NGSLR:
NASA's Next Generation Satellite Laser Ranging System

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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 ~ 1000 km to 20000 km. Completion of the NGSLR prototype will occur during the Space Geodesy Proposal.

OMC ranging plot of satellite returns
AJISAI 04/10/2009 (100)

Four quadrant satellite returns

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
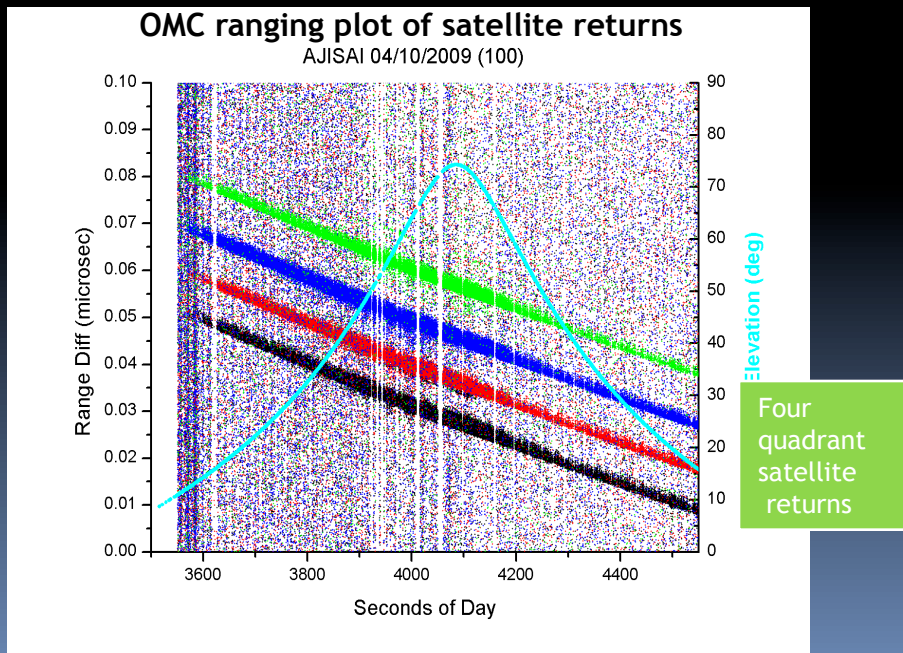
Team

John Annen (automation lab lead, hardware development) - GSFC/693
Jack Cheek (software lead, sysadmin, real-time software) - SigmaSpace
Bart Clarke (software: OD, SLR data analysis, signal processing) - Honeywell
John Degnan (lasers, SLR theory, original SLR2000 concept) - SigmaSpace
Bud Donovan (hardware lead, deputy NGSLR lead, laser safety) – Honeywell
Felipe Hall (documentation lead) – Honeywell
Evan Hoffman (hardware development & sustaining engineering) - Honeywell
Julie Horvath (config control & collocation lead, i/f with ILRS) - Honeywell
Tony Mann (software: unix sysadmin, device drivers) - Honeywell
Jan McGarry (NGSLR lead, algorithm & software development) - GSFC/694
Don Patterson (hardware develop., sustaining & system engineering) - Honeywell
Randy Ricklefs (software & OS, device drivers, algorithm) – Cybioms
Mark Torrence (SLR analysis) - SGT
Tom Varghese (system engineering) – Cybioms
Scott Wetzel (cross-SGP integration) - Honeywell
Tom Zagwodzki (system engineering) - Cybioms

Combined total of > 250 years SLR experience

Historically Important Dates
NGSLR was originally called SLR2000

1994: Original SLR2000 concept, limited to LAGEOS (< 8500 km slant range) and lower satellites, was first presented to, and endorsed by, the NASA Belmont SLR Workshop.

1997: SLR2000 technical approach reviewed and approved by GSFC MTPE Office (Dr. Robert Price). First substantial funding provided.

2000: Revised 2000 ANSI laser safety standards for subnanosecond pulses have major impact on maximum transmitted energy and minimum pulsewidth affecting both receive signal strength and single shot range accuracy.

2001: All major subsystem tests completed successfully.

2002: Prototype system assembled and ready for field tests. Phase III laser on order from Q-Peak.

2003: Visual tracking of sunlit satellites demonstrated. Two to three arcsecond star calibrations routinely achieved.

2004: LEO satellite tracking demonstrated under operator control.

2006: Many automated subsystems (variable beam expander, PRF, upgraded sky and star cameras) are integrated and operational except for transmitter point ahead and quadrant detector pointing correction.

2008: Night tracks of GLONASS demonstrated with eye-safe laser. System mods begun for intermittent tracking of Lunar Reconnaissance Orbiter (LRO) with high power laser.

2009: Robust day/night tracking of LAGEOS and night tracks of GNSS satellites (GLONASS, Etalon) with eyesafe laser and transmitter point-ahead capability demonstrates original goals of SLR2000 development.

2010: New in-house built mJ laser installed, replacing eye-safe Q-Peak laser.

2011: SGP starts its 2-year effort, major funding received.

Original Goals*

"...the primary technical goals of the SLR 2000 system are:

Unmanned, eyesafe operation
24 hour tracking of LAGEOS and lower satellites
One centimeter (RMS) single shot precision or better
Minimum 100 ranges per normal point
Mean time between failures: > 4 months
Automated two-way communications with a central data processor via Internet
System free of optical, electrical, and chemical hazards

Secondary goals for the system, presently viewed as highly desirable but perhaps difficult to achieve, include a capability to range to high altitude satellites such as GPS, GLONASS, and ETALON and the ability to retrofit two color technology at some later date."

*Extracted verbatim from J.J. Degnan, "SLR 2000: An autonomous and eyesafe satellite laser ranging station ", Proc. Ninth International Workshop on Laser Ranging Instrumentation, pp. 312-323, Canberra, Australia, November 7-11, 1994.

