Improvements at NASA's NGSLR in support of GNSS ranging

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Abstract:

In the quest for daylight ranging to GNSS satellites at NGSLR, we have replaced our laser with one that is capable of transmitting anywhere from eyesafe levels to near 1 milliJoule at 2 kHz rates. We have a new high QE (40%) Hammamatsu single anode detector, and we are working on reducing the laser backscatter and possibly adding a sun shield to the telescope. In addition we maintain the laser divergence at 4 arcseconds (FWHM) and use a Risley Prism pair to point the laser ahead of the telescope so that we can reduce the field of view during daylight to approximately 11 arcseconds. Results from recent GNSS passes will be presented.

16-20May2011-TZ&JM/NASA

NGSLR Background & Status – Pre 2011

- System has a requirement to demonstrate totally automated operations:
    - In US only way to do this is with eyesafe system due to FAA restrictions,
    - Eyesafe laser at 532nm requires longer pulsewidth (~300 ps) and low energies (<120 microJoules).

- In this eye-safe configuration, NGSLR has successfully ranged to multiple GLONASS and ETALON passes at night above 60 degrees elevation, and many LAGEOS passes during both night & daylight down to 20 degrees.

- NGSLR uses common optics for transmit & receive.

- Many issues had to be addressed to get to this point:
    - Track with a laser divergence of 4 arcsec.
    - Set field of view of 11 arcseconds for daylight ranging.
    - Point transmit and receive paths separately to maintain both divergence and field of view (using Risley Prism pair updated at 2 hz).
    - Develop passive polarizing T/R switch.
    - Vary PRF of laser to avoid collisions of transmit & receive pulses.
    - Work to eliminate laser backscatter from optics.
    - Generate very good starcals (2-3 arcsec).

Daylight Ranging to GNSS

• Both because of NASA HQ requirement in 2010 and as part of the new Fundamental Multi-Technique system at Goddard, NGSLR must track GNSS satellites during daylight.

• Eye-safe configuration of system probably isn't capable of daylight GNSS. New higher per pulse transmit power laser needed.

• New laser is in-house built by Coyle and Poulios (team that has built many lasers for Goddard, for airborne and spaceborne applications).
- Keeps eye-safe capability (can dial energy from 100 microJoules to 1 mJ).
- Provides daylight capability of reaching GNSS with ILRS standard array.
- Pulsewidth currently 200 ps but can be changed to 350 ps.
- Form fits into existing space on optical bench.

• Also purchased 40% QE Hammamatsu single anode detector to try in place of Photek 12% QE detector.

► Total effective gain in system capability: ~ x30
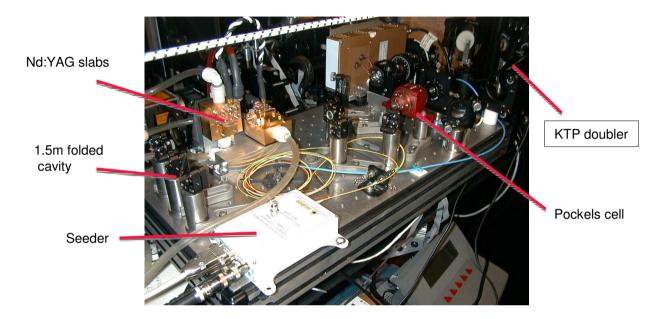
Laser upgrade

The original SLR2000 eyesafe laser is a 1064nm passively Q-switched microchip laser (Northrop Grumman Synoptics) with an energy of 15uJ per pulse. A proprietary diode pumped multi-pass designed Q-Peak amplifier raises the output energy, and when doubled, produces ~250uJ at 532nm. The NASA mJ laser uses a regenerative amplifier seeded by a fiber optically coupled gain-switched diode laser. The regenerative amplifier cavity is 1.5 m long and utilizes a Pockels cell to switch out a single pulse when reaching maximum energy. The folded 1.5m long cavity design enabled a package size small enough to fit within the Q-Peak footprint and avoid a NGSLR system redesign.

