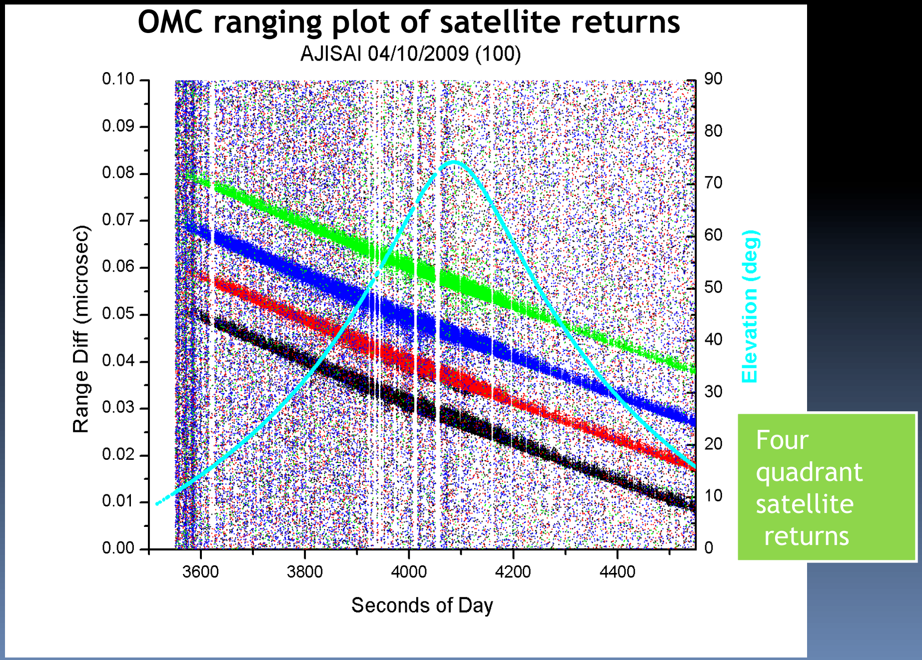
NGSLR:
NASA's Next Generation Satellite Laser Ranging System

Jan McGarry
NASA/GSFC/694
Solar System Exploration Division

April 2012

Overview

NGSLR is a high repetition rate single photon detection laser ranging system capable of tracking cube corner reflector (CCR) equipped satellites in Earth orbit. The concept of NGSLR was developed by J. Degnan (GSFC, retired) in the 1990s. Technical development continues at Goddard. The system has demonstrated tracking of Earth orbit satellites with altitudes from 300 km to 20000 km. Completion of the NGSLR prototype will occur during the Space Geodesy Project.



System Features:

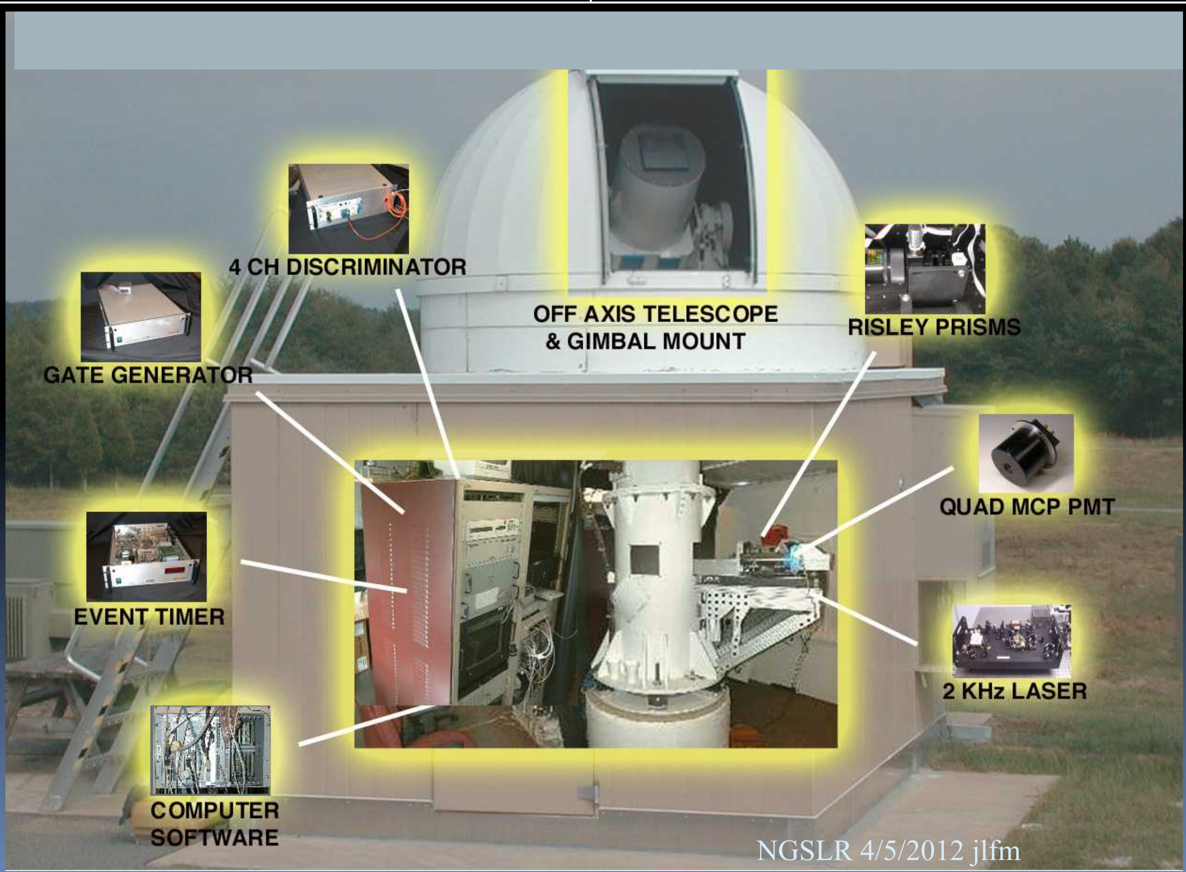
- 1 to 2 arcsecond pointing/tracking accuracy
- Track CCR equipped satellites to 20,000 km altitude, 24/7 operation
- Reduced ocular, chemical, electrical hazards
- Semi automated tracking features
- Small, compact, low maintenance, increased reliability
- Lower operating/replication costs

