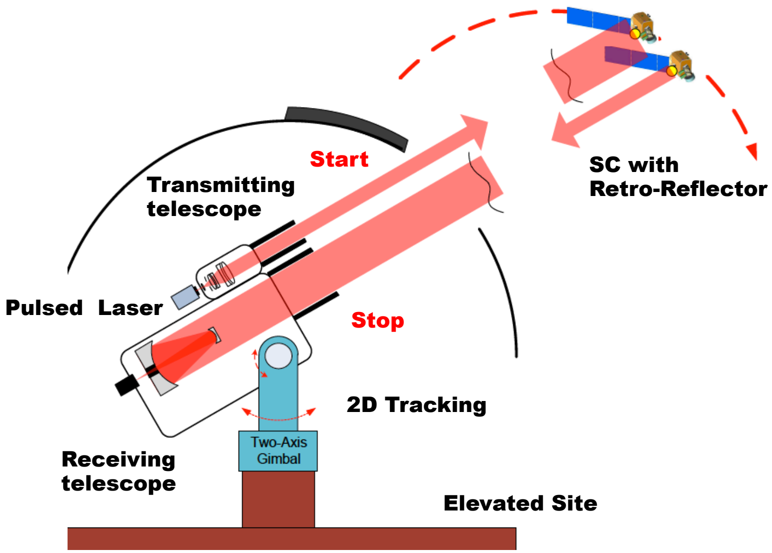
2.4 SC/Sensor Attitude (beacon):

- **Laser beam transmitted to Target sensor on LEO/GEO orbit.**
- **Radiometric accuracy or polarization are not required (only good signal-to-noise ratio).**

3. GSLC Heritage: SLR, SLC and Radiometric

3.1 Satellite Laser Ranging (SLR):

- Satellite tracking
- Pulsed laser (100 – 2000 Hz)
- Time-of-Flight measurements



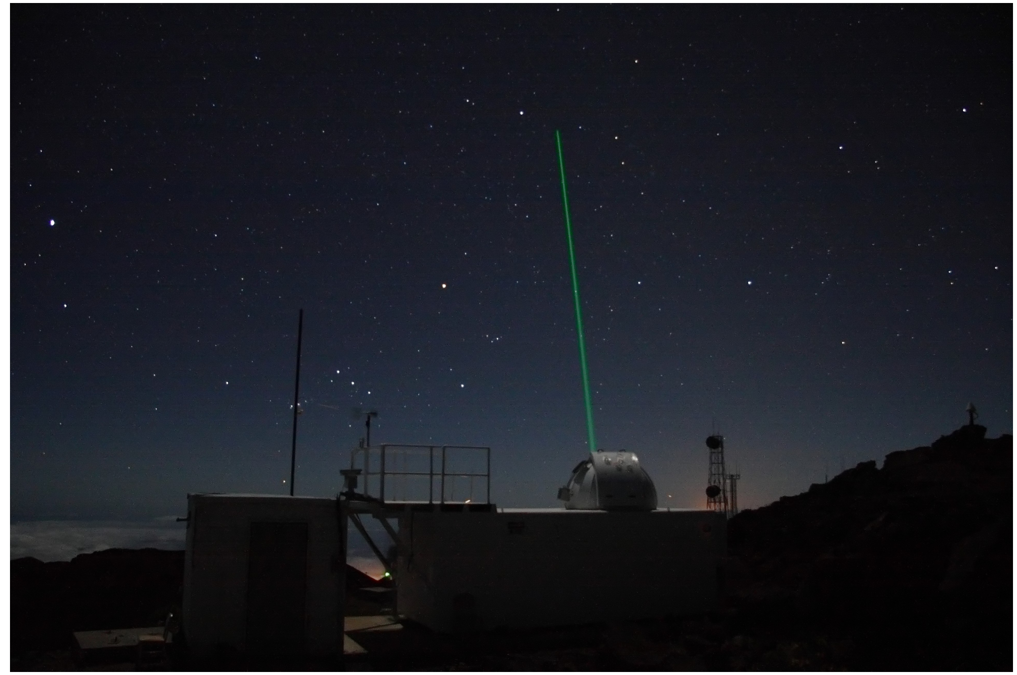


Figure: Operational SLR station

3.2 Satellite Laser Communications (SLC):

- Satellite tracking, beacon CW laser beams (4)
- Pulsed Communication Laser in MHz range

Optical data links (ongoing project, JPL):

