SLR2000: Progress and Future Applications

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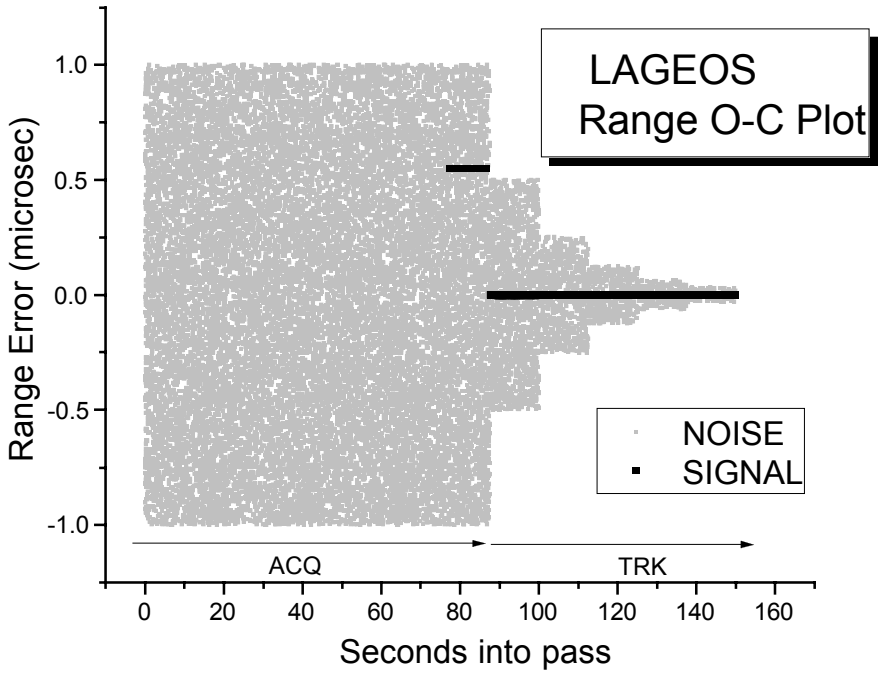
SLR2000 Technical Goals

- Unmanned, eyesafe operation
- 24 hour laser tracking to satellites up to 22,000 Km slant range (GPS, GLONASS, ETALON)
- One cm (1σ RMS) single shot ranging or better
- 1 mm precision normal points to LAGEOS
- Mean Time Between Failures: >4 months
- Automated two-way communications with central processor via Internet
- Free of optical, electrical, and chemical hazards
- Reduce system replication cost to ~$1M per system
- Reduce network operations costs through standardization and COTS technology utilization.

SLR2000 Unique Features

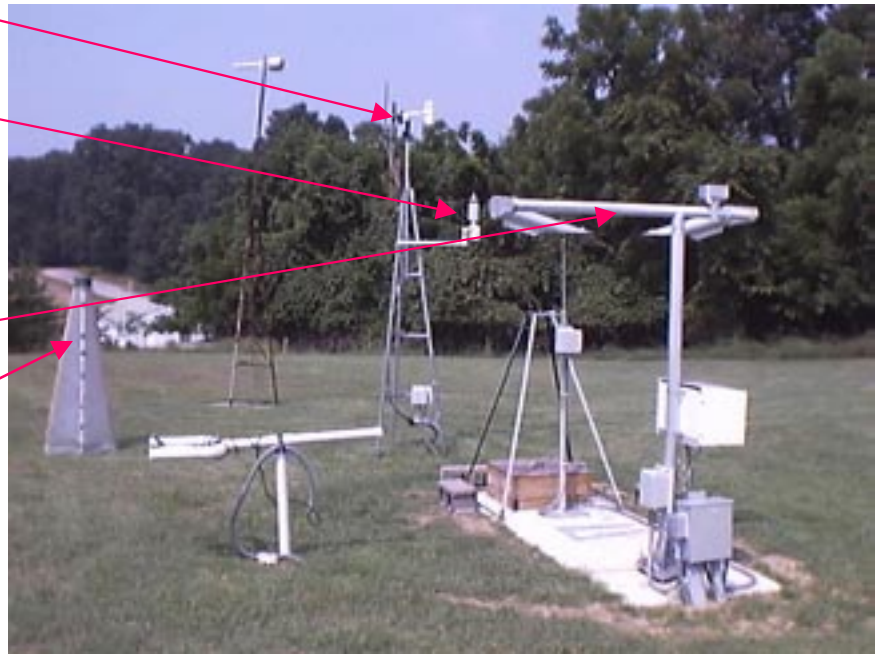
- **Totally Automated and Eyesafe Operation**
  - **Unmanned operations.**
  - **Uses low energy microlasers (130 μJ/pulse) at high repetition rates (2 kHz)**
  - **Laser beam fills 40 cm transmit/receive telescope to meet OSHA radiation standards**
  - **No aircraft safety radars needed**
- **Sub-unity Signal-to-Noise Ratios (SNR) during daylight operations**
  - **Mean signal strength: <<1 photoelectron per laser fire**
  - **Uses Post-Detection Poisson Analysis to extract satellite signal from noise background in real time, center signal in range gate, and reduce gate width**
  - **Photon-counting quadrant detector/multichannel receiver provides both high resolution ranging (1 mm precision) and sub-arcsecond angular tracking error feedback to mount.**