Current Requirements

- 24 hour tracking of LEO, LAGEOS & GNSS satellites (that have ILRS approved retro-reflector lidar cross sections)
- One millimeter normal point precision on LAGEOS
- Accuracy and stability at the MOBLAS level or better
- Semi-autonomous operations
- Radar for all satellite ranging
- Mean time between failures: > 4 months

Major Subsystems

1. Time & Frequency 2. Telescope 3. Transceiver Bench 4. Laser 5. Laser Hazard Reduction System (LHRS)	6. Tracking 7. Receiver 8. Computer and Software 9. Weather 10. Shelter and Dome



New Technologies Developed for NGSLR

The requirements of SLR2000 (i.e. eye safety and unmanned operation) led to a number of unique computer-controlled hardware devices including:

- **Totally Passive Transmit/Receive Switch** allows the full aperture of the telescope to be shared simultaneously , with minimal optical loss, by the transmitter (for eye safety) and receiver (for signal strength) independent of the laser repetition rate and receive signal polarization.

- **Transmitter Beam Expander** allows the transmitter beam divergence to be varied as a function of satellite range for enhanced signal strength while maintaining a fixed beam diameter at the telescope exit window for eye safety.

- **Variable Spectral Filter** optimizes the filter transmission and spectral bandwidth for daylight, twilight, and night operations.

- **Dual Risley Prism Device** permits independent arcsecond accuracy pointing of the transmitter and receiver allowing smaller receiver fields-of view for reduced solar noise.

- **Variable Iris Spatial Filter** allows adjustment of the receive FOV for less solar noise.

New Technologies Developed for NGSLR (continued)

- **Variable Laser Trigger** varies laser repetition rate about the nominal 2 kHz to prevent backscatter from the outgoing laser pulse from overlapping satellite returns at receiver.

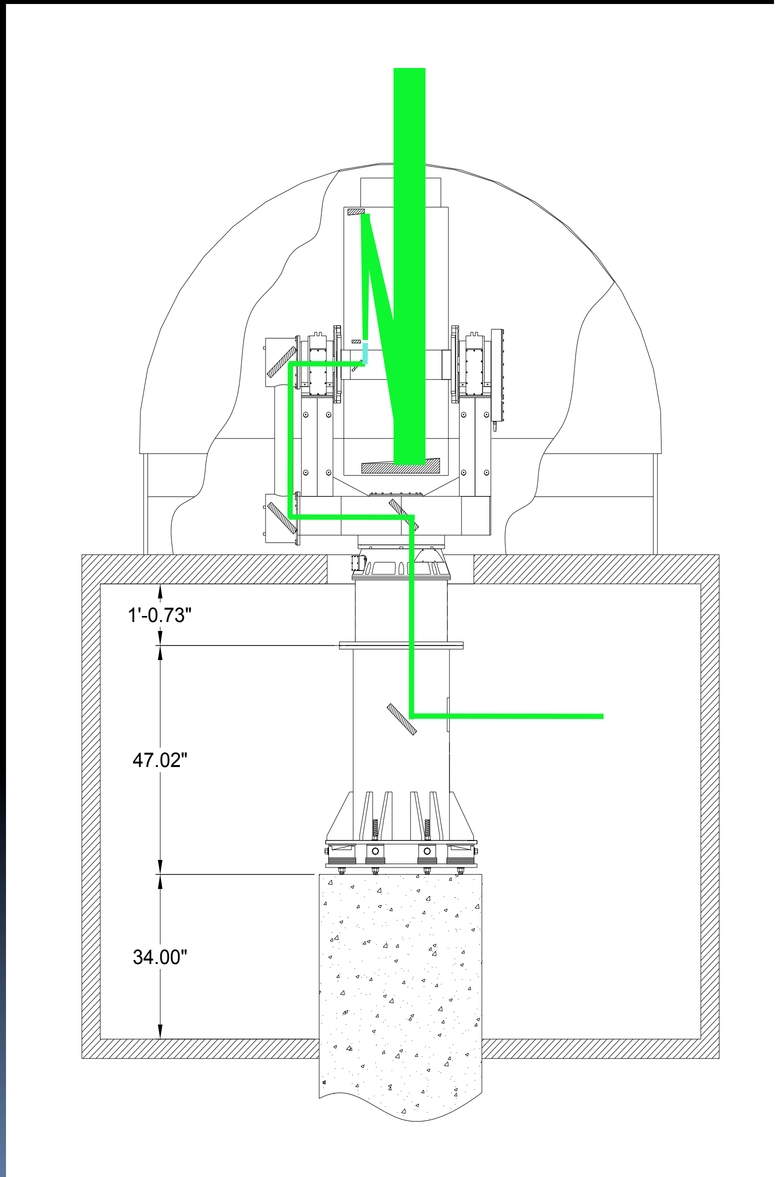
- **Dual Liquid Crystal Optical Gates** further reduces laser instrument and atmospheric backscatter by more than two orders of magnitude, independent of polarization.

- **Smart Meteorological Station** monitors hemispherical cloud cover and ground visibility (to support satellite selection and efficient operations), precipitation (for system protection), wind speed and direction, while providing the usual atmospheric surface pressure, temperature, and relative humidity measurements needed to support atmospheric refraction corrections to the range measurements.