- GEO-to-LEO
- LEO-to-Ground
- Turbulence mitigation: multiple laser beams

3.3 Initial Radiometric measurements:

Aruga et al., 1984 (Japan): LEO Satellite at 1000 km altitude. Signal detected by on-board camera (nighttime, clear-sky), **no pointing ability.**

Aruga et al., 1985 (Japan): Signal detected by GEO weather imager (nighttime, clear-sky). The imager is on a spinning S/C, **no pointing ability.**

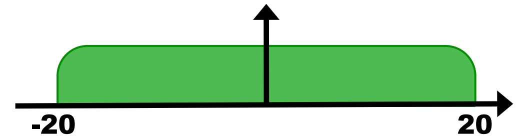
4. GSLC Physics Concept: Radiometry & Polarization

S/C size = does NOT drive the system design !

Major Driver: effects From atm. turbulence !

LEO RS Sensor:
609 km orbit.
t_{int} = 67 ms (15 Hz)

Relative beam profile

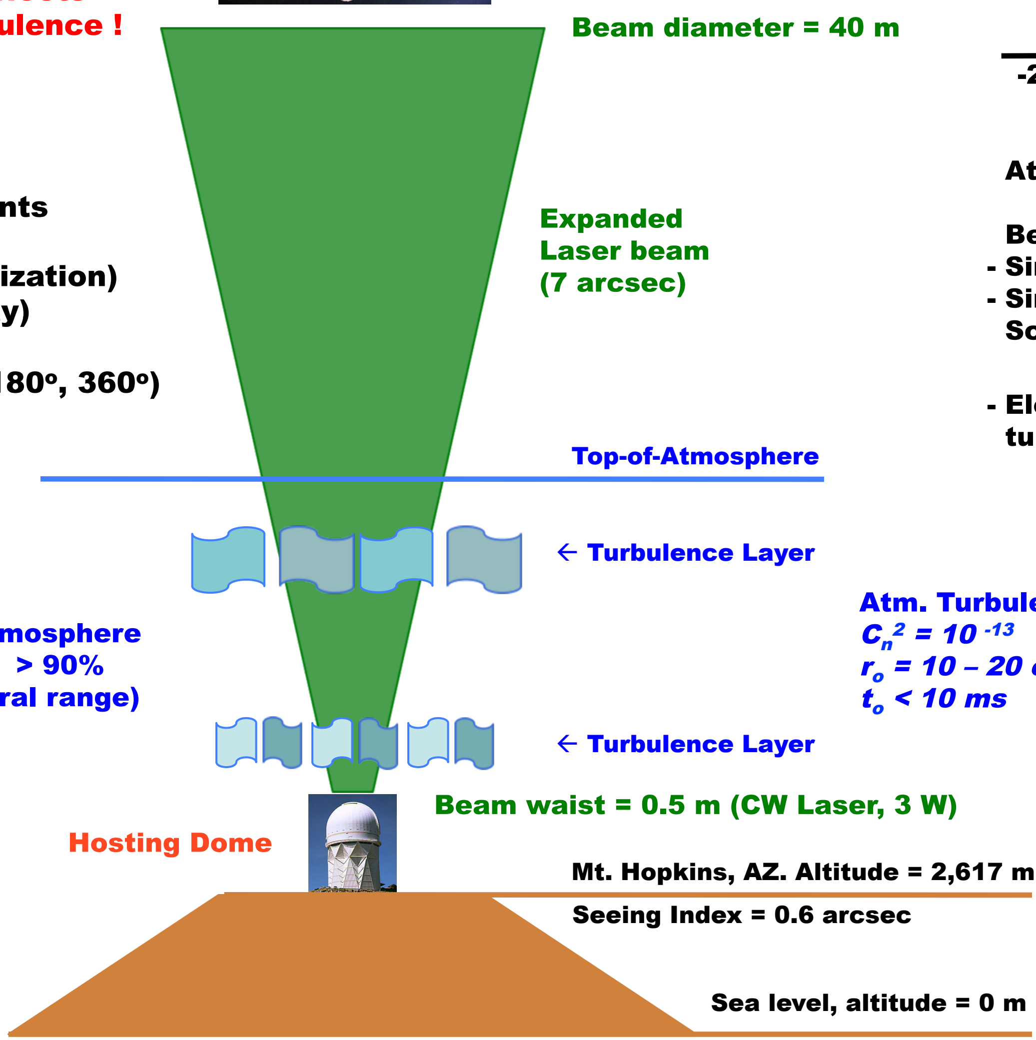


All measurements are RELATIVE:
- S_S / I_T (normalization)
- S_R / I_T (stability)
- S_{blue} / S_{nir}
- S_{pol} / S_{pol} (0°, 180°, 360°)