LAGEOS Acquisition Simulation at 8600 km Slant Range (20° elevation)

SLR 2000 "Smart" Meteorological Station

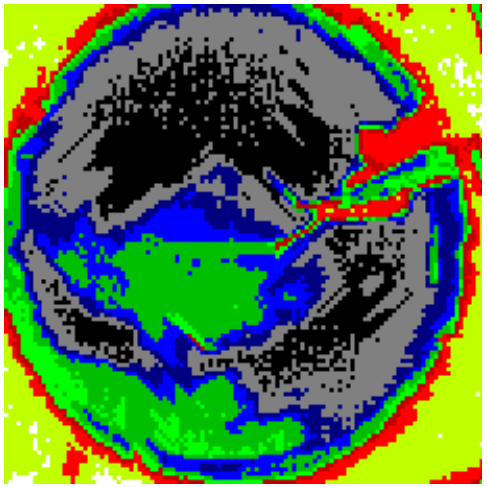
- **Wind Monitor**
  - Belfort 200 (Cost: $800)
  - Wind speed -Range: 0 to 135 mph; Accuracy: ± 0.6 mph
  - Wind Direction: Range: 0 to 360°; Accuracy: +3°
- **Pressure/Temperature/Humidity Monitor**
  - Paroscientific MET3-1477-001 (Cost: $3,995)
  - Pressure:Range: 800 to 1100 mbar; Accuracy: ~0.1 mbar; stability<0.1 mbar/yr
  - Temperature: Range: -40 to 70 °C;Accuracy<0.5 °C; Stability <0.1 °C/yr;
  - Relative Humidity: Range: 0 to 100%; accuracy:±2%; stability: <1%/yr
- **Precipitation/Visibility Sensor**
  - Vaisala FD12P (Cost: $ 17,895)
  - Measures visibility from 10 m to 50 Km
  - Measures type, intensity, and accumulation of precipitation
- **All-Sky Cloud Sensor**
  - Inframetric Thermasnap™ Thermal Infrared Camera (8 -12 microns) senses ~ 25°F temperature difference between clouds and clear sky via electroformed convex mirror (Cost : $20,000)
- **Total Subsystem Hardware Cost: $42,690**



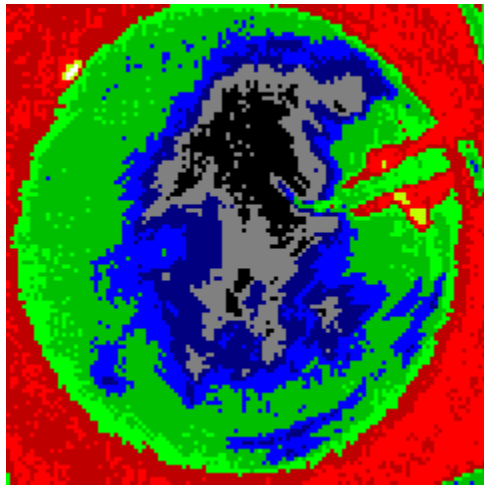
"Smart" Meteorological Station at GGAO/GSFC

SLR2000 Day/Night All-Sky Cloud Sensor

Uncooled IR Camera



Daytime thermogram shows clear cooler) skies to the north and east. A cloud (warm) covers zenith and extends to the southwest. The red object in the northeast is a support arm. Temperatures are 17 to 33 °C.

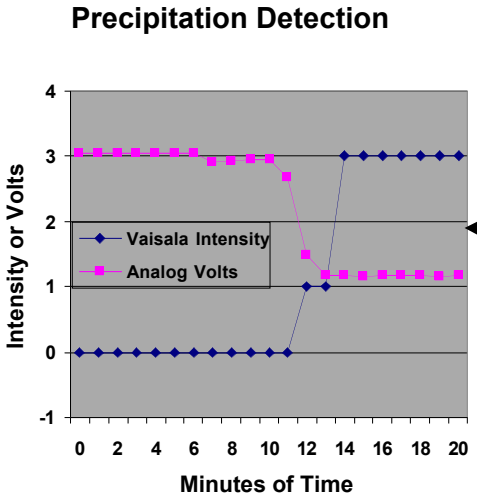


Nighttime thermogram reveals a large patch of clear sky at zenith, extending to the north and south. The east and west are cloudy. Temperature range is 4 to 21 °C.