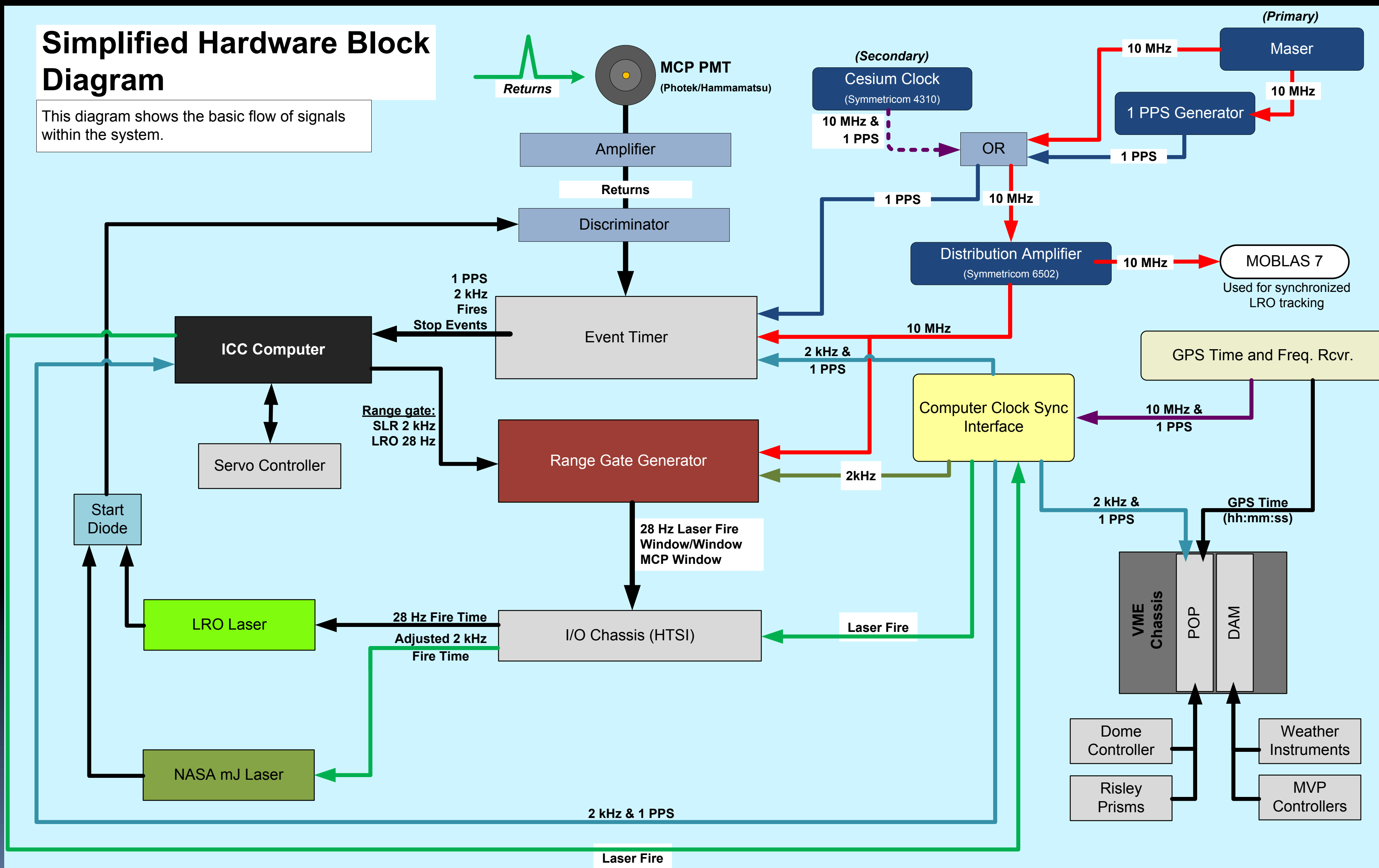
- **Algorithms and related software** to give NGSLR the ability to autonomously (1) determine when and how to change the laser pulse repetition frequency (PRF) to avoid collision between outgoing and incoming laser pulses, (2) process returns to find satellite events in very low signal to noise environments, (3) continually monitor the angular proximity of the telescope to the sun and move the mount to avoid getting sunlight into the detector, (4) direct the transmit beam as an angular offset from the telescope to put laser pulses where the satellite will be when the light arrives.

NGSLR System Characteristics

- **Telescope:**
- 40 cm Telescope Aperture Off-Axis Parabola
- No Central Obscuration
- **Tracking:**
- AZ/EL with 1 arcsec RMS gimbal pointing accuracy
- **Transceiver Bench:**
  - Common Optics for Transmit and Receive
  - Passive Transmit/Receive Switch
  - Risley Prism Point-Ahead of Transmit
- **Laser:**
  - Subnanosecond pulse, 2 kHz
  - Asynchronous PRF, software controlled
  - Divergence control by software
- **Receiver:**
  - High QE, GaAsP Microchannel Plate Photomultiplier
  - Constant Fraction Discriminators
  - GPS-synchronized Rubidium Oscillator /Time and Frequency Receiver
  - Picosecond Precision Event Timer
- **Weather:**
  - Day/Night All-Sky Cloud Sensor (thermal)
  - Wind Monitor
  - Surface Pressure, Temperature, and Humidity Monitors
  - Visibility/Precipitation Sensor