	Q-Peak Laser	GSFC mJ laser
Energy	~100 uJ	<1mJ
Pulsewidth	350 psec	200 psec
Wavelength	532nm	532nm
PRF	2 KHz	2 KHz
Divergence (final)	5-8 arcsec	4 arcsec

Laser upgrade

Nd:YAG slabs

1.5m folded cavity

Seeder

KTP doubler

Pockels cell

The laser was built by Barry Coyle of Goddard and Demetrios Poulios of American University. It utilizes a regenerative amplifier seeded by a gain-switched diode laser. The regenerative amplifier cavity is 1.5 m long and utilizes a pair of Nd:YAG zigzag slabs in a crossed-head configuration as the gain medium. A pulse from the diode seeder is trapped in the regenerative amplifier cavity using a Pockels cell, where it can make 10s - 100s of passes through the gain medium. When the pulse reaches   its maximum energy, it is then switched out and directed through a KTP frequency doubler. The regenerative amplifier system is designed to run at a repetition rate of 2 kHz with ~1 mJ/pulse at 532 nm and a ~200ps pulse width.

Detector upgrade

The quadrant PMT used at NGSLR is a 3 stage Photek model PMT308Q with a 12% Q.E. quardant photocathode. The gain is 3×10^5 with a rise time of ~180 psec and a transit time spread of ~45 psec. The single element Hamamatsu model R5916U has a 40% Q.E., gain of 3×10^5, rise time of 178 psec, and a transit time spread of ~136psec.

Photek model PMT 308Q

Hamamatsu model R5916U

Noise reduction

- All optical surfaces in the transmit and receive path are AR coated for 532nm and are kept clean. Backscatter into the MCP detector is minimized by introducing a small angular tilt in all outgoing optical surfaces in which the laser must pass through. This enables effective spatial filtering in the receive FOV iris. Efficient beam dumps (>99% absorption) are used where needed and beam paths are baffled to improve isolation.

- Further reduction in back scatter can be effected by use of the liquid crystal optical gate developed for NASA by SigmaSpace.

- Additional solar noise reduction will be done using a narrower range gate, introduction of a solar shield on telescope, and possibly reducing spectral filter (now 0.3 nm) and spatial filter (now 11 arcsec).