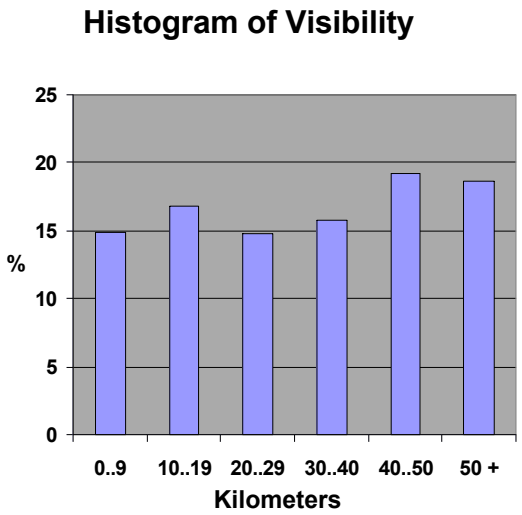
Color codes:
warmer = blue, green and red
cooler = gray and black.

SLR2000 Precipitation and Visibility Sensing

The Vaisala optics are comprised of an infrared beam and a detector aimed across the beam. Scattering particles in the intersection of the two paths reflect IR light to the detector. These reflections are analyzed and the particles are characterized. The CPU combines this information with temperature data, reports the type and intensity of precipitation, as well as the visibility, and decides whether the dome should be open or closed.



The Vaisala reports precipitation within 2 to 3 minutes of its detection by a sensitive analog device, allowing time to close the dome and protect the equipment.

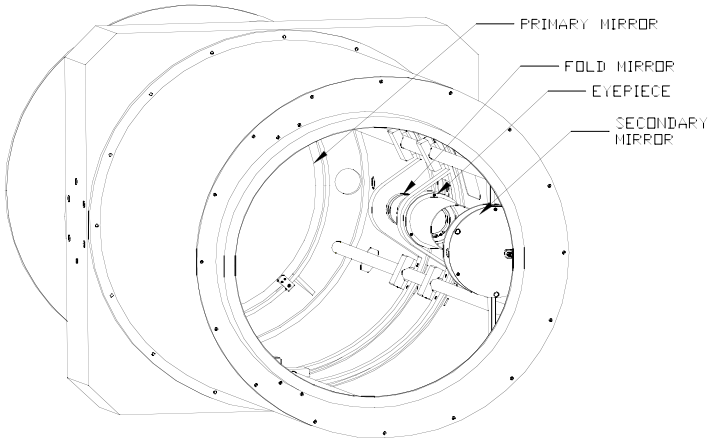


Visibility is defined as the distance that an observer can distinguish a black object against the horizon. At NASA/GSFC, the Vaisala instrument reports a fairly even distribution from 0 to 50 km over a year's time.

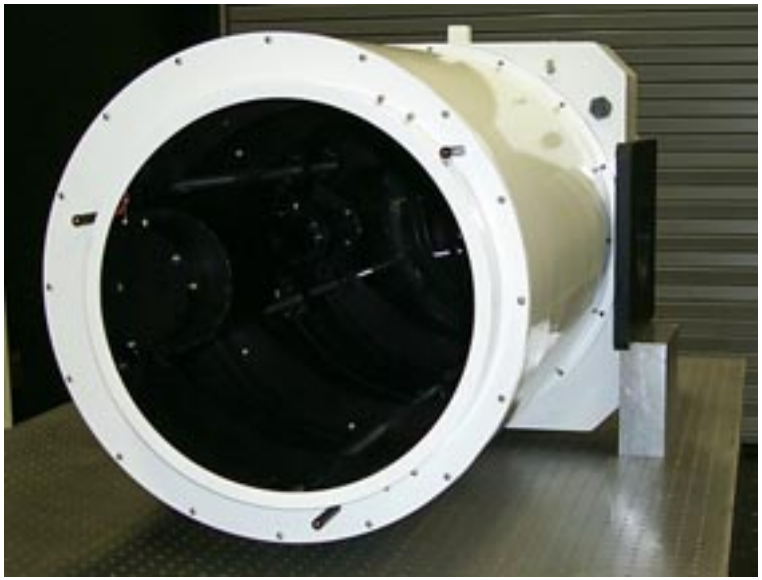
GSFC

SLR2000 Telescope

- **Physical Specifications:**
  - Dimensions: 56” long x 22.5” diameter.
  - Weight: 251 lb.
  - Optics mounted to 4 invar rods for axial stability over wide temperature range.
  - Optics enclosed in a cantilevered inner barrel which is decoupled from the weight of the front window.
  - Minimum resonance: 120 Hz.
  - Surfaces: interior- black anodized aluminum, exterior- white enamel paint.
  - Heaters on front/side windows and desiccant system used for dew mitigation.
  - Telescope O-ring sealed for contamination and moisture control.
  - Air bladder compensates for thermally induced internal pressure changes
  - Sun shield reduces stray light infiltration
- **Optical Specifications:**
  - Off-axis Cassegrain with 17” diameter primary mirror
  - 16” clear aperture
  - 10X magnification
  - Edge obscuration due to secondary: ~9%
  - Performed optical wavefront test through entire telescope system and measured .36 waves rms.