NGSLR System Block Diagram



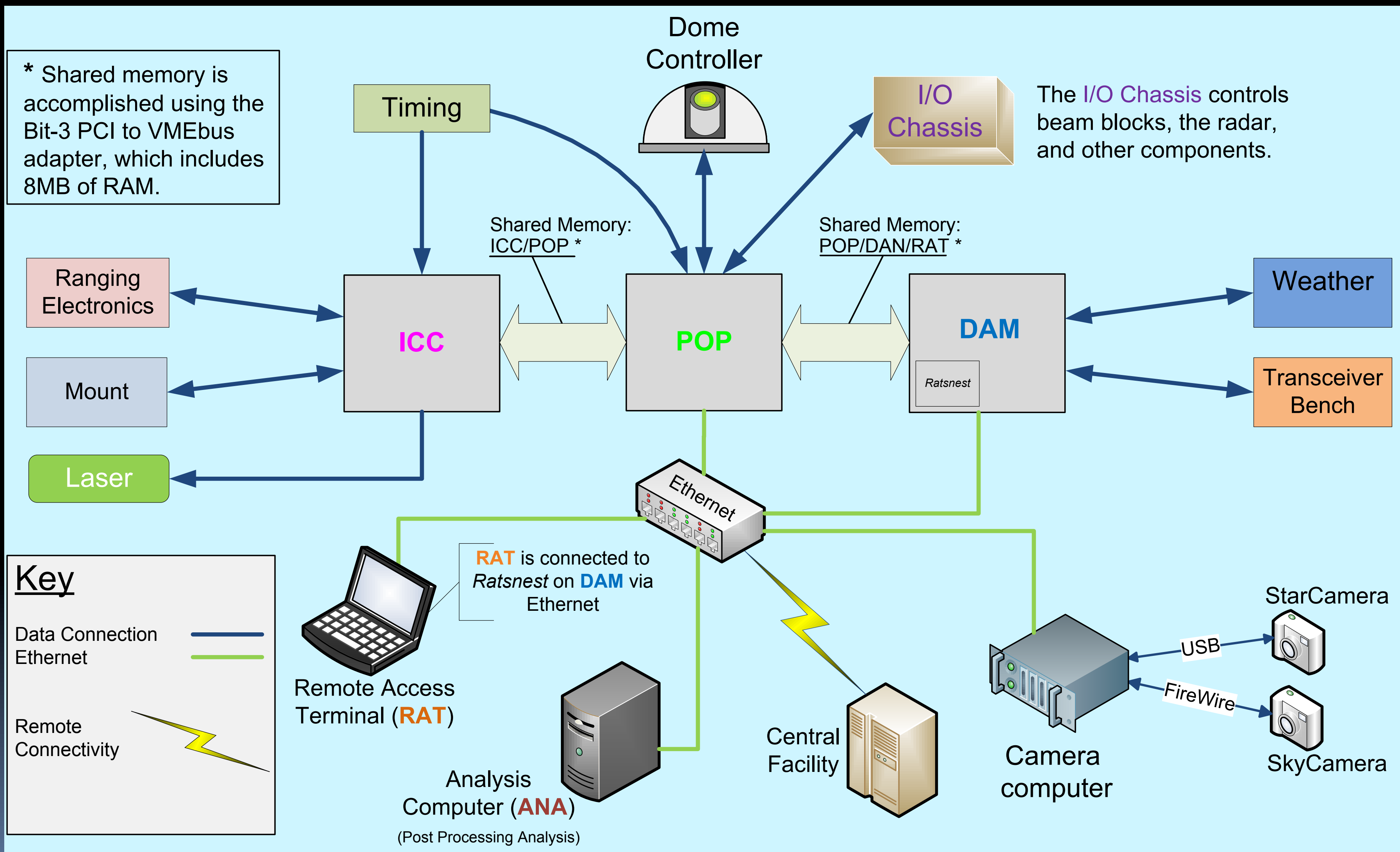
Software/Computer Overview

- Computers:
  - Pseudo Operator (POP) – performs operator decisions
  - Device Access Manager (DAM) – optical bench controller
  - Interface & Control Computer (ICC) – real-time data I/O
  - Remote Access Terminal (RAT) – interface to human
  - Analysis Computer (ANA) – post-processing
  - Camera computer – start and sky camera interface
  - Dome controller – slaves dome to telescope during operations

- Backplanes: VME, PCI, ISA.

- Software
  - Operating systems: LynxOS, Linux, Windows, DOS
  - Languages: "C", assembly, perl.
  - Lines of code: ~200,000

NGSLR Computer Interfaces



Automation Overview
(some of the functions that will be performed by software)

- **Obtaining input files:**

- automatically pull prediction and other data files from the server.

- **System scheduling:**

- software completely determines/controls what is tracked and when.

- **Operator decision making:**
  - open/close dome based on weather,
  - keep telescope from pointing into the sun,
  - determine if we can track and where in the sky based on cloud cover.
- **Signal processing and closed-loop tracking:**
  - determine if system is hitting the satellite,
  - search for the satellite and optimize the pointing.
- **Transmit / receive path optics configuration and control:**
  - determine and control optical bench configuration,
  - decide configuration based on target, day/night.
- **Data processing and product delivery:** normal points delivered hourly.

Current Automation Status

- Completed, tested and working
  - Automated star calibration
  - Sun avoidance (software)
  - Laser pulse collision avoidance
  - Point-ahead tracking using Risley Prisms
  - Obtaining input data and system scheduling

- Almost complete
  - Dome shutter open/close decisions based on weather
  - Determination what can be tracked based on cloud cover
  - Determination if system is hitting the satellite
  - Search for the satellite if not getting signal returns
  - Normal point generation and data delivery
  - Fully automated ground calibration
  - Complete control by software of optical bench motor controls

- Being worked
  - New I/O chassis software interface
  - Closed loop tracking (optimizing biases during tracking)

NGSLR Automation Laboratory

- **Development Efforts in Lab**
  - -Development of new optical bench layout
  - -Design and testing of specialized mounting hardware for optics
  - -Verification of selected optical components
  - -Design and verification of alignment aids and alignment procedure
  - -Assembly and alignment of new optical bench
  - -Verification and Testing of COTS high energy, short pulse laser
  - -Integration of COTS laser onto optical bench