Atmospheric Turbulence effect:

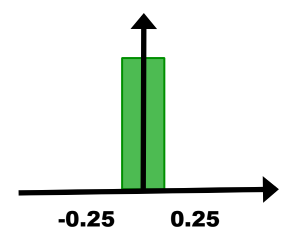
Beam wandering:
- Similar to pointing jitter > 100 Hz;
- Similar to dynamic tracking error. Scintillation.

- Elevated site reduces atmospheric turbulence effects about 60%.



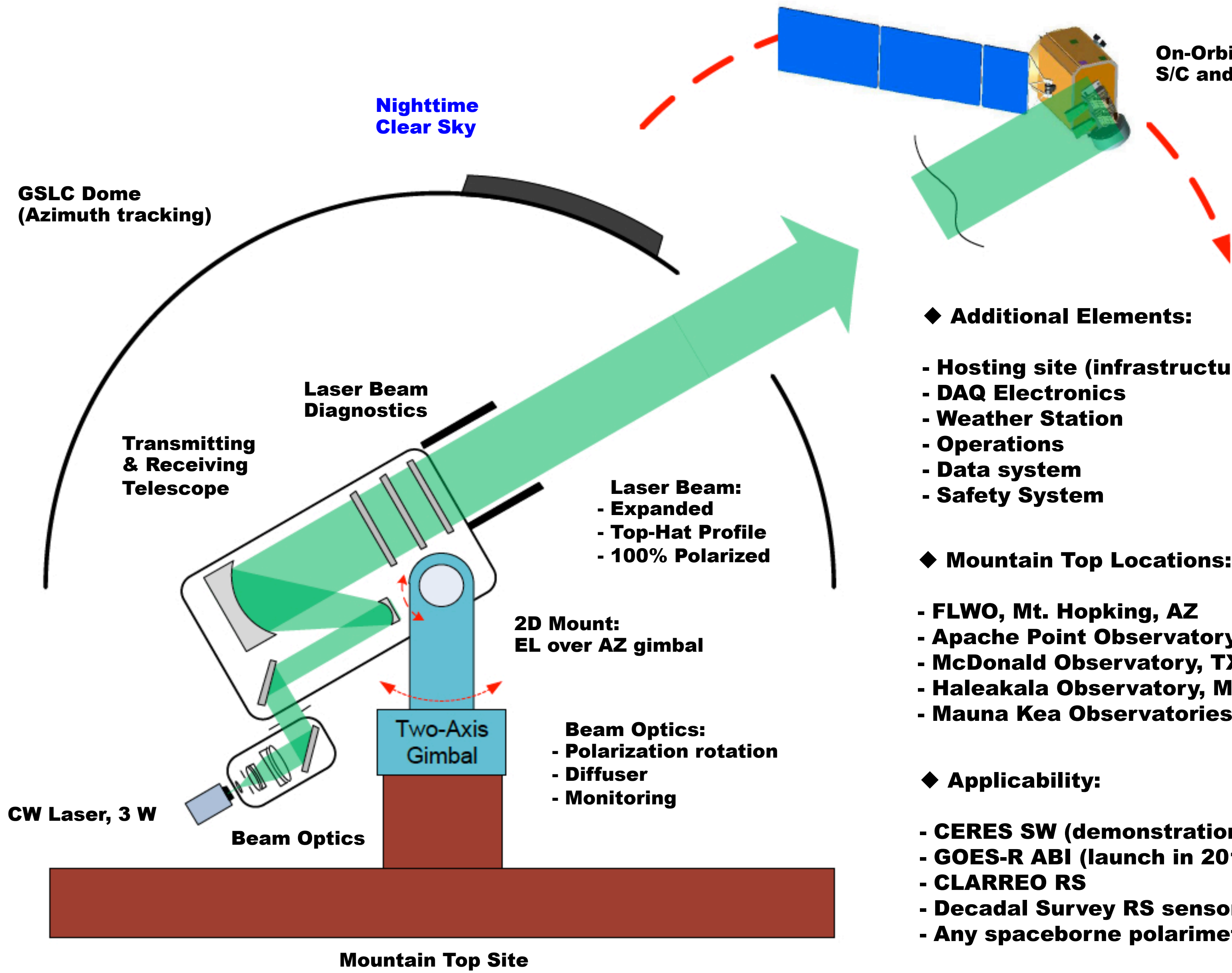
NIGHTITME
CLEAR SKY Atmosphere
Transmittance > 90%
(window spectral range)