VIEW LOOKING INTO FRONT WINDOW
(SUN SHIELD NOT SHOWN)

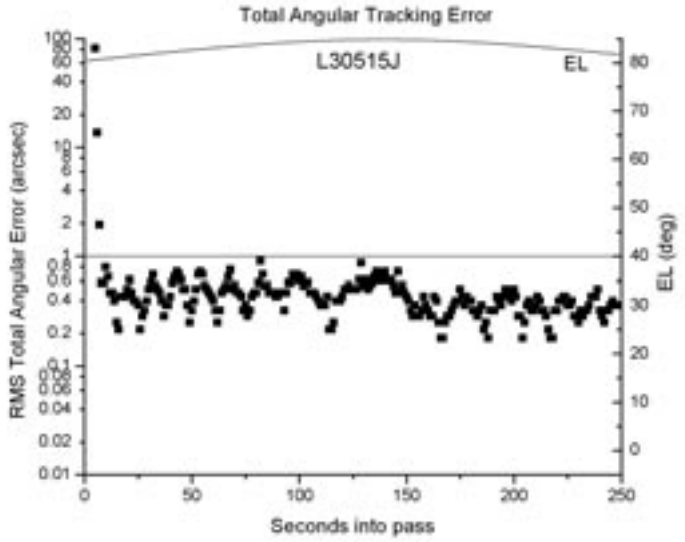


SLR2000 Tracking Mount

Specifications

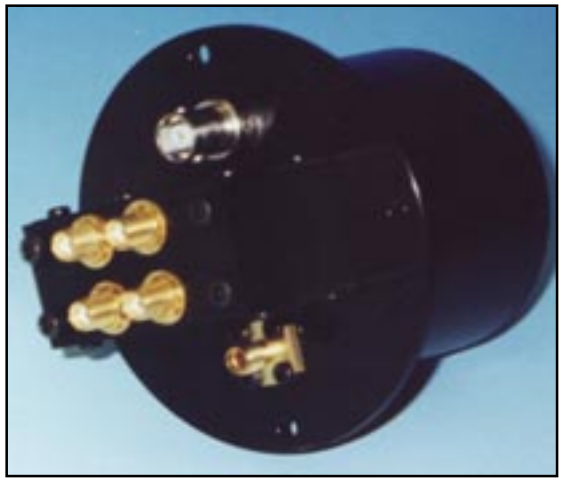
- **Slew Rate**
  - **Azimuth: 30 deg/sec**
  - **Elevation: 20 deg/sec**
- **Total Travel**
  - **Azimuth: continuous (slip rings)**
  - **Elevation: -5° to 185°**
- **Maximum Tracking Rate: >5 deg/sec both axes**
- **Minimum Tracking Rate: Sidereal**
- **Position Resolution: ±0.3 arcsec**
- **Dynamic Tracking Accuracy: <1.0 arcsec RMS**

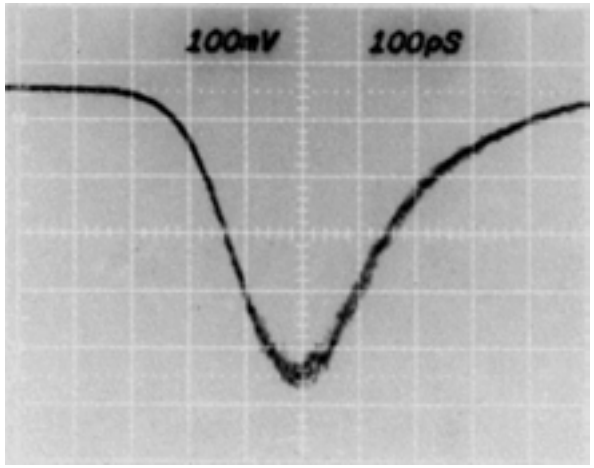
Simulated LAGEOS pass near PCA during Factory Acceptance Testing (Nov 2001)