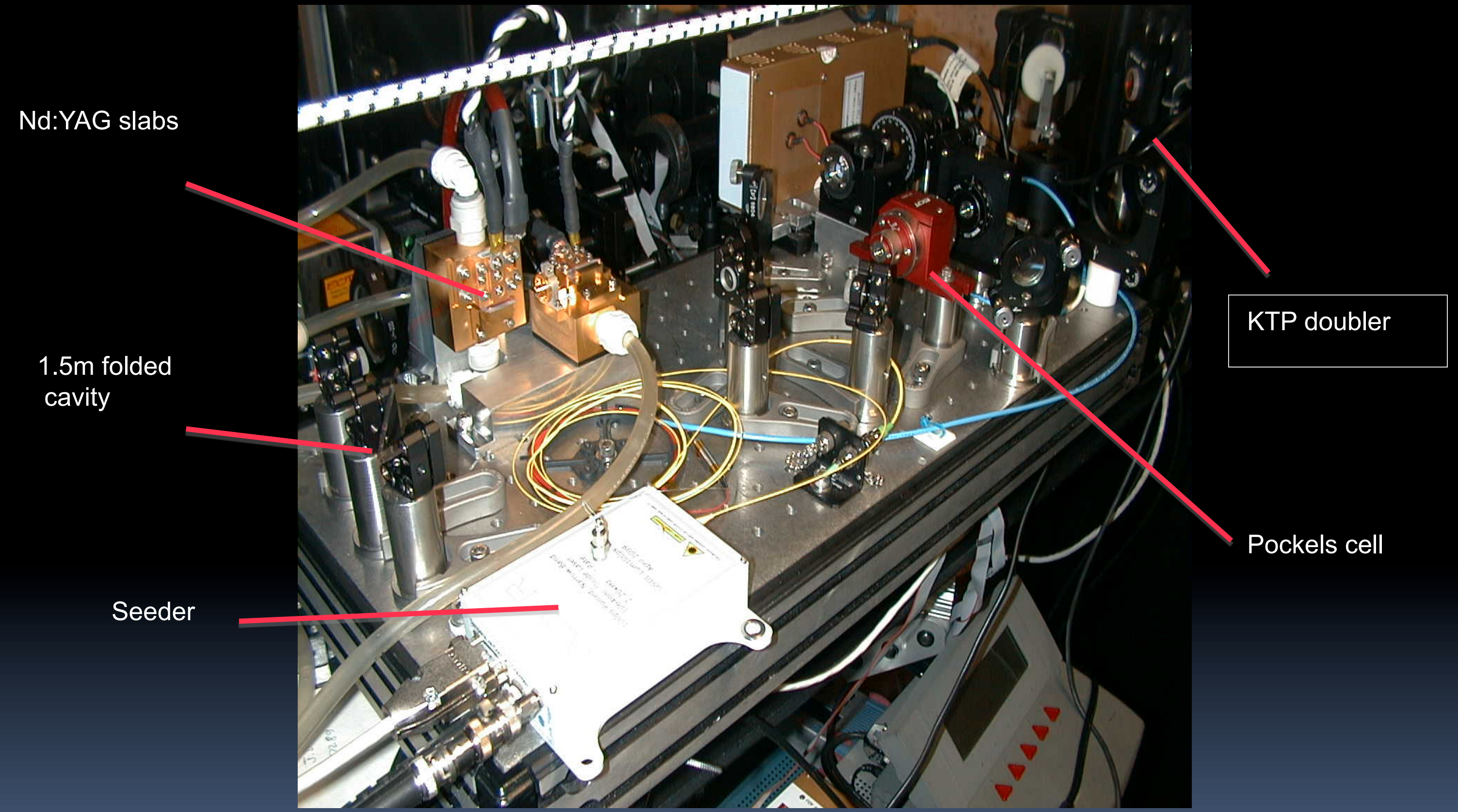
- **Benefits of Lab Work**
  - -Introduce a fully automated layout
  - -Isolate transmit/receive path on the bench to reduce system noise
  - -Improve access to all devices for alignment
  - -Upgrade alignment procedure
  - -Increase system efficiency
  - -Allows work to go on without disturbing NGSLR tracking

Once aligned and tested, the new bench will be moved into the NGSLR shelter, accelerating the integration process

