The Collocation of NGSLR with MOBLAS-7 and the Future of NASA Satellite Laser Ranging

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Abstract

In July 2013 NASA's prototype Next Generation Satellite Laser Ranging System (NGSLR) completed a five week successful collocation with the NASA SLR Network station MOBLAS-7. This was the final system test to validate the NGSLR design.

During collocation NGSLR demonstrated its ability to perform day and night tracking to satellites from LEO to GNSS altitudes, even through thin clouds and between thick clouds. The system has tracked almost all of the ILRS satellites from GRACE and TanDEM-X to GLONASS and Galileo. The ground calibration stability was shown to be less than 1 mm RMS over 1-2 hour periods. Preliminary analysis of the system range bias, for the LAGEOS and LAGEOS-2 satellites, shows that NGSLR is somewhat long when compared to the collocated MOBLAS-7 ranges, but is very stable, and this is confirmed by independent analysis performed with SLR Network generated orbits.

NGSLR has performed extremely well and at the required levels for future NASA SLR systems. Within the next year the NGSLR automation will be completed and this prototype system will be made more operational. Future NASA systems are planned to be fabricated in the next few years and these systems will build upon the foundation laid by NGSLR.

NGSLR Overview

System Requirements

- 24 hour tracking of LEO, LAGEOS & GNSS satellites
- One millimeter normal point precision on LAGEOS
- Ground cal stability at the 1mm level over hour
- Successful collocation with MOBLAS-7
- Semi-autonomous operations
- Automated aircraft avoidance laser safety system

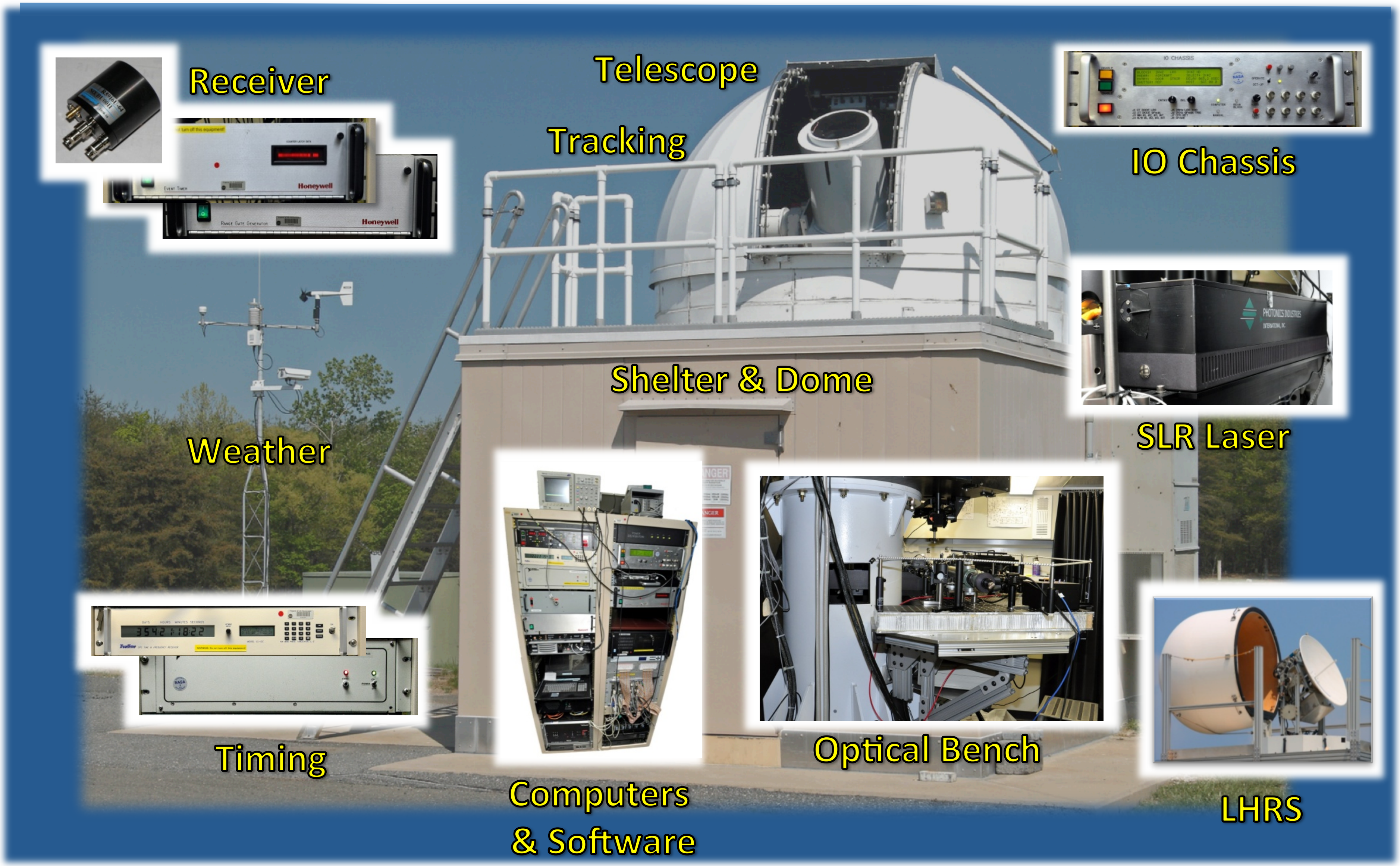
Major Components

1. Shelter and dome
2. Telescope assembly
3. Tracking system
4. Optical bench
5. Laser subsystem
6. Computers & software
7. IO Chassis
8. Time & frequency
9. Receiver subsystem
10. Meteorological system
11. LHRS subsystem

System Schedule

Successful GNSS daylight ranging	Apr 2012
Simultaneous ranging & system performance assessment	June 2012
New optical bench build complete	July 2012
Performance verification of system with new optical bench	Feb 2013
Semi-automated operations demonstrated	June 2013
Collocation w/MOB-7 complete	July 2013

Major Components



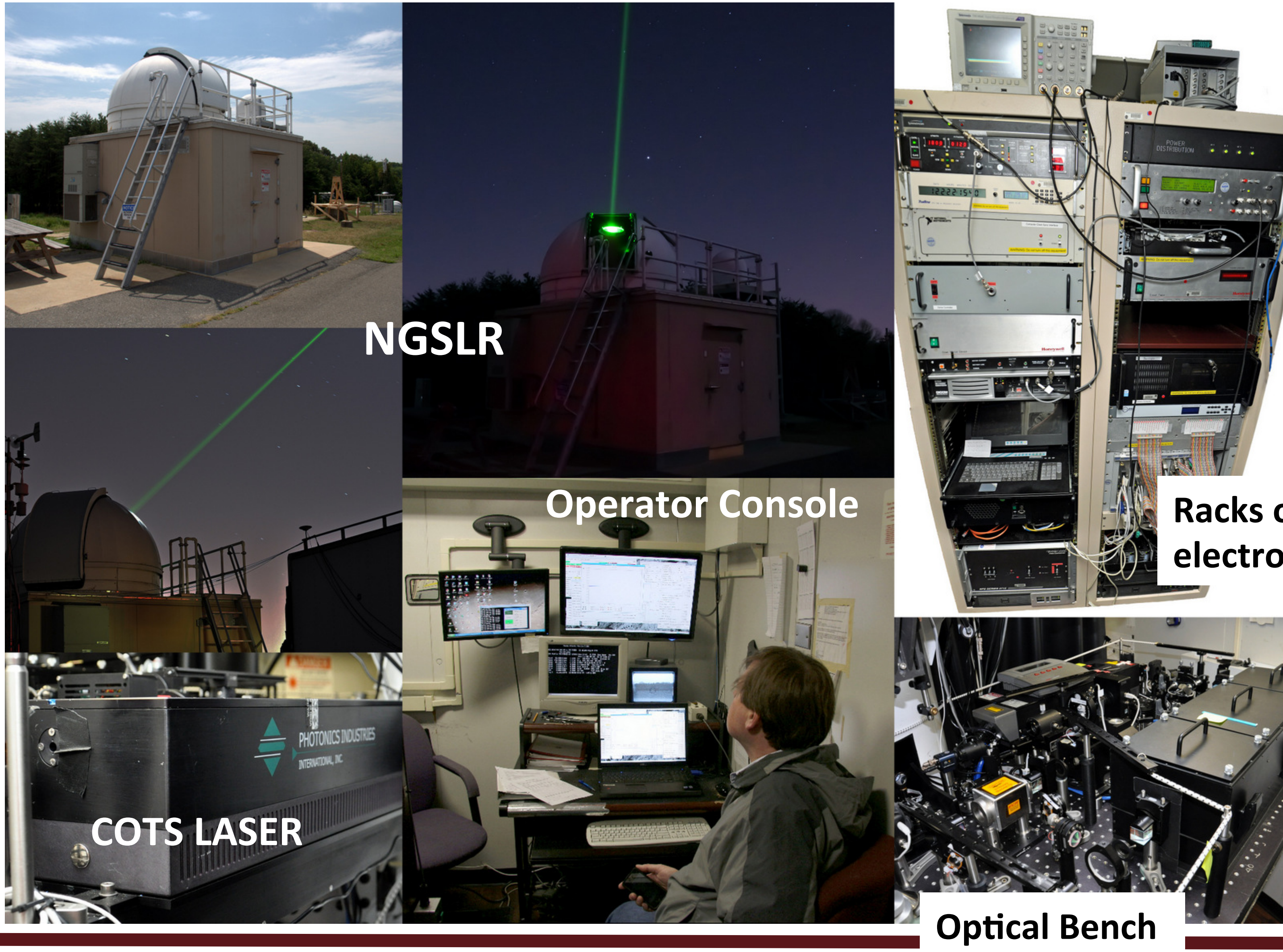
Recent Upgrades to NGSLR

Over the past two years NGSLR has been upgraded to improve performance:

- Replaced in-house built laser with COTS Photonics Industries laser
  - More robust and stable, narrower pulsewidth, easier to use and maintain.
- Entire optical bench redesigned and many of the components replaced
  - Cleaner design, easier to align, greater stability, automation in changing configurations, increased isolation of receive from transmit.
- Interface between laser safety system and software redesigned and rebuilt
  - Allows for system automation and adds more safety checks to system.
- Liquid crystal gating added to system
  - Provides greater reduction in backscatter from transmitter into receiver.
- Tracking automation
  - Software features for real-time signal processing, automated decisions on sky conditions, automated target search, and automated ground calibrations were all advanced significantly and are close to completion.

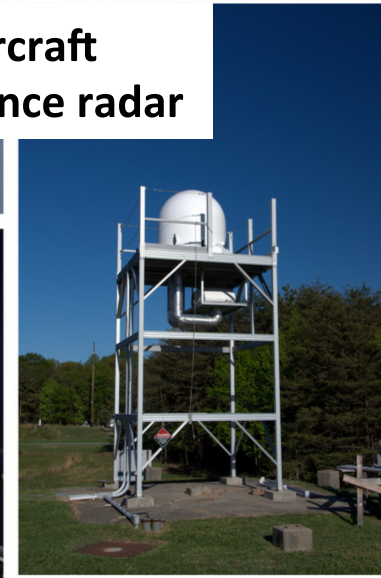
See Donovan talk for more details

NGSLR and Interior Subsystems

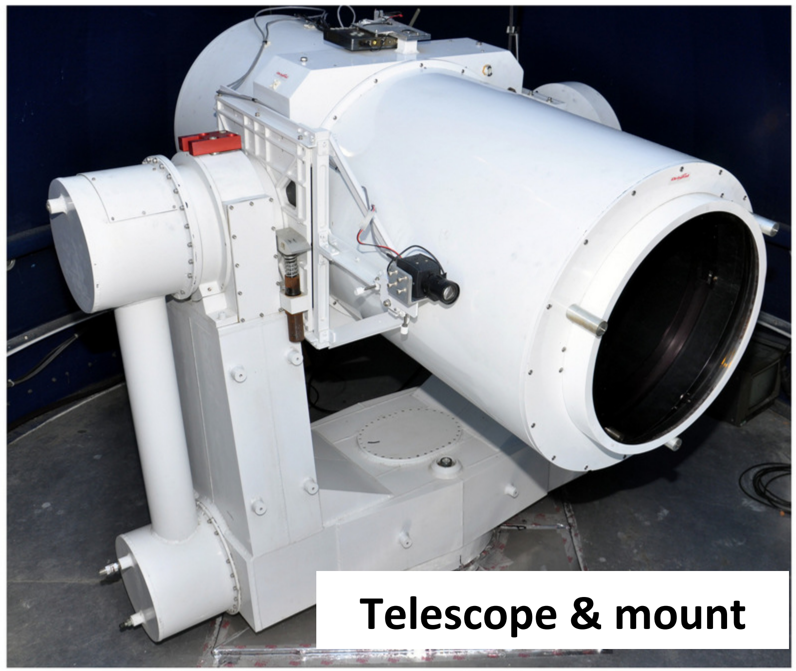


Telescope & Exterior Subsystems

Cloud camera



Aircraft avoidance radar