GSFC

SLR2000 High Speed, Photon-Counting, Quadrant Detector



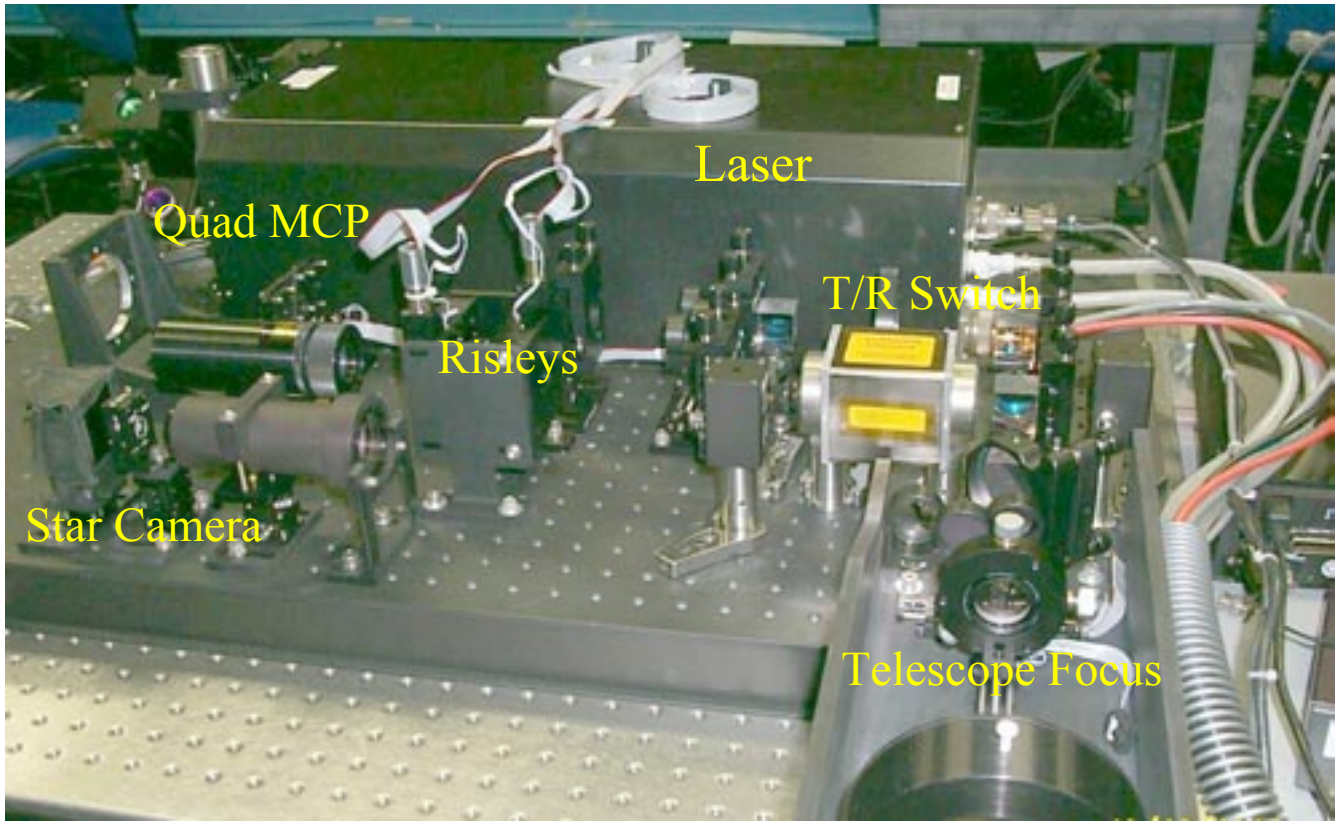


Characteristics:

- Microchannel Plate Photomultiplier
- Active cathode area: 12 mm diameter
- Cathode material: Multialkali
- Quantum Efficiency: >13%
- Minimum Gain: 3 x 10^{6} for single pe detection
- Segmented quadrant anode with separate SMA connectors
- Risetime at anode (10% -90%): <140 psec all quadrants
- Max time delay between quadrants (symmetric design): < 8 psec
- Timing jitter < 28 psec RMS, <40 psec between channels
- Externally gated at 2 KHz rate

Simultaneously provides high precision timing of single photon events and subarcsecond pointing corrections in photon-counting mode !