In-house built 2 kHz mJ laser

Regenerative amplifier seeded by a gain-switched diode laser

Currently installed & in use at NGSLR



~200 ps pulsewidth, ~1 mJ per pulse energy

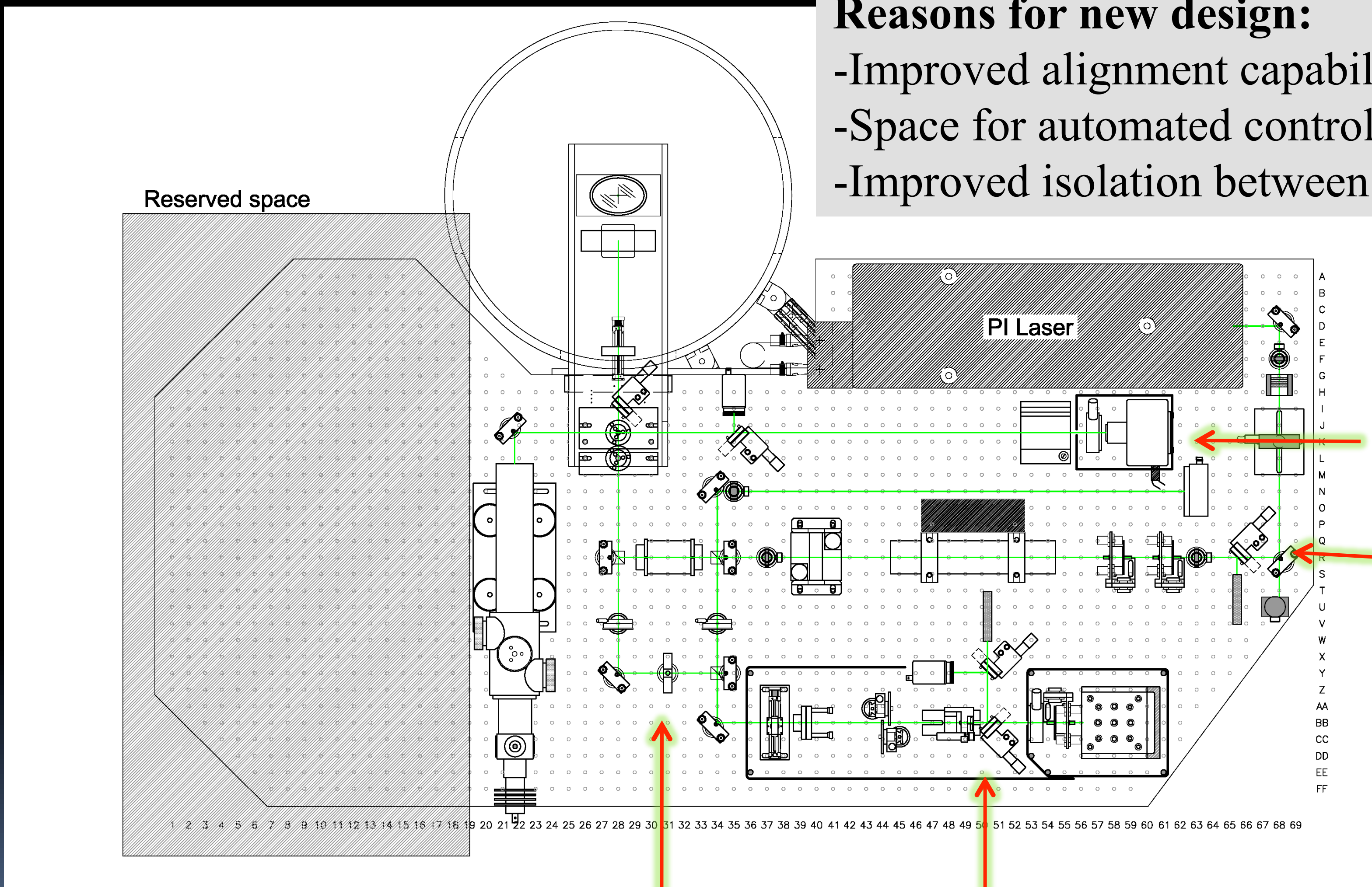
New Optical Bench

Reasons for new design:

-Improved alignment capability

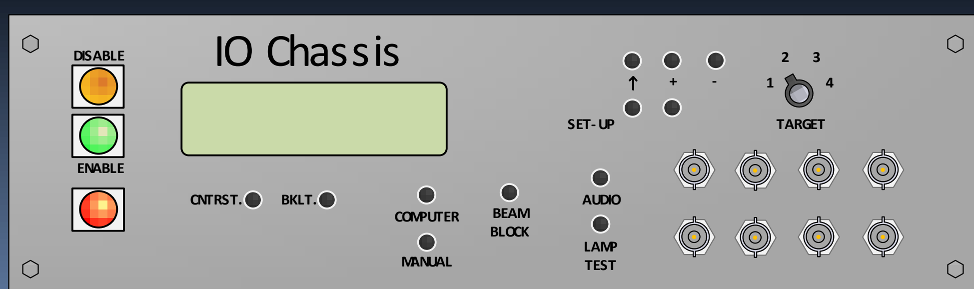
-Space for automated controls

-Improved isolation between Xmit/Rcv



IO Chassis

- Controls and distributes the proper gate signals for the PMT and discriminator during ground calibrations and satellite tracking using its internal delay circuits and the RGG inputs as well as electronics for the MCP blanking circuit.
- Contains electronics and firmware enabling computer interface and control and/or monitoring of various hardware on the Optical Bench such as beam blocks, optical density filters, shutters, gradient ND filter wheels, etc.
- Provides interface electronics for the Remote Control Box which allows manual control of various elements on the Optical Bench for maintenance and alignment purposes.
- Serves as the safety interlock chassis providing power and control to beam blocks when a safety condition occurs such as an aircraft detect, opening of the Shelter door, and unauthorized access of the stairway to the telescope area.
- Provides the interface electronics for the control of the radar subsystem.



Software Development and Testing
(Using NGSLR Automation Lab)

- Facilitates the development of new software without disturbing the operational system and serves as a test location for operational spare computers.
- Uses a complete set of duplicate computers, motor controllers, an optical bench, and an IO chassis (both a software simulator and a hardware setup).
- Uses software simulators when/where spare components are not available.
- Enables the designing, coding and testing of IO chassis software and automation control software.
- Permits testing of the automated search and cloud decision software.
- Allows the testing of star assessments, star calibrations, ground calibrations, satellite tracking as well as “real world” scenarios.

Final System Configuration

Hamamatsu High QE MCP PMT:

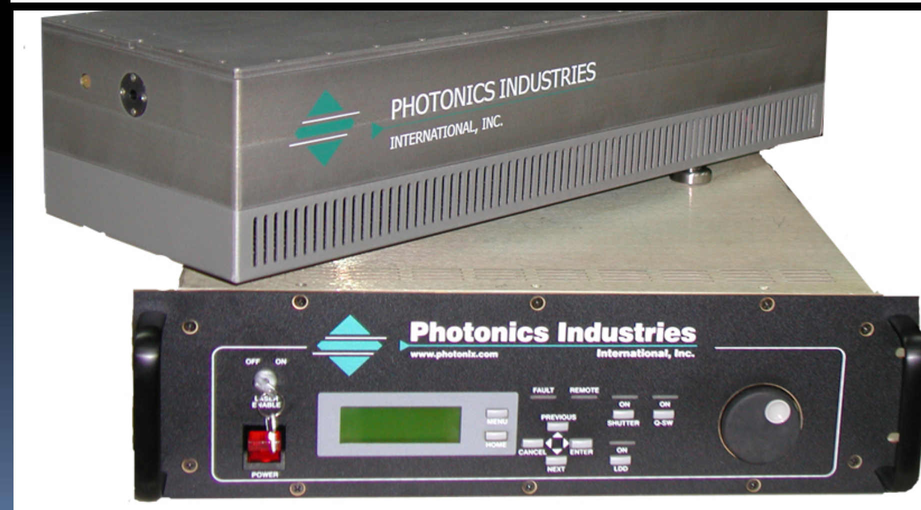
- Model R5916U-64
- GaAsP Photocathode
- QE > 43%
- Rise Time <178 ps
- Photocathode Input = 25mm Ø