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

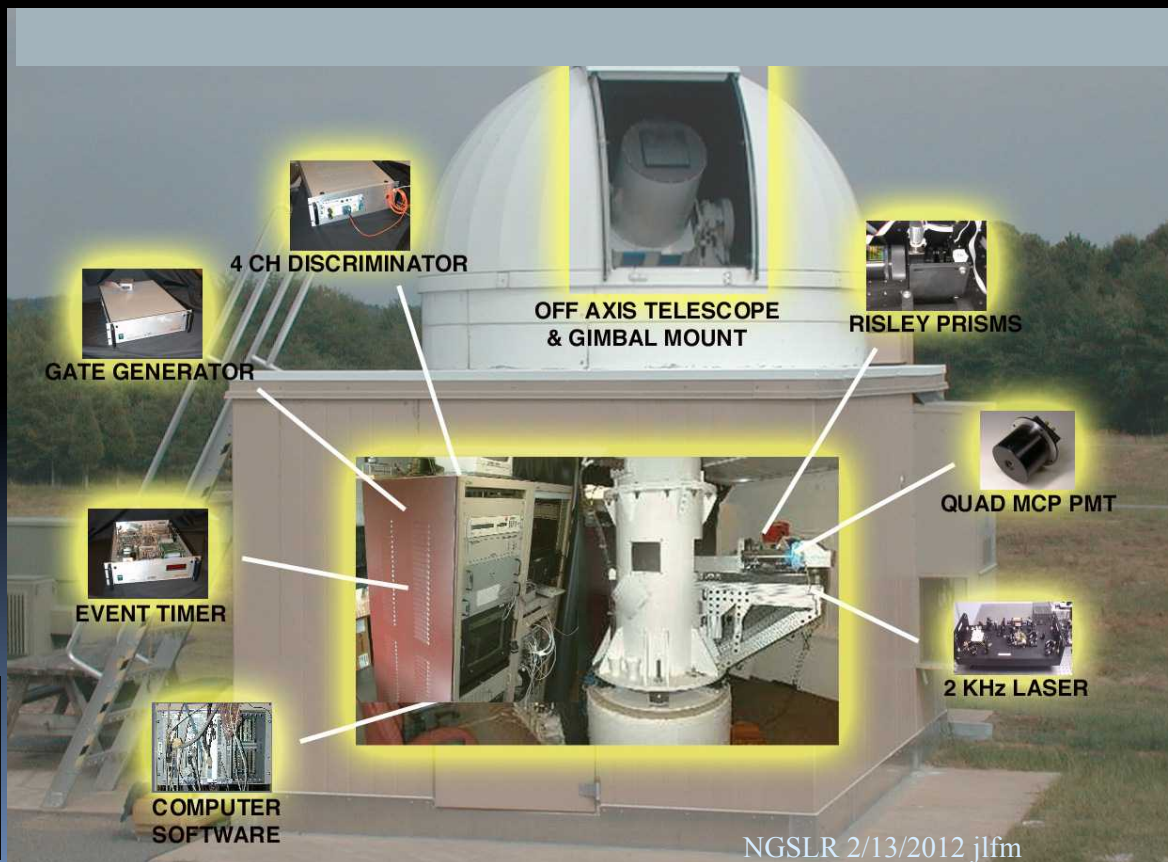- Radar for all satellite ranging

- Mean time between failures: > 4 months

# SYSTEM Description

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

NGSLR 2/13/2012 jlfm

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
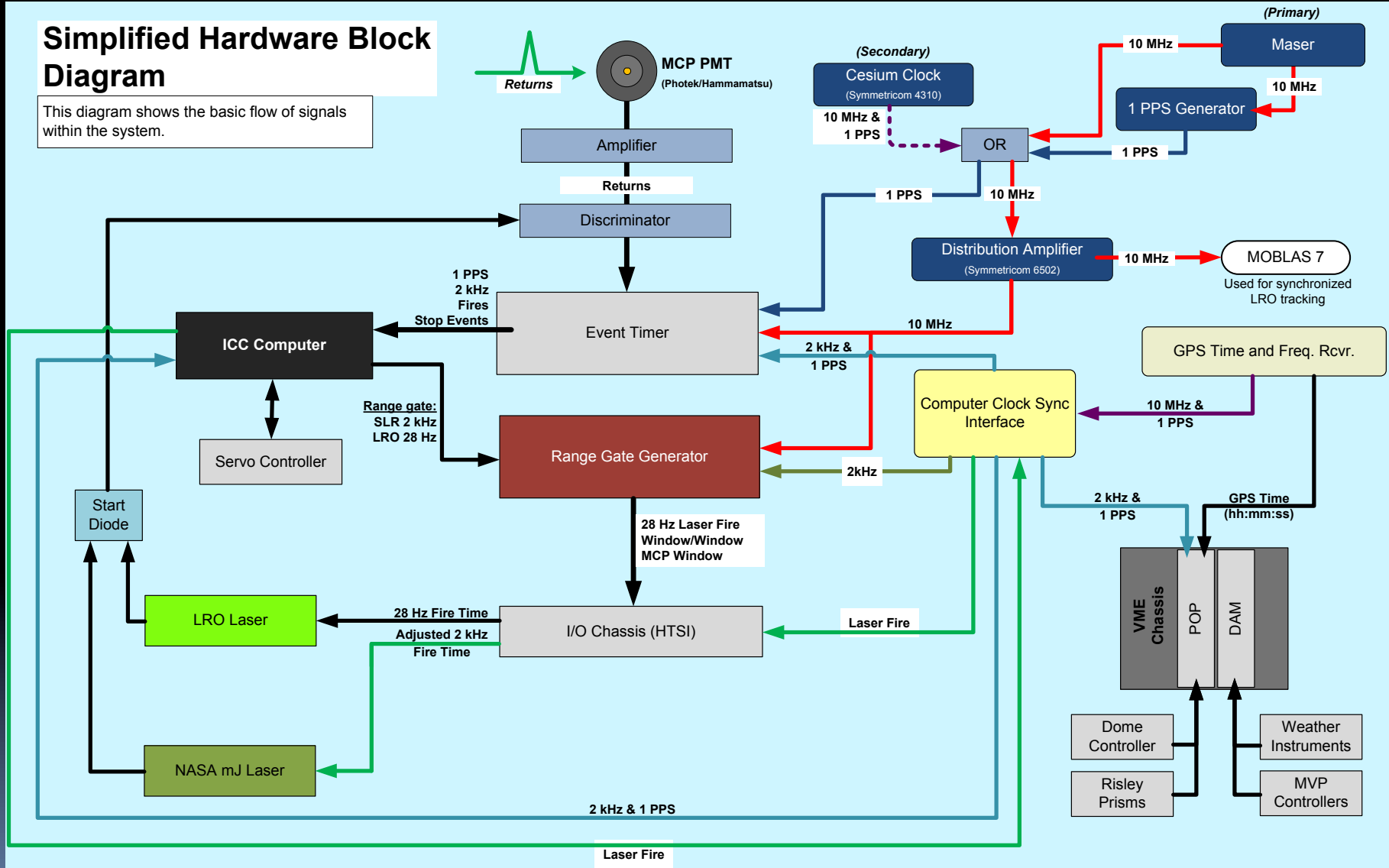 - Visibility/Precipitation Sensor
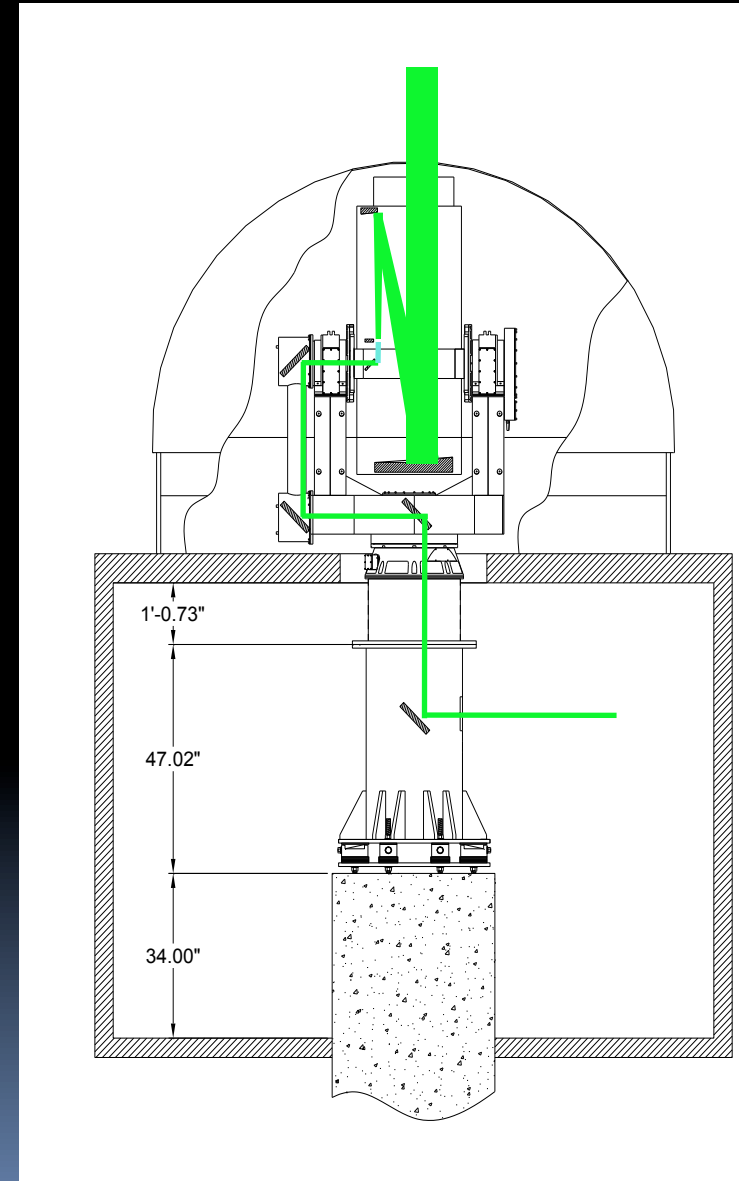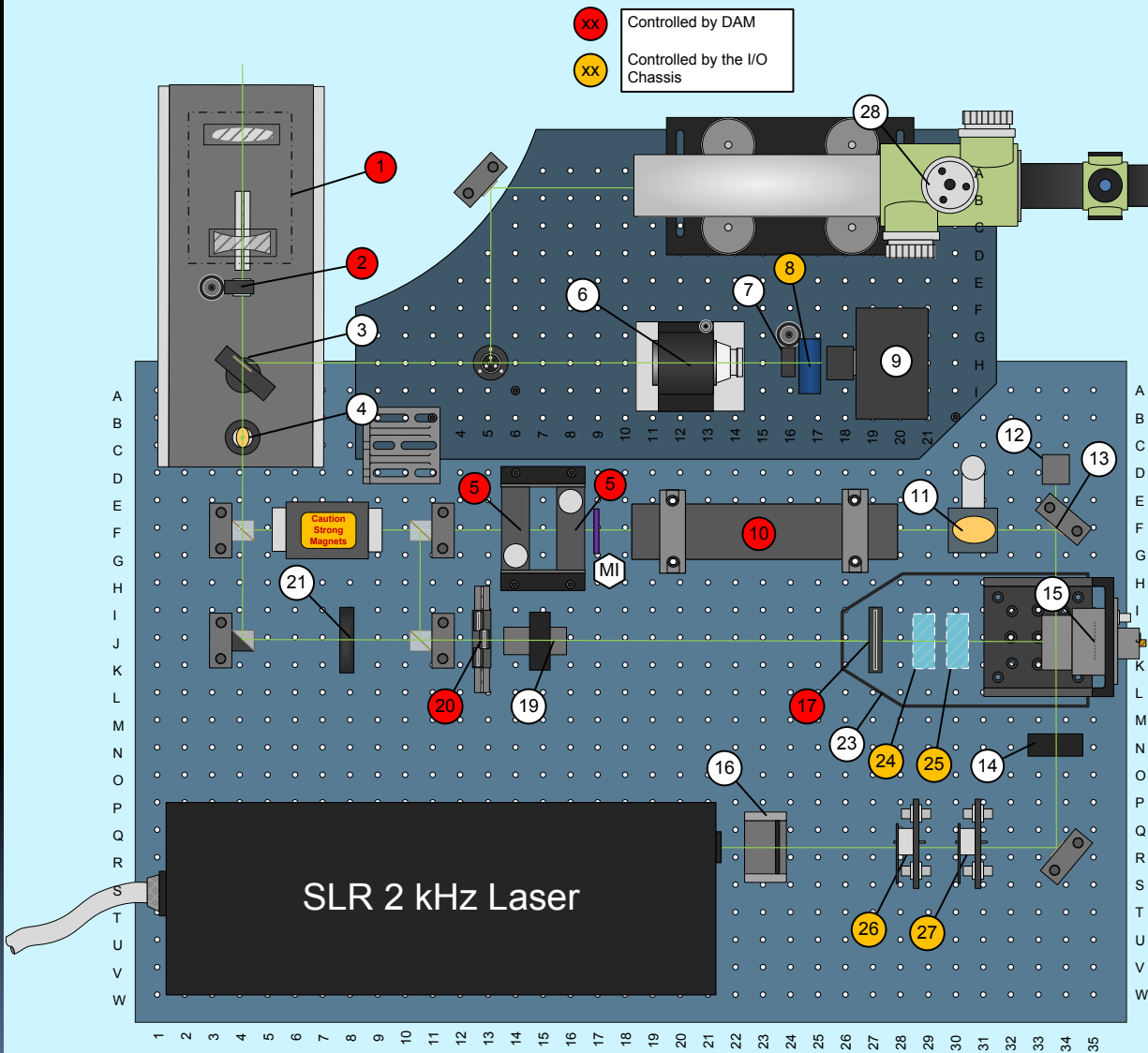
NGSLR System Block Diagram