Atm. Turbulence:
$C_n^2 = 10^{-13}$
r_o = 10 – 20 cm
t_o < 10 ms



Top-hat beam profile

5. GSLC Elements:



◆ **Additional Elements:**

- **Hosting site (infrastructure)**
- **DAQ Electronics**
- **Weather Station**
- **Operations**
- **Data system**
- **Safety System**

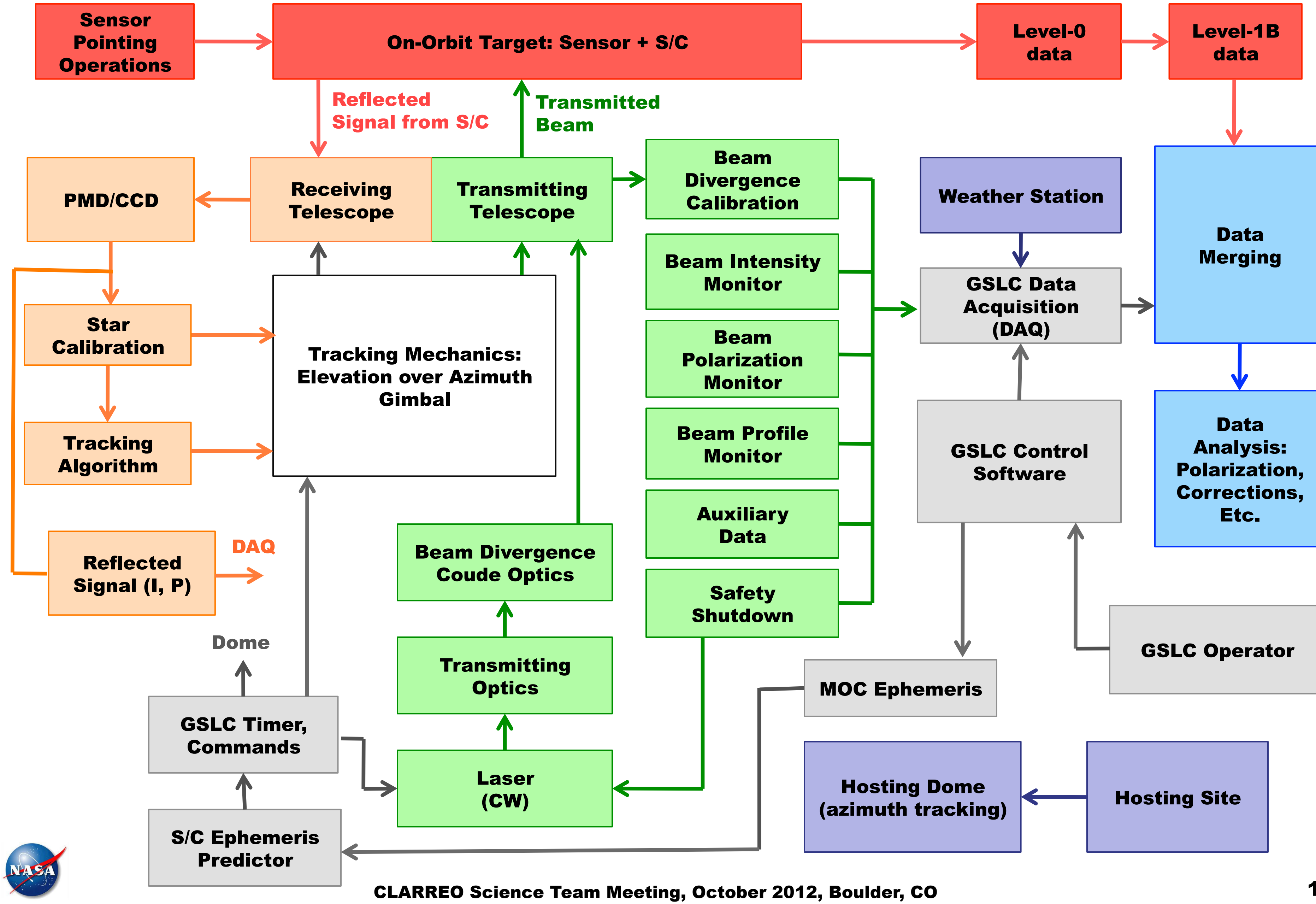
◆ **Mountain Top Locations:**

- **FLWO, Mt. Hopking, AZ**
- **Apache Point Observatory, NM**
- **McDonald Observatory, TX**
- **Haleakala Observatory, Maui, HI**
- **Mauna Kea Observatories, HI**