In NGSLR now

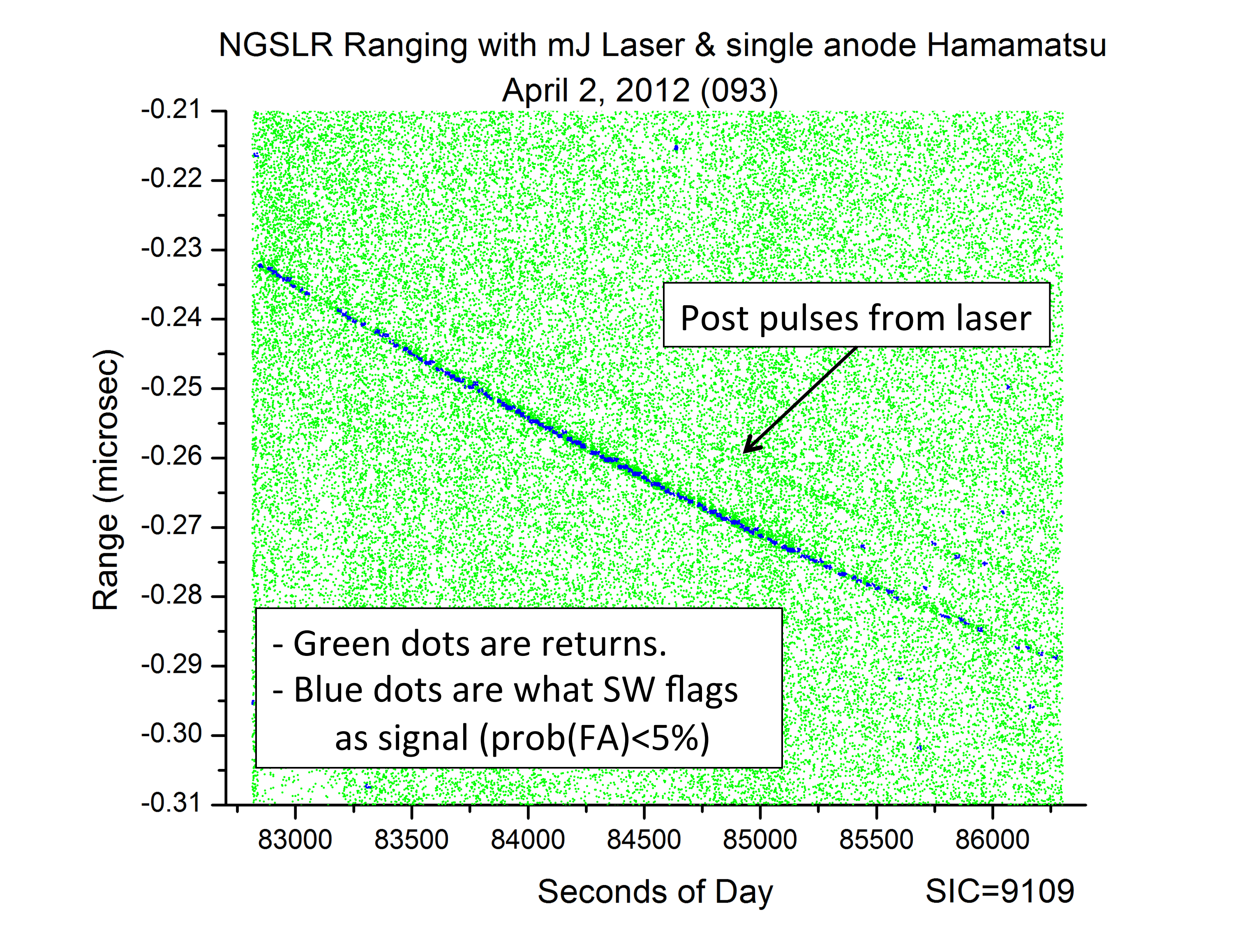
Photonics Industries Short Pulse, Hi Energy, Hi Rep Rate Laser:

- Model RGL532-2.5
- Maximum Energy = 3 mJ
- Pulse Width FWHM = 50 ps
- Repetition Rate = Single Shot to 5 kHz
- Beam Divergence < 1 mR
- Output Beam Diameter = 1.7mm
- Spatial Mode Profile = TEM_{00}
- Long Term Stability < +/- 2%
- Pulse to Pulse Stability < 2% RMS