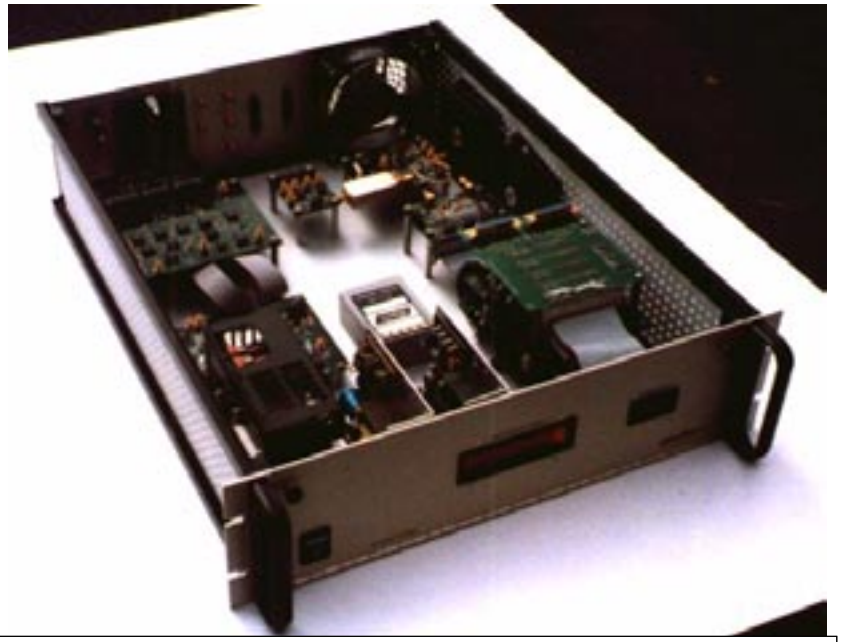
SLR2000 Optical Transceiver



Features

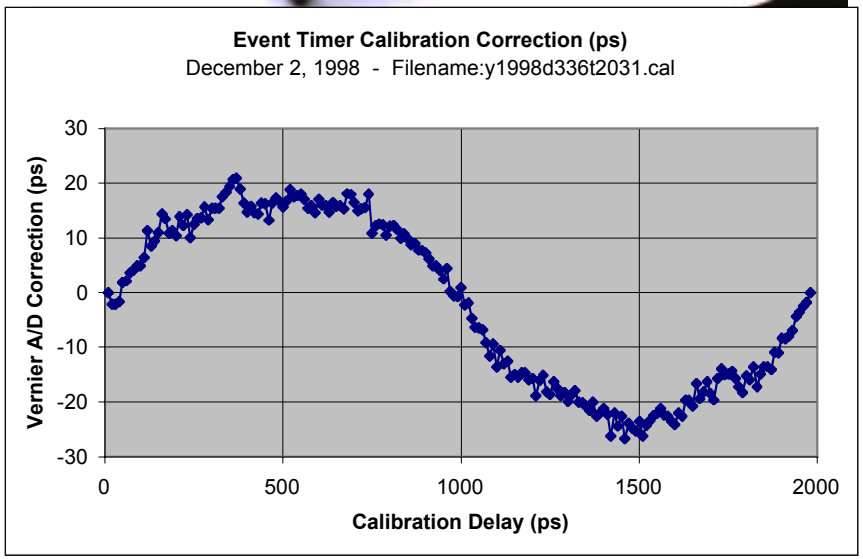
- 36” x 24” x 2” honeycomb optical bench
- Full aperture sharing by transmitter and receiver
- Totally passive, low-loss transmit/receive switch
- Passively Q-switched Microlaser transmitter
- Quadrant Photon-Counting MCP/PMT
- CCD Camera for mount star calibrations
- Automated telescope focus adjustment
- Transmitter point-ahead Risleys (0 to 11 arcsec)
- Spatial and spectral filtering
- Energy monitors
- Alignment and boresighting aids
- Optical attenuator for ground calibrations

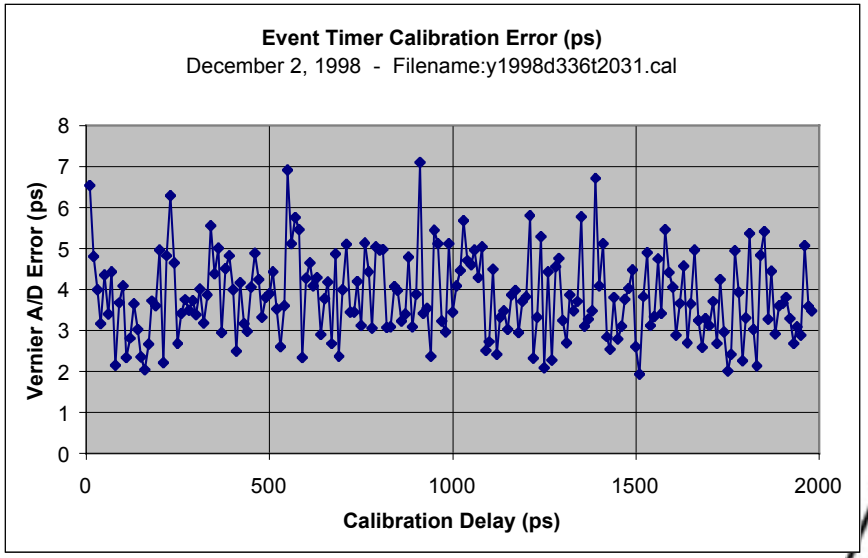
SLR 2000 Millimeter Precision Event Timer