◆ **Applicability:**

- **CERES SW (demonstration ?)**
- **GOES-R ABI (launch in 2016 ?)**
- **CLARREO RS**
- **Decadal Survey RS sensors**
- **Any spaceborne polarimeter**

5. GSLC Elements: block diagram



5.1 GSLC Elements: Common Elements with SLR / SLC

5.1.1 Tracking Requirements

- 2D Elevation over Azimuth gimbal.
- Slew rates: no less than $20^{o}\ s^{-1}$ (EL) and > $30^{o}\ s^{-1}$ (AZ).
- Acceleration: no less than $5^{o}\ s^{-2}$ (EL) and > $5^{o}\ s^{-2}$ (AZ).
- Dynamic Tracking Error: RMS < 1 arcsec.
- Total Beam Deviation: +/- 6 arcsec (characterized).

5.1.2 Ground Systems

- Hosting Dome with Azimuth tracking.
- Auxiliary Weather station (e.g. 5 sensors).
- Recording all monitoring data (laser, beam, weather, etc.)

5.1.3 Data Storage

- Data volume in Gb range (small).
- Data storage and data system: small size.
- CLARREO SCF (funded) is sufficient.

5.1.4 Operations

- Predicting calibration opportunities using most recent TLE (ephemeris).
- Satellite tracking.

5.2 GSLC Elements: Specific Elements

5.2.1 Tunable CW Laser

- CW (or quasi-CW) laser for high stability.
- Power: 3 W is sufficient for most applications.
- Operation at different wavelengths (fixed).
- Wavelength tuning (dynamic).

5.2.2 Laser Beam Profile and Monitor

- Uniform expanded laser beam with top-hat profile (to mitigate beam wandering)
- Off-axis Transmit Telescope to avoid beam obscuration.
- Reduce effect of beam scintillation (see Slide 13).

5.2.3 Polarization Control and Monitor

- Polarization is not changed by the clear atmosphere !
- Polarization rotation optics and monitor is required.

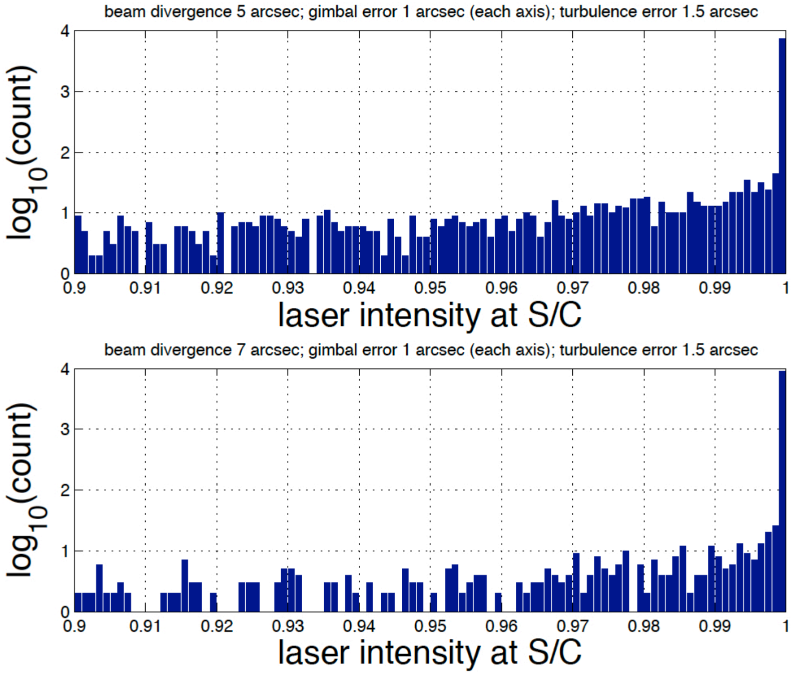
5.2.4 Accurate Intensity Monitor

- Frequent recording of outgoing beam intensity, to be used for normalization.