Simplified Hardware Block Diagram

This diagram shows the basic flow of signals within the system.

Returns

MCP PMT
(Photek/Hammamatsu)

Amplifier

Returns

Discriminator

(Secondary)
Cesium Clock
(Symmetricom 4310)

(Primary)
Maser

10 MHz

10 MHz

1 PPS Generator

10 MHz & 1 PPS

OR

1 PPS

1 PPS

10 MHz

1 PPS
2 kHz
Fires
Stop Events

Event Timer

Distribution Amplifier
(Symmetricom 6502)

10 MHz

MOBLAS 7

Used for synchronized LRO tracking

10 MHz

2 kHz & 1 PPS

GPS Time and Freq. Rcvr.

ICC Computer

Computer Clock Sync Interface

10 MHz & 1 PPS

Servo Controller

Range gate:
SLR 2 kHz
LRO 28 Hz

Range Gate Generator

2kHz

2 kHz & 1 PPS

GPS Time
(hh:mm:ss)

Start Diode

28 Hz Laser Fire
Window/Window
MCP Window

VME Chassis | POP | DAM

LRO Laser

28 Hz Fire Time
Adjusted 2 kHz
Fire Time

I/O Chassis (HTSI)

Laser Fire

NASA mJ Laser

Dome Controller

Weather Instruments

Risley Prisms

MVP Controllers

2 kHz & 1 PPS

Laser Fire

Current Optical Bench Layout

DRAWING NOTES:

- xx Controlled by DAM
- xx Controlled by the I/O Chassis

1. System Focus (Motorized negative lens)
2. Alignment Cube
3. Star CAM Insertion Mount*
4. LRO Laser Insertion Mount
5. Risley Prisms (Set of 2)
6. Star Camera Beam Expander
7. Star Camera Flip Filter (1 ND, Manual)**
8. Star Camera ND Filter (Manual)**
9. Star Camera (with 1" Focal length lens)
10. Transmission Beam Expander
11. Periscope Mirrors
12. Start Diode
13. Turning Mirror (Typical)
14. Polarization Rotator
15. Detector (Quadrant or Single MCP)
16. Manual ND filter holder
17. Field of View / Iris
18. *Unused*
19. 900 mm Lens (Extended Focal Length)
20. Day/Night/Twilight Bandpass Filter
21. Optical Path Length Comp.
22. *Unused*
23. Light Tight Enclosure
24. Shutter for MCP (future)
25. Flip ND Filter for MCP (4-5 ND) (future)
26. Flip Eye-safe / Ground Cal. ND Block (2 ND)
27. Flip Beam Block
28. Auto Collimator

Δ! The mount used changes with the MCP. The mount used with the Photek is shown.

SLR 2 kHz Laser

Caution Strong Magnets

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
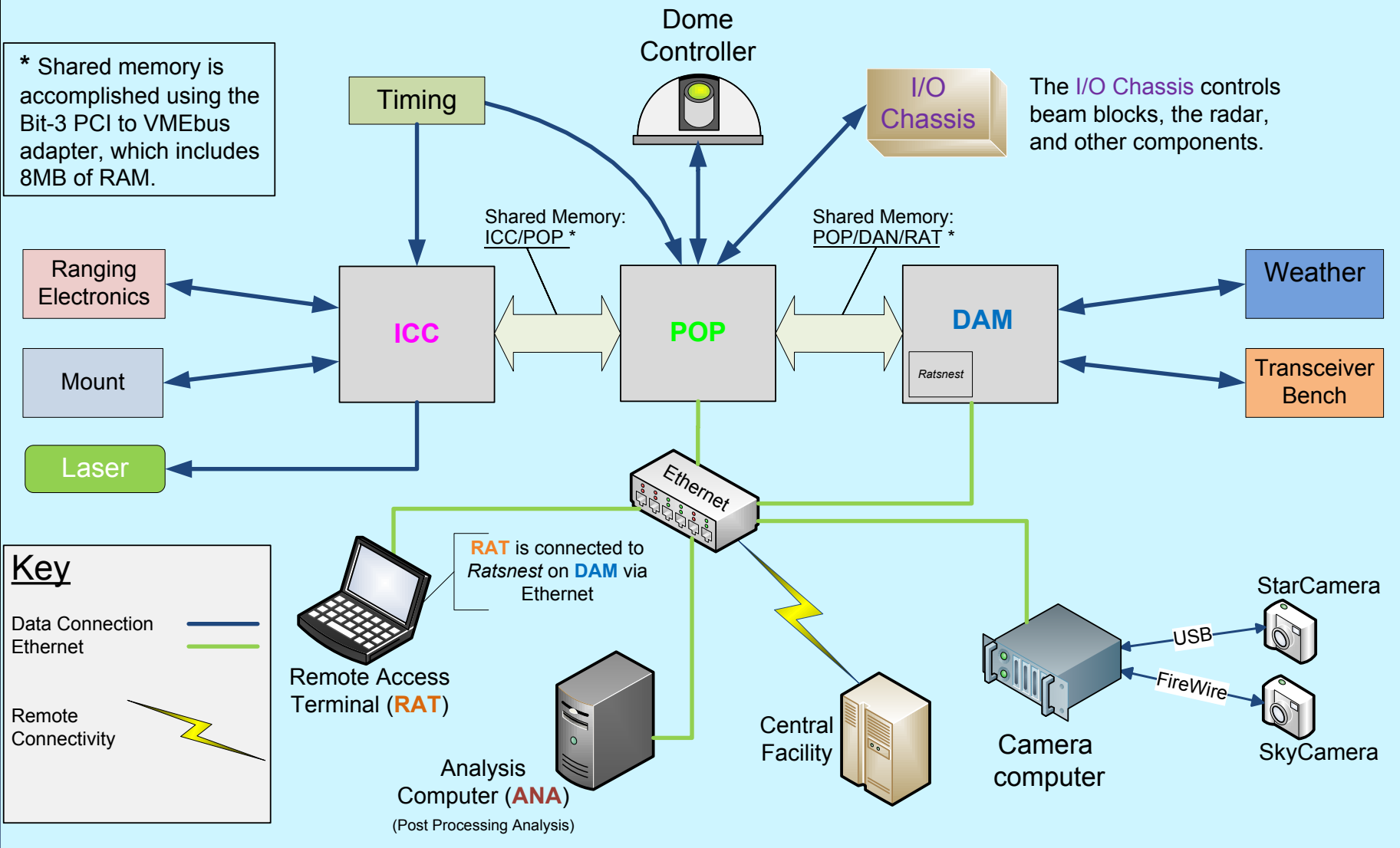
- Backplanes: VME, PCI, ISA.

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

NGSLR Computer Interfaces

* Shared memory is accomplished using the Bit-3 PCI to VMEbus adapter, which includes 8MB of RAM.
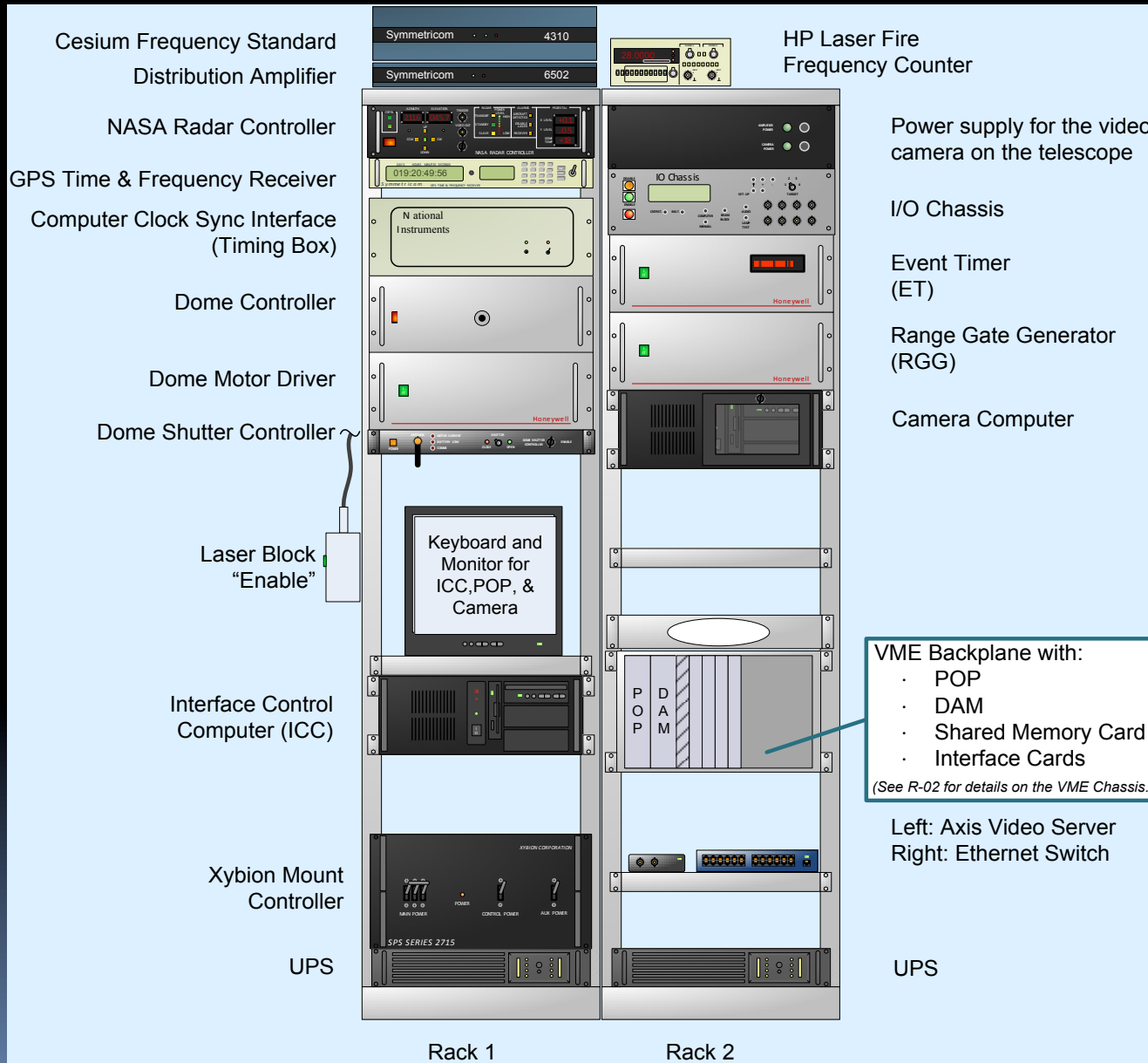
Dome Controller

I/O Chassis

The I/O Chassis controls beam blocks, the radar, and other components.

Timing

Shared Memory: ICC/POP *

Shared Memory: POP/DAN/RAT *

Ranging Electronics

Mount

Laser

ICC

POP

DAM

Ratsnest

Weather

Transceiver Bench

Ethernet

RAT is connected to *Ratsnest* on **DAM** via Ethernet

Key

Data Connection
Ethernet

Remote Connectivity

Remote Access Terminal (**RAT**)

Analysis Computer (**ANA**)

(Post Processing Analysis)

Central Facility

Camera computer

USB

FireWire

StarCamera

SkyCamera

Computer & Equipment Racks

Cesium Frequency Standard

Distribution Amplifier

NASA Radar Controller

GPS Time & Frequency Receiver

Computer Clock Sync Interface
(Timing Box)

Dome Controller

Dome Motor Driver

Dome Shutter Controller

Laser Block
"Enable"

Interface Control
Computer (ICC)

Xybion Mount
Controller

UPS

Symmetricom · · · 4310

Symmetricom · · · 6502

Keyboard and
Monitor for
ICC, POP, &
Camera

HP Laser Fire
Frequency Counter

Power supply for the video
camera on the telescope

I/O Chassis

Event Timer
(ET)

Range Gate Generator
(RGG)

Camera Computer

VME Backplane with:
· POP
· DAM
· Shared Memory Card
· Interface Cards
(See R-02 for details on the VME Chassis.)

Left: Axis Video Server
Right: Ethernet Switch

UPS

Rack 1   Rack 2

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.

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.
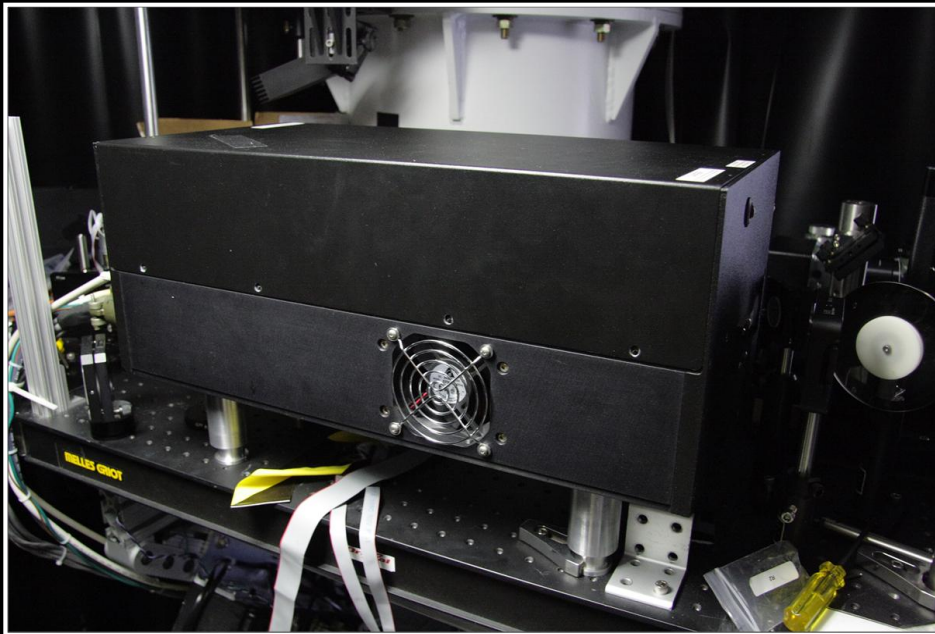
STATUS

Original System Configuration
Q-Peak Laser and Photek QMCP

Q-Peak Laser:

- Model MPV-2000, doubled YVO_4
- 200 µJ, 532 nm, 350 ps, 2 kHz, 0.9 x 1.8 mR, 1.1 x 0.5 mm Ø
- Rationale for Replacement
  - Laser performance degraded – energy decreased from 200 µJ to 60 µJ
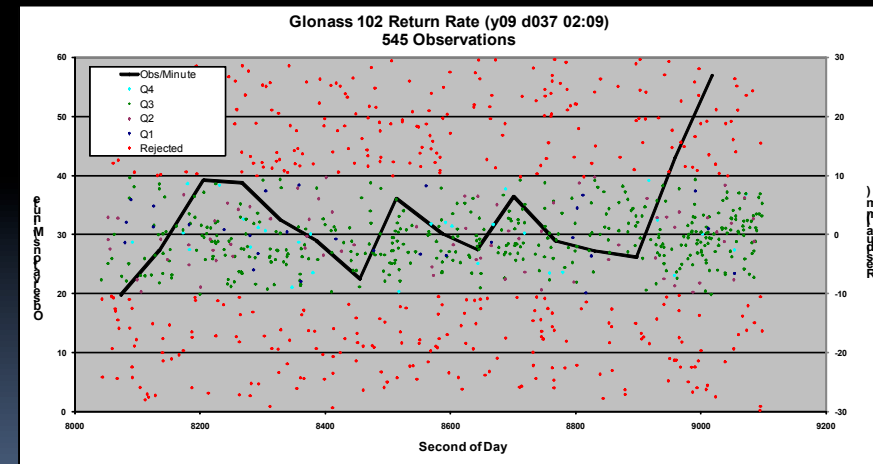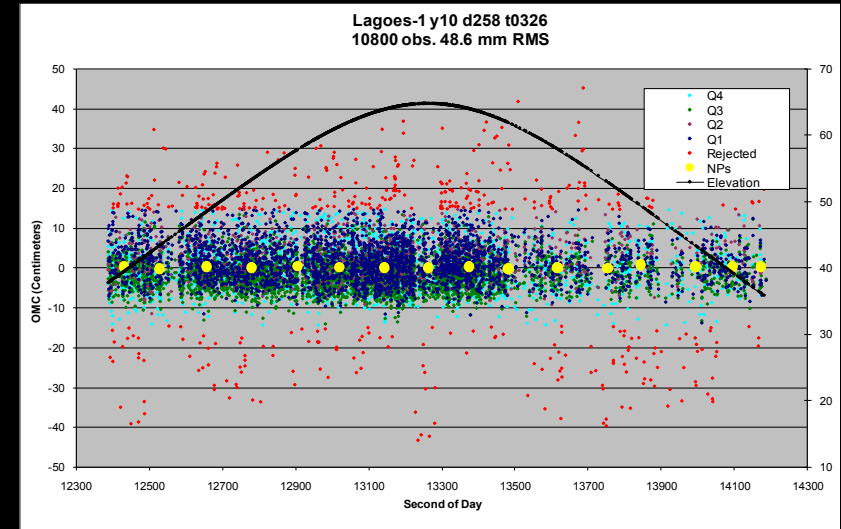 - Daytime GNSS tracking requirement necessitated increased energy

Photek QMCP Installation:

- Quadrant Anode, 12% QE, 140 ps t_r
- Rationale for Replacement
  - QE decreased from 12% to <6%
  - New technology MCPs have High QE >30%

NGSLR Performance with Q-Peak Laser

- **Q-Peak Laser**
    - Low energy/eye-safe
    - 2KHz repetition rate
    - 350 ps pulsewidth
- **NGSLR Successful Tracking with Q-Peak Laser**
    - LEO (day/night):
        - BEC, Jason, Ajisai, Starlette, Stella
    - Lageos 1 & 2 (day/night)
    - HEO (night)
        - Etalon, GLONASS
- **NGSLR System Performance**
    - Ground Cal RMS: 20mm
    - Lageos Single Shot RMS: 40 mm
    - Lageos Normal Point RMS: mm's
    - Ground cal stability: +/- 5mm
    - Bias between NGSLR and MOB-7: ~2 cm

Lagoes-1 y10 d258 t0326
10800 obs. 48.6 mm RMS

Glonass 102 Return Rate (y09 d037 02:09)
545 Observations

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**
    - Open/close of dome 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

- **Being worked**
    - Remaining optical bench motor controls
    - New I/O chassis software interface
    - Closed loop tracking (optimizing biases during tracking)
    - Fully automated ground calibration