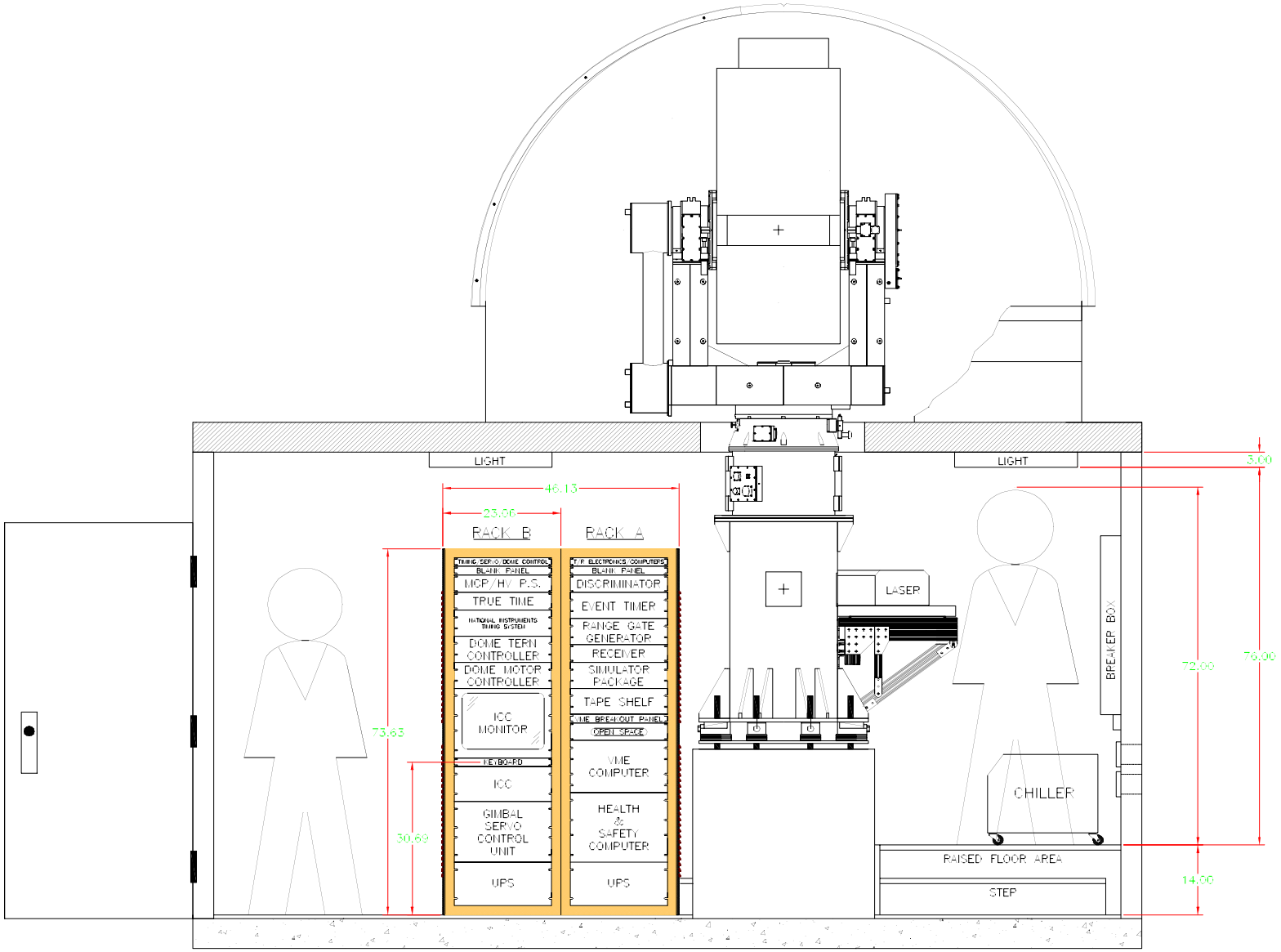
Features

- Clock Speed: 500 MHz
- RMS Jitter: <5 ps (calibrated)
- RMS Range Precision: <1 mm
- Max Event Rate 10 MHz Burst with duration limited by computer (<100 nsec "dead time")
- Internal Data Buffer: 500 events
- Quad Input with Digital ID of input port
- Internal Coarse Clock 500 MHz
- 12-bit A/D sampling over 2 ns period