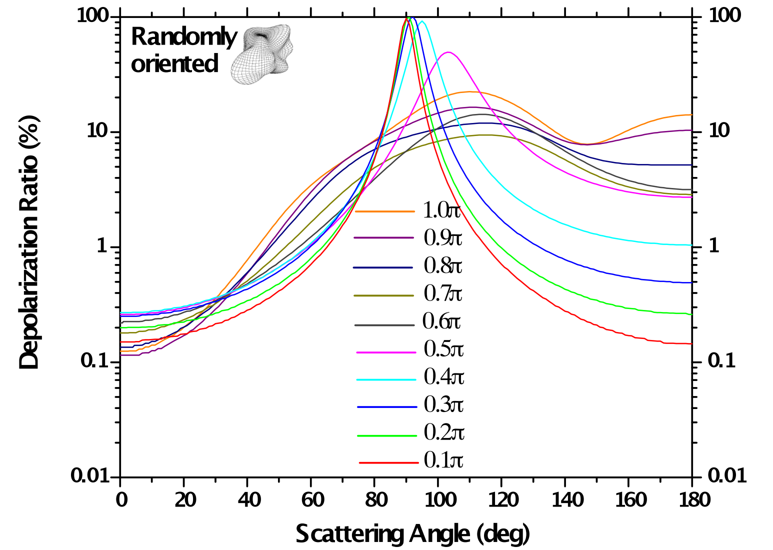
5.2.5 Operations

- **Special Operations by Target Sensor: staring/pointing at the GSLC site.**

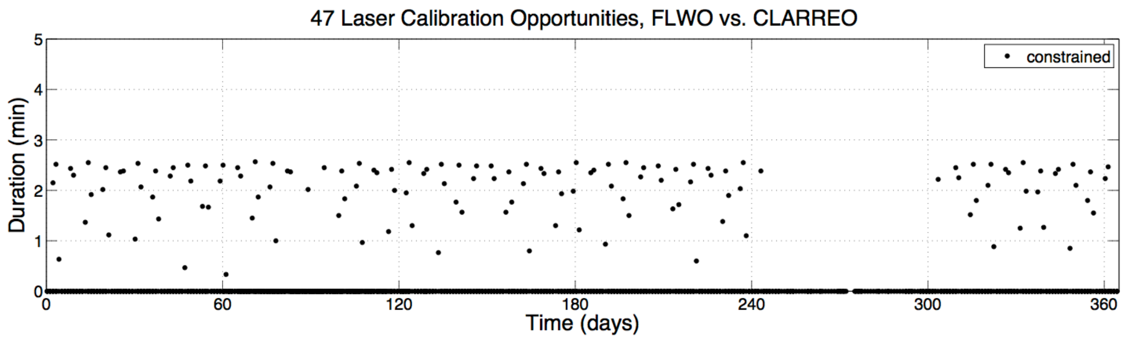
5.3 GSLC Elements: modeling



🡡 **Simulation of beam relative intensity on orbit: in both cases we used top-hat beam profile with ideal uniformity and Gaussian tales of σ = 2 arcsec, tacking error contribution 1 arcsec (each gimbal axis), and error due beam wondering 1.5 arcsec. Plots show distribution of relative beam intensity with beam divergence of 5 arcsec (top), and 7 arcsec (bottom).**



🡡 **RT 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%.**



🡠 **Time duration of 47 calibration opportunities for CLARREO RS (90°P orbit, 609 km altitude) and GSLC (FLWO location, Mt. Hopkins). Constrain in EL is 45°, in SZA > 105°, slew rates and acceleration limits.**

6. Required Technology Development

6.1 Expanded Beam Top-Hat Profile (to reduce beam wandering)

- Current diffusers: RMS = 5% uniformity. Goal → RMS = 1%.

6.2 Laser Beam Polarization (uniform polarization > 99%)

- Optics optimization to have uniform polarization across the beam profile.

6.3 Reduction of Scintillation (Steve Brown, NIST)

- Laser system concept for reducing scintillation due to atmospheric turbulence.

7. Roadmap Forward

7.1 Publication of the concept & recommendations for implementation.

7.2 Possibility: next ESTO IIP Announcement of Opportunity, Spring 2013. Collaboration of LaRC, NIST, LASP, and UNM groups:

- LaRC: RT and orbital modeling, S/C tracking, demonstration with CERES SW (?)
- NIST: Laser system and optics, beam diagnostics, profile, and polarization.
- LASP: Demonstration with instrument prototype for CLARREO RS.
- UNM: Atmospheric corrections, hosting site logistics, operations.