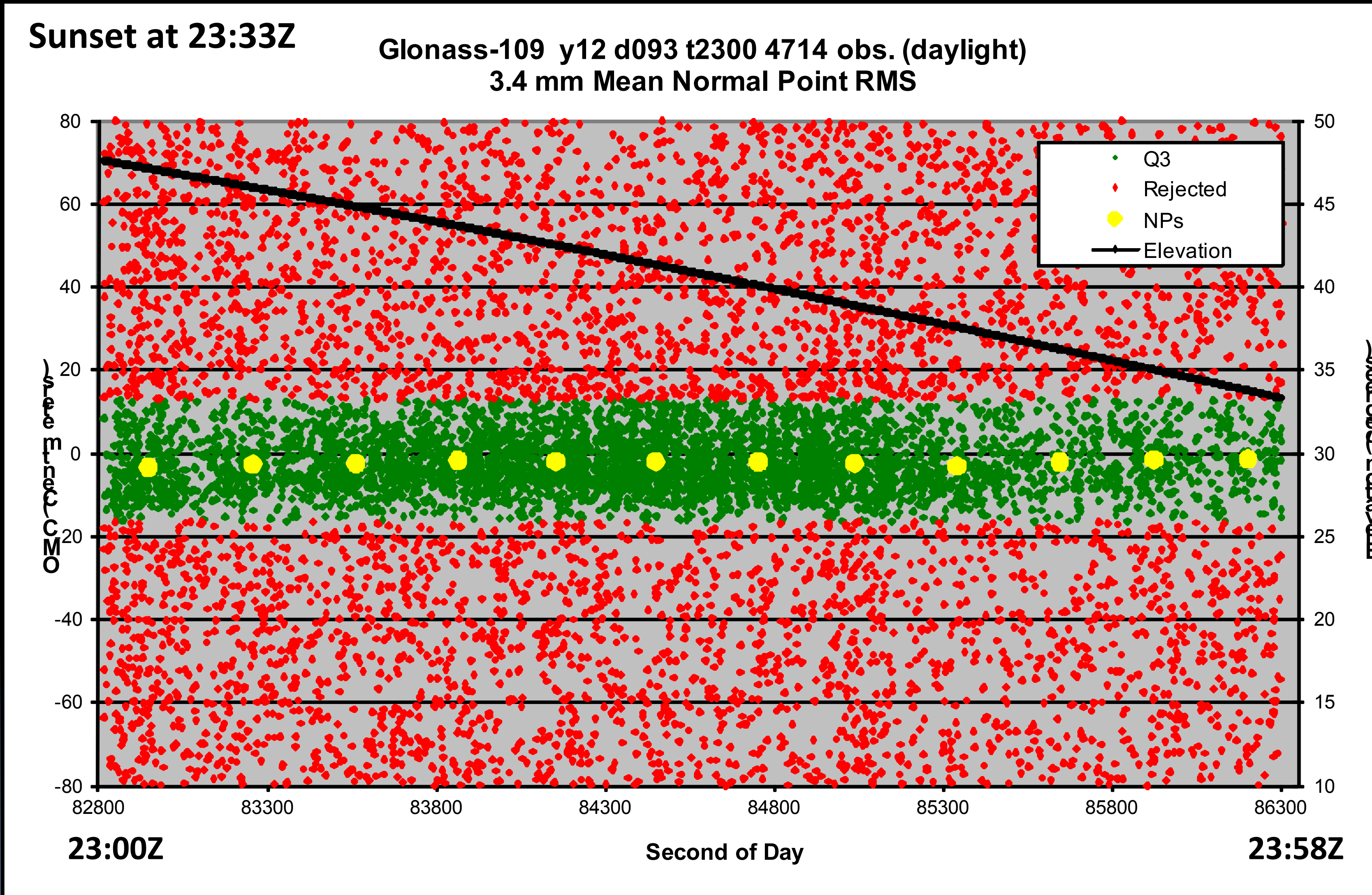
At GSFC and in laboratory testing



Daylight Ranging to GNSS
Observed Minus Calculated (OMC)



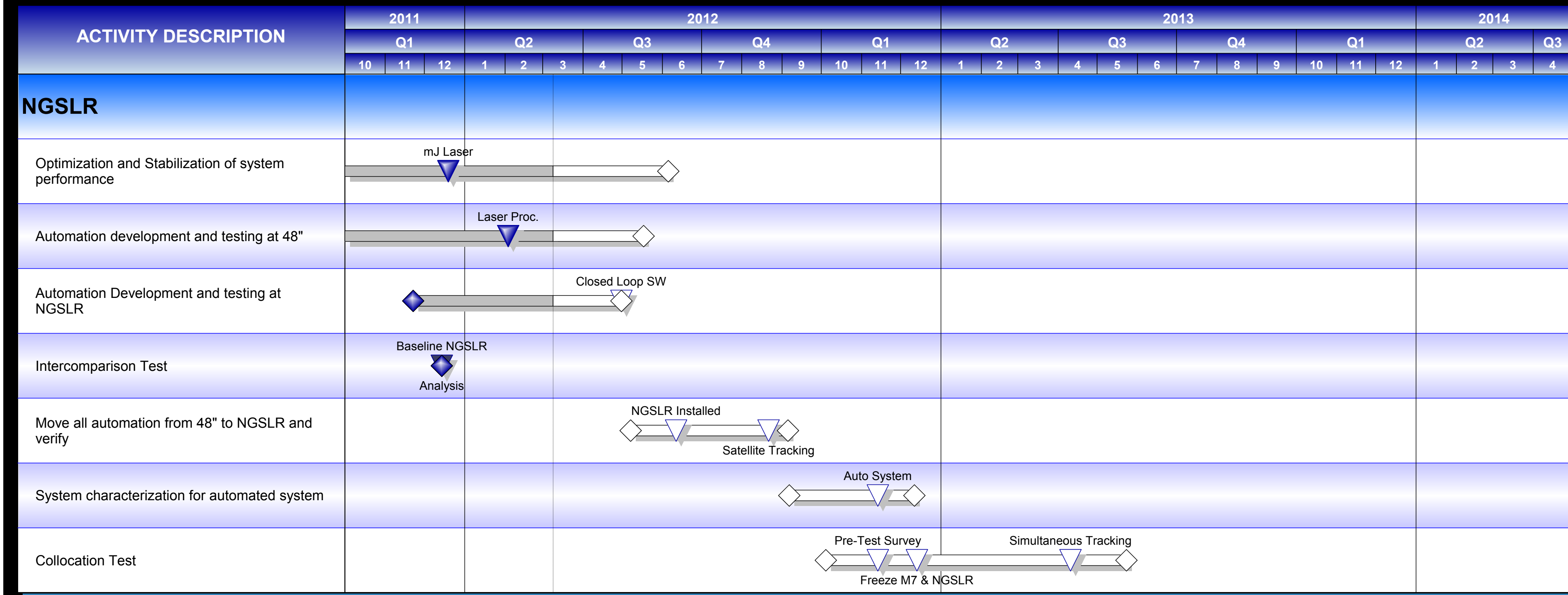
Daylight Ranging to GNSS: Normal Pts



NASA mJ laser and Hamamatsu detector

NGSLR Schedule to Completion

Space Geodesy Project



SUMMARY

- **Significant progress has been made in automation.**

- **System routinely tracks LEO to GNSS at night, LEO to LAGEOS day and night, and has just recently demonstrated daylight ranging to GNSS (GLONASS).**

- **Currently working on system performance.**

- **Major technology developments:**

  Passive T/R switch, Risleys for point-ahead, transmitter beam expander, smart Met station, liquid crystal optical gates, …

- **Major software achievements:**

  Sun avoidance software, laser PRF changes for pulse collision avoidance, point-ahead angular calculations, signal processing, operator decision automation, …

- **Documentation – have version 1 of major system documents & drawings.**