NGSLR Documentation

- **Production of Documentation is proceeding as planned**
- **All critical documentation will be updated before December 2012, documenting the NGSLR system in its final state.**

NGSLR Documentation Schedule

| Document Number	Title	Year	Description
NASA-NGSLR-OPS-LRO(v1.5)	LRO-LR Operations Manual (LRO-LR Only)	*5/1/2010*	**Preliminary version completed**
NASA-NGSLR-DWG-06	NGSLR - System Drawing Set	*4/1/2011*	**Preliminary version completed**
NASA-NGSLR-HWR-Manual	NGSLR - Hardware Manual	*4/1/2011*	**Preliminary version completed**
NASA-NGSLR-SWR-Prog.Manual	NGSLR - Programmer's Manual (Eyesafe)	*4/1/2011*	**Preliminary version completed**
NASA-NGSLR-OPS-NGSLR(v0.6)	NGSLR - Operations Manual (EyeSafe)	*7/1/2011*	**Preliminary version completed**
NASA-NGSLR-SWR-RAT.Manual	NGSLR - RAT User's Manual	*7/1/2011*	**Preliminary version completed**
NASA-NGSLR-DWG-07	NGSLR - Engineering Drawings for Automation of Optical Bench	*10/1/2011*	*Projected completion date*
NASA-NGSLR-HWR-SysAlign	NGSLR - System Alignment, Focus, and Maintenance Manual	*11/1/2011*	*Projected completion date*
NASA-NGSLR-HWR-Dome	NGSLR - Dome Guide	*1/1/2012*	*Projected completion date*
NASA-NGSLR-SWR-LR Schedule	NGSLR - Laser Ranging Schedule	*2/1/2012*	*Projected completion date*
NASA-NGSLR-SWR-PostProces.Manual	NGSLR - Post Processing Manual	*3/1/2012*	*Projected completion date*
NASA-NGSLR-SWR-Misc.Soft.	NGSLR - Miscellaneous Software Guide	*4/1/2012*	*Projected completion date*
NASA-NGSLR-SWR-Camera	NGSLR - Star Calibration and Sky Camera Software Guide	*5/1/2012*	*Projected completion date*
NASA-NGSLR-HWR-SysInterface	NGSLR - System Interface Manual and Drawing Set	*7/1/2012*	*Projected completion date*
NASA-NGSLR-HWR-SysTiming	NGSLR - System Timing Manual	*7/1/2012*	*Projected completion date*
NASA-NGSLR-INT-Overview	NGSLR - General Systems Overview	*8/1/2012*	*Projected completion date*
Bring all manuals up to Version 1.0		*12/1/2012*	Update all manuals
Post 2012			
NASA-NGSLR-HWR-Install	NGSLR - Hardware Installation Manual	*TBD*	*Date indicates a preliminary revision*
NASA-NGSLR-SWR-Installation.Manual	NGSLR - Software Installation Manual	*TBD*	*Date indicates a preliminary revision*
NASA-NGSLR-SWR-Scripts	NGSLR - Scheduling and other System Scripts	*TBD*	*Date indicates a preliminary revision*
NASA-NGSLR-SWR-Sim.Manual	NGSLR - Simulation Software Manual (ICC, RAT, POP, DAN)	*TBD*	*Date indicates a preliminary revision*
NASA-NGSLR-SWR-Sys.Admin	NGSLR - System Administration & Maintenance Manual	*TBD*	*Date indicates a preliminary revision*

The Path to Completion

In-house built 2 kHz laser
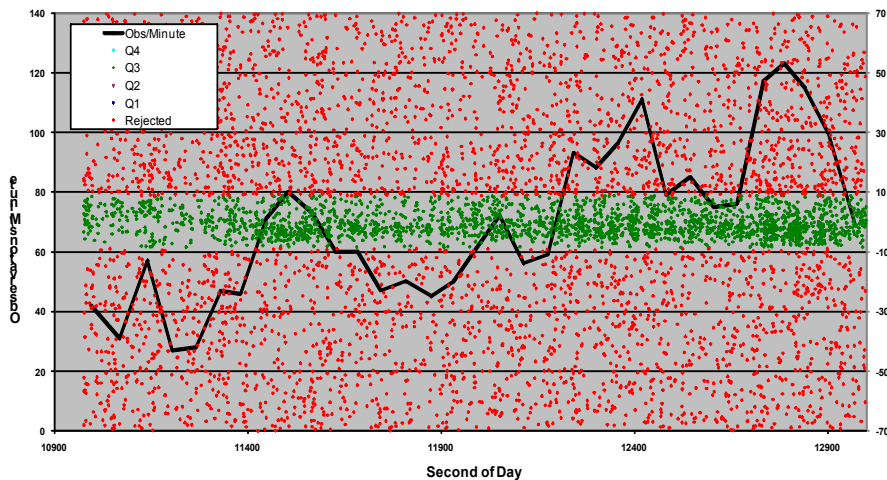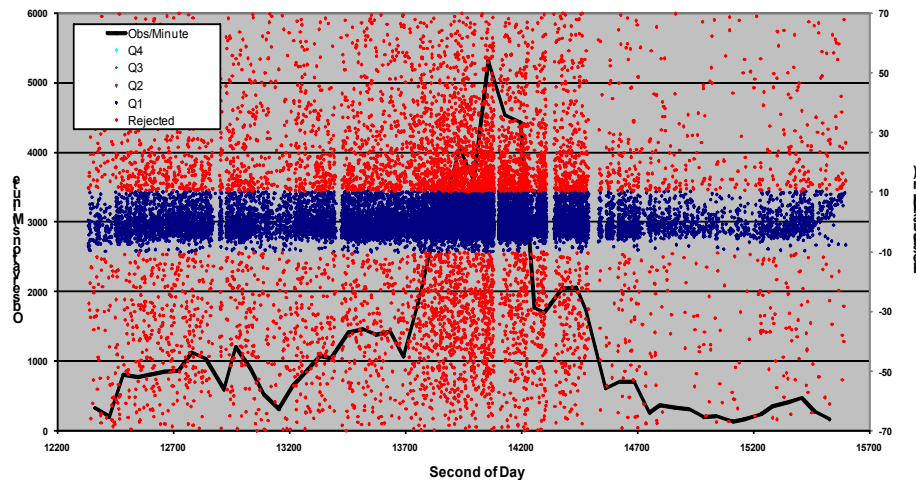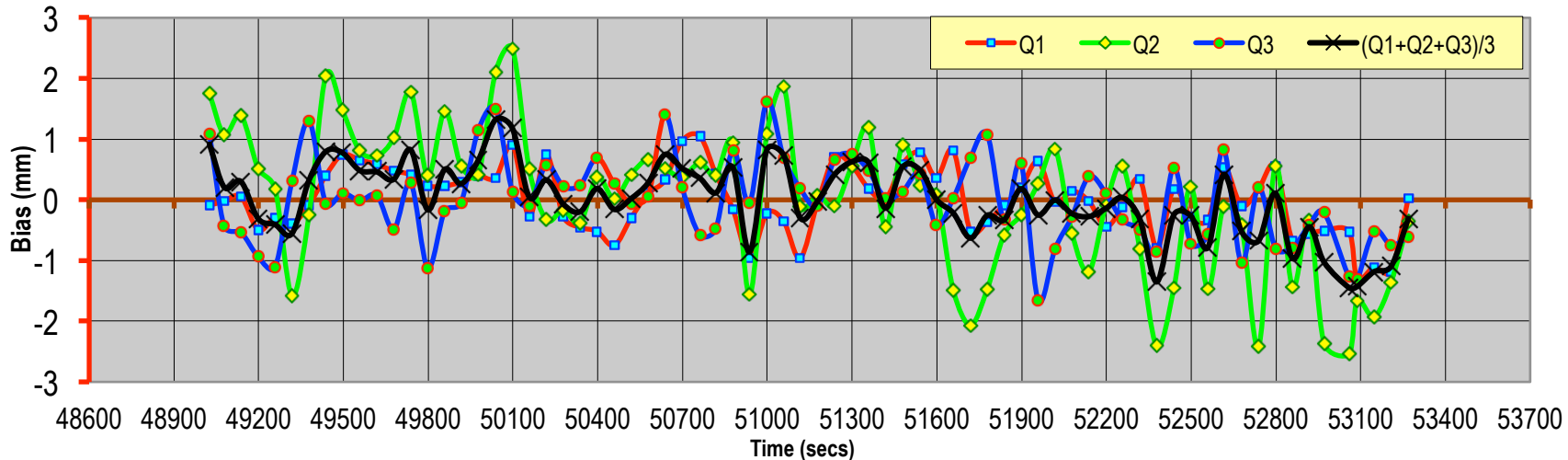## Regenerative amplifier seeded by a gain-switched diode laser
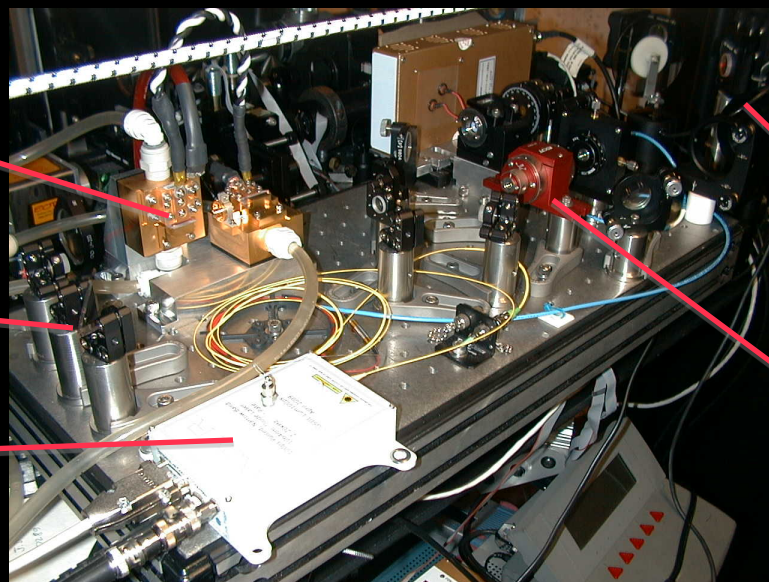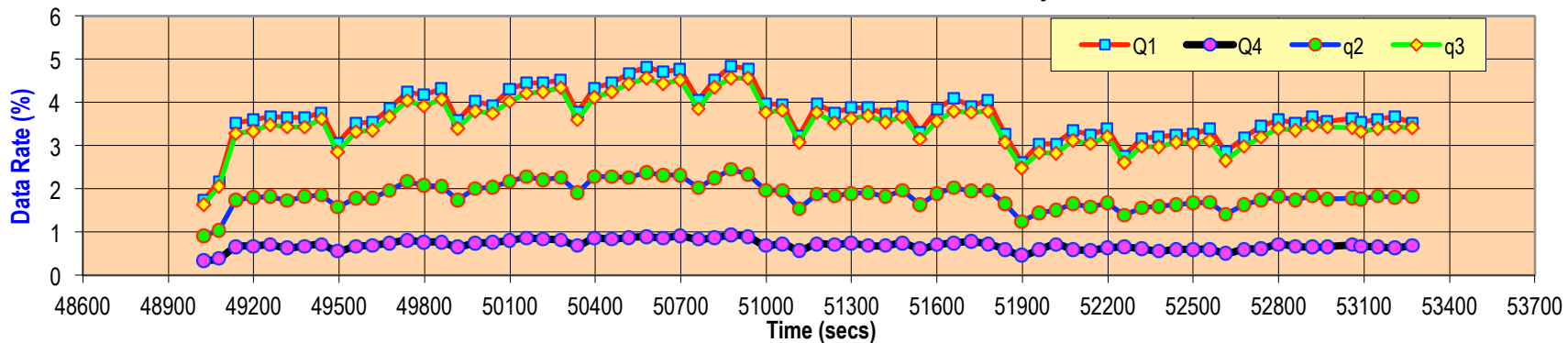
System Stability Results
Ground calibration data using Photek quadrant detector

Ground Cal-Ch1, Ch 2, Ch3, -(Ch1+2+3)/3-2kHz-Photek MCP-PMT-75min - Stability: March 23-2011-d82-t1336

Ground Cal-1mJ Laser-Ch1, 2,3,4-2000 Hz-Photek MCP-PMT- 75 min - Stability: March 23-2011-d82

- **External Cal Data Session Stability**: Plot of External Cal Residual (millimeter) and Data Rate (%) vs. Time for a duration of 75 minutes; 4th channel (BLACK line) in the upper plot shows the mean of 3 channels; Lower plot shows the data rates for each of the Q1 thru Q4 Channels; Horizontal scale is 5 minutes

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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
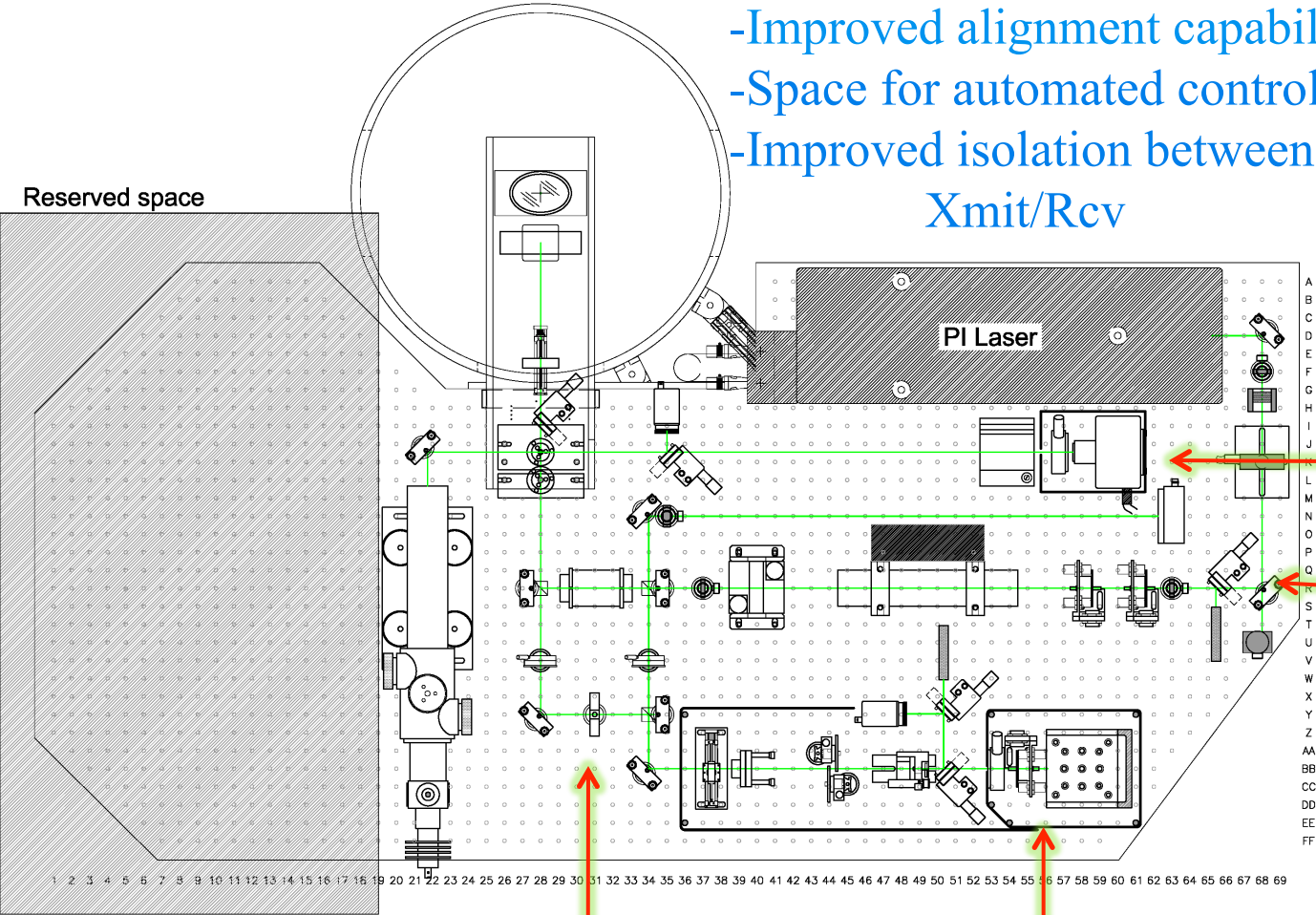 - -Allows work to go on without disturbing NGSLR tracking