Solar Background Noise Suppression

Daytime tracking operations should be improved with the use of a sun shield which will reduce solar noise. The removable assembly consists of thin black anodized aluminum honeycomb cells approximately 5/8 inch diameter and 6 inches in length. The individual cells will reduce the telescope solar background noise by limiting the field of view.
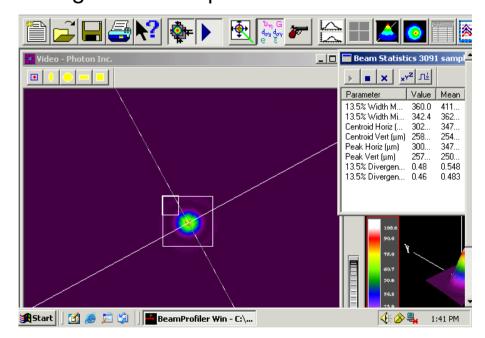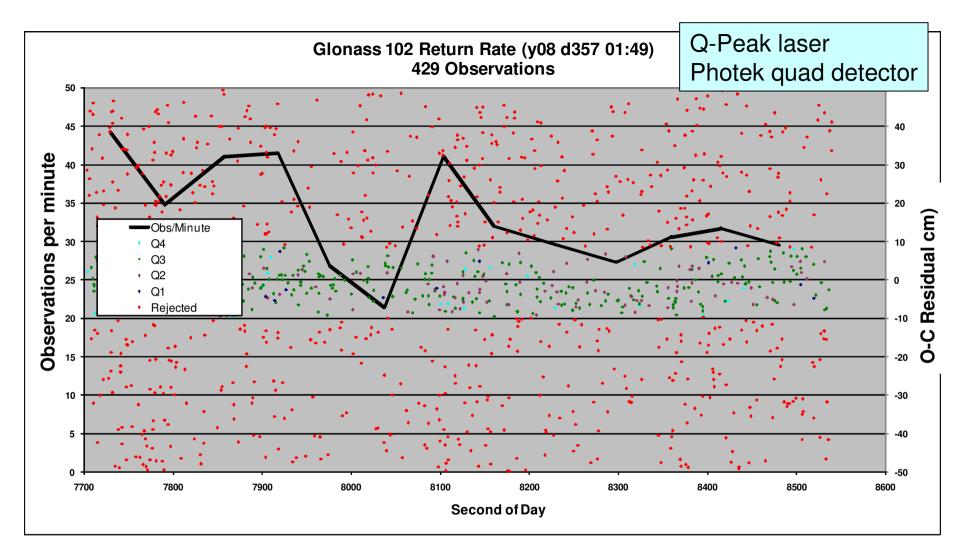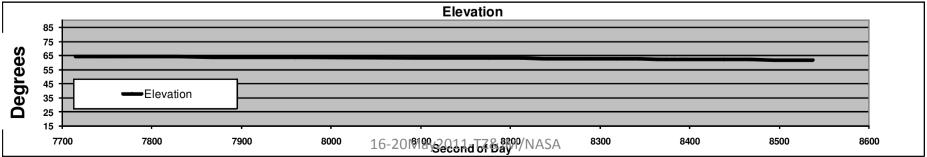