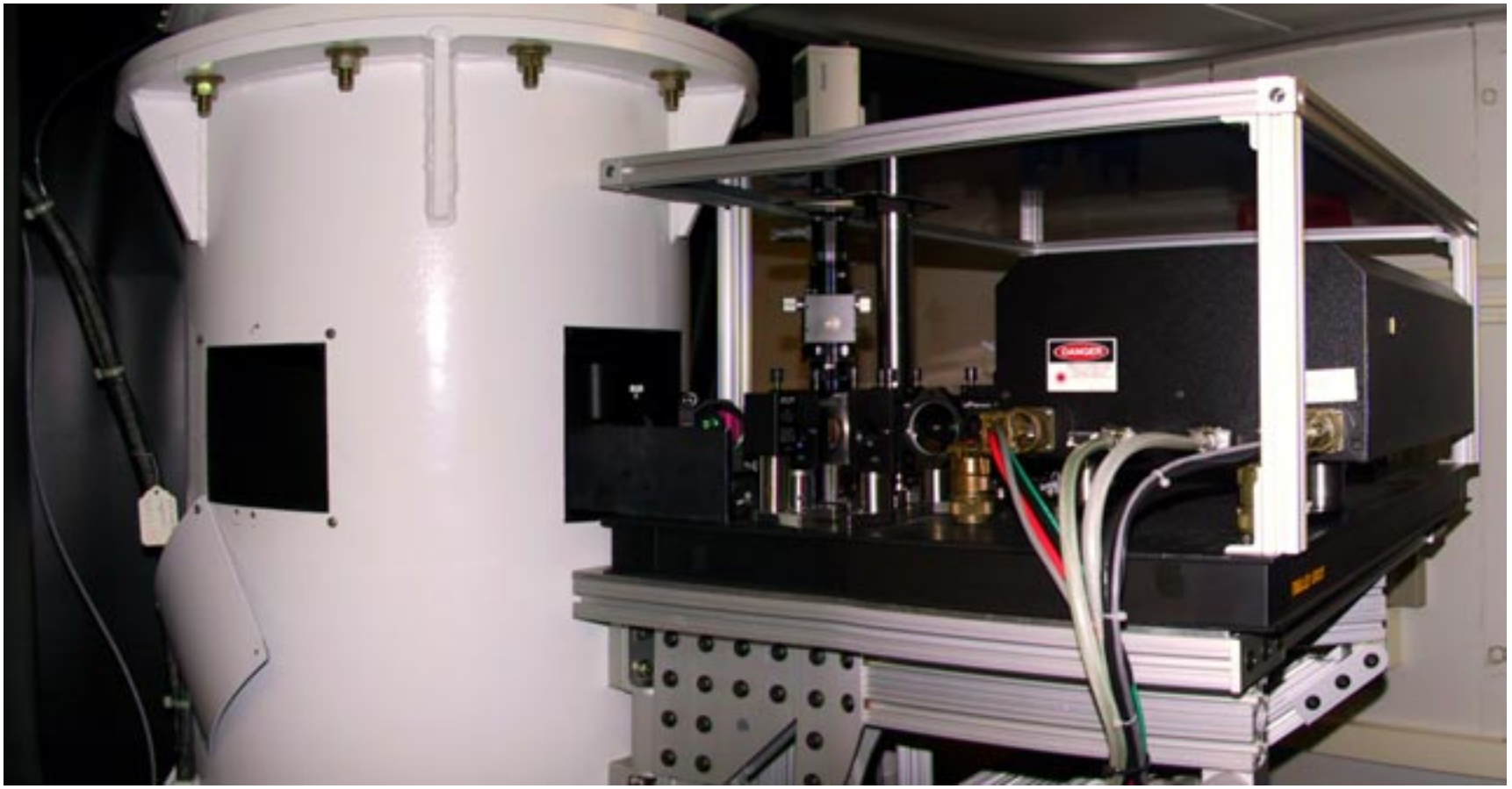


SLR2000 Shelter Layout, Side View



GSFC

SLR2000 Shelter Interior
(as of October 2, 2002)



SLR2000 Status

- **Status (as of October 2, 2002)**
  - **All prototype subsystems have been fabricated and tested and have met specifications at subsystem level**
  - **Software about 90% complete.**
  - **Contract awarded in January 2002 for upgraded transmitter: shorter pulsewidth, more energy, more compact packaging, no water cooling**
  - **Prototype system has been assembled and is undergoing final alignment prior to field testing**
- **Near Term Plans**
  - **Complete and install upgraded field laser by January 2003**
  - **Complete field testing and documentation by June 2003**
  - **Release replication contract by late Summer 2003.**

Tracking mount and telescope installed in prototype SLR2000 facility

Future Upgrades and Applications

- **Two Color Upgrade**
  - **Technical approach described in 2000 Matera Workshop Proceedings**
  - **Add third harmonic crystal and receiver channel for second color**
  - **Compute range difference between different color normal points**
- **Interplanetary Transponder for Inner Solar System**
  - **Technical approach described in previous workshop proceedings (1996, 1998, 2000) and J. Geodynamics, November, 2002.**
  - **Need to extend maximum transmitter point-ahead capability from current 11 to 45 arcseconds**
- **Terminal for Automated Space-to-Ground Laser Communications**
  - **Currently working with JPL to design a modified SLR2000 system that simultaneously ranges to, and communicates optically with, a spacecraft**
  - **SLR2000 performs all of the field operations required to support an automated lasercom station**
    - **Assesses weather and cloud cover and provides necessary safety and health functions**
    - **SLR tracking defines orbit for initial spacecraft acquisition and confirmation**
    - **Ranging beam provides Earth beacon for space-based lasercom system to lock onto**
  - **Simple wavelength splitter in SLR2000 diverts lasercom beam to communications receiver**