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

New Optical Bench

Reasons for new design:
-Improved alignment capability
-Space for automated controls
-Improved isolation between
Xmit/Rcv

Reserved space

PI Laser

Star Camera

Xmit Path

T/R switch

Detector

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.
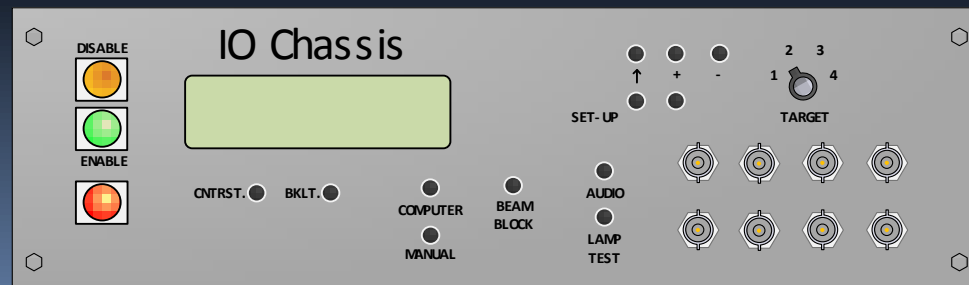
Software Development and Testing
(Using NGSLR Automation Lab)

- 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

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

Laser will not be available for use until early 2012

NGSLR Collocation with MOBLAS-7

- **What is a Collocation?**
  - Collocation is the process of geometrically comparing ranging data from two or more SLR systems in close proximity (preferably <60 meters) by simultaneously ranging to common targets, ground and satellite based.

- **Why do Collocation?**
  - Collocation analysis is the best engineering tool available for rapid identification of sub-centimeter systematic error sources.
  - Because the Collocation technique was used extensively prior to deploying the Heritage NASA Network, it is probably the reason that the NASA SLR systems have performed with so few biases since the mid-1980's. The NASA SLR systems are still considered some of the best in the world.

- **NGSLR / MOBLAS-7 Collocation will establish criteria for, and verify:**
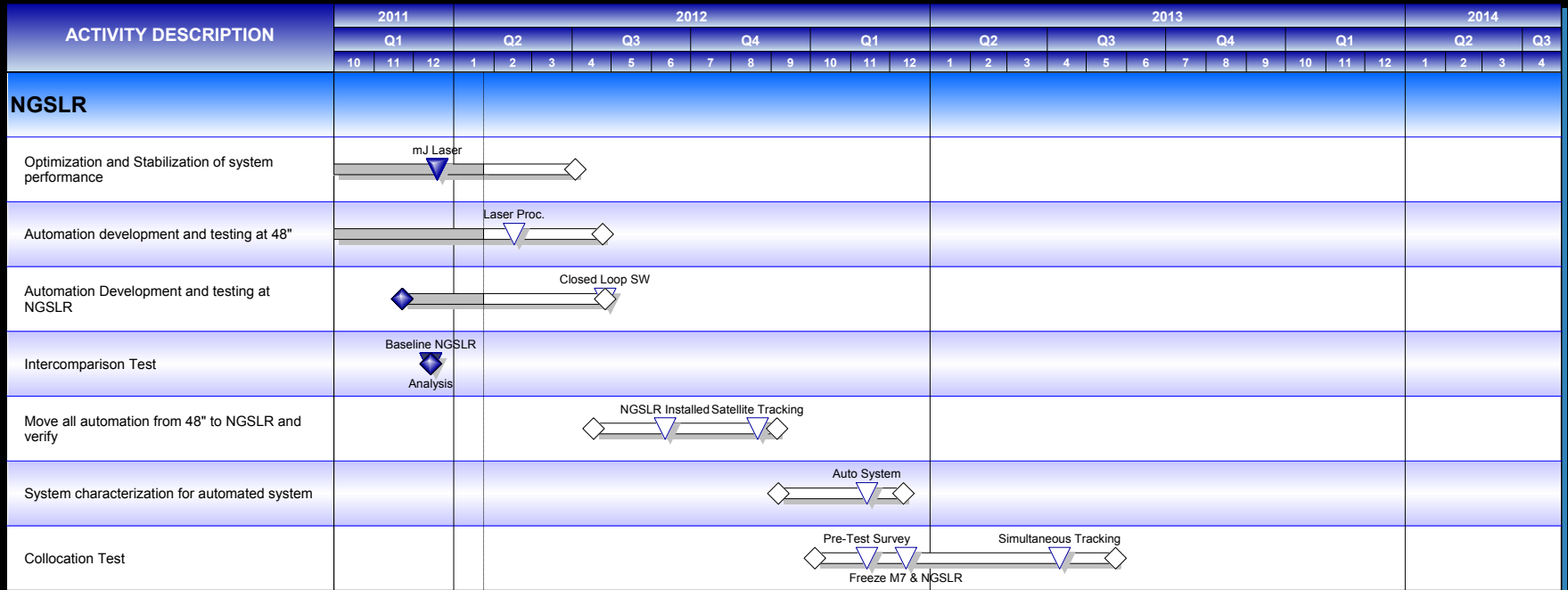 - System Stability
  - System Precision
  - System Accuracy
  - System Timing
  - System Bias

NGSLR Schedule to Completion

Space Geodesy Project

ACTIVITY DESCRIPTION	2011			2012																			2013																		2014			
	Q1			Q2			Q3			Q4			Q1			Q2			Q3			Q4			Q1			Q2			Q3	
	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4

NGSLR

- Optimization and Stabilization of system performance — mJ Laser
- Automation development and testing at 48" — Laser Proc.
- Automation Development and testing at NGSLR — Closed Loop SW
- Intercomparison Test — Baseline NGSLR / Analysis
- Move all automation from 48" to NGSLR and verify — NGSLR Installed Satellite Tracking
- System characterization for automated system — Auto System
- Collocation Test — Pre-Test Survey / Simultaneous Tracking / Freeze M7 & NGSLR

SUMMARY

- **Most of the original goals for SLR2000 have been achieved.**
- **Significant progress has been made in performance and automation.**
- **LEO to LAGEOS ranging demonstrated day & night with eye-safe energies.**
- **GNSS tracking demonstrated at night with eye-safe energies.**
- **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, …

- **NGSLR lab has been setup - allowing parallel progress in automation, software checkout and system performance.**
- **Significant progress on documentation – have initial version of several major system documents & drawings.**