NGSLR sun shield

NGSLR Divergence Measurement

NGSLR raw laser beam divergence is measured by placing a CCD imager (Photon Inc. BeamProfiler) in the focal plane of a long focal length lens (750mm) and measuring the spot size. This image size is a direct measure of the far field laser beam divergence.   Once measured the divergence l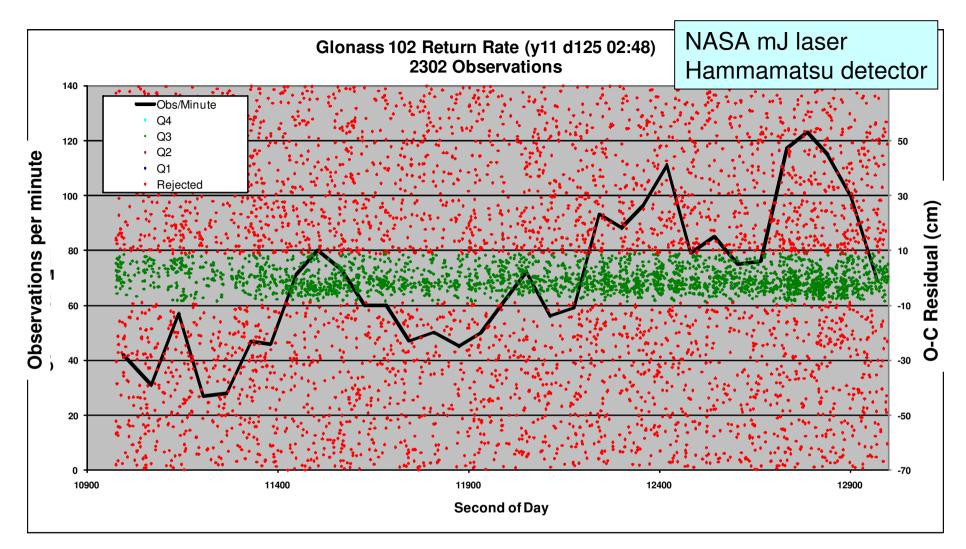eaving the telescope can then be calculated. The NGSLR Telescope has a beam expansion ratio of 28.7 so the final system divergence Is reduced by that factor. These calculations are later confirmed during tracking operations.
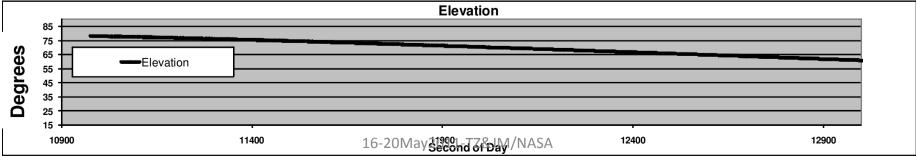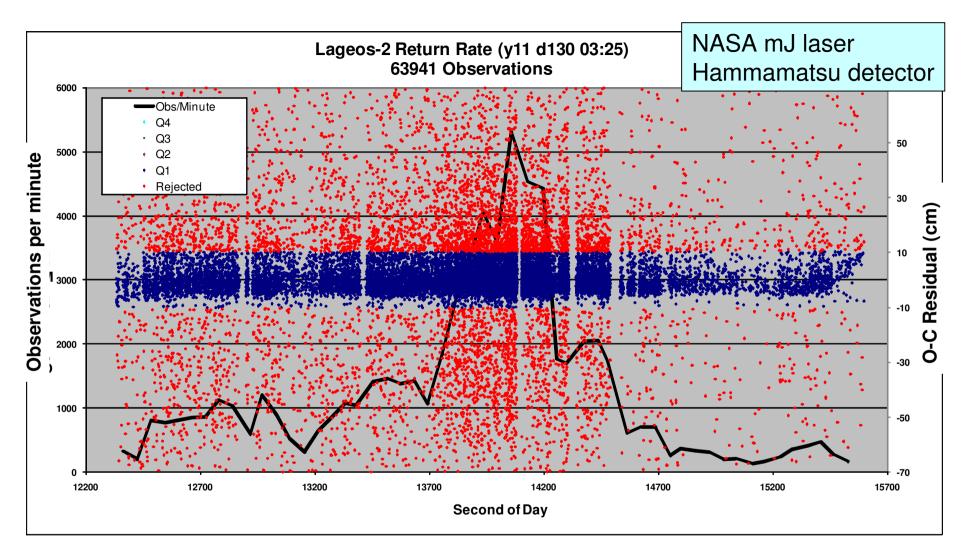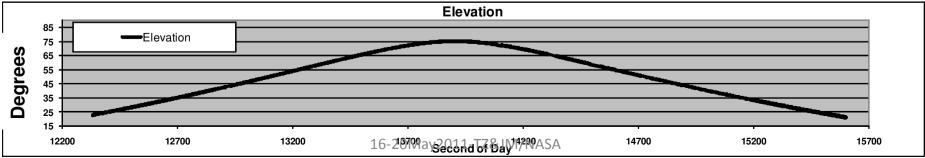
Glonass 102 Return Rate (y08 d357 01:49)
429 Observations

Q-Peak laser
Photek quad detector

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Glonass 102 Return Rate (y11 d125 02:48)
2302 Observations

NASA mJ laser
Hammamatsu detector

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Lageos-2 Return Rate (y11 d130 03:25)
63941 Observations

NASA mJ laser
Hammamatsu detector

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Summary

Successful GNSS daylight tracking at NGSLR will require optimization of the system:

- Laser divergence of nominally 5 arcseconds
- Laser energy of ~1 mJ/pulse or more
- Receiver FOV held to 10 arcseconds or less
- Reduced PMT and discriminator gating to 400 nsec or less
- May need additional optical shuttering of the T/R switch
- Possibly narrower spectral filter
- Good starcal and/or pointing correction

Preliminary look at new laser and detector show:
- Stronger signal rates for GLONASS tracks
- Capability to range to lower elevations for GLONASS
- Promising for daylight GNSS –
        but still more work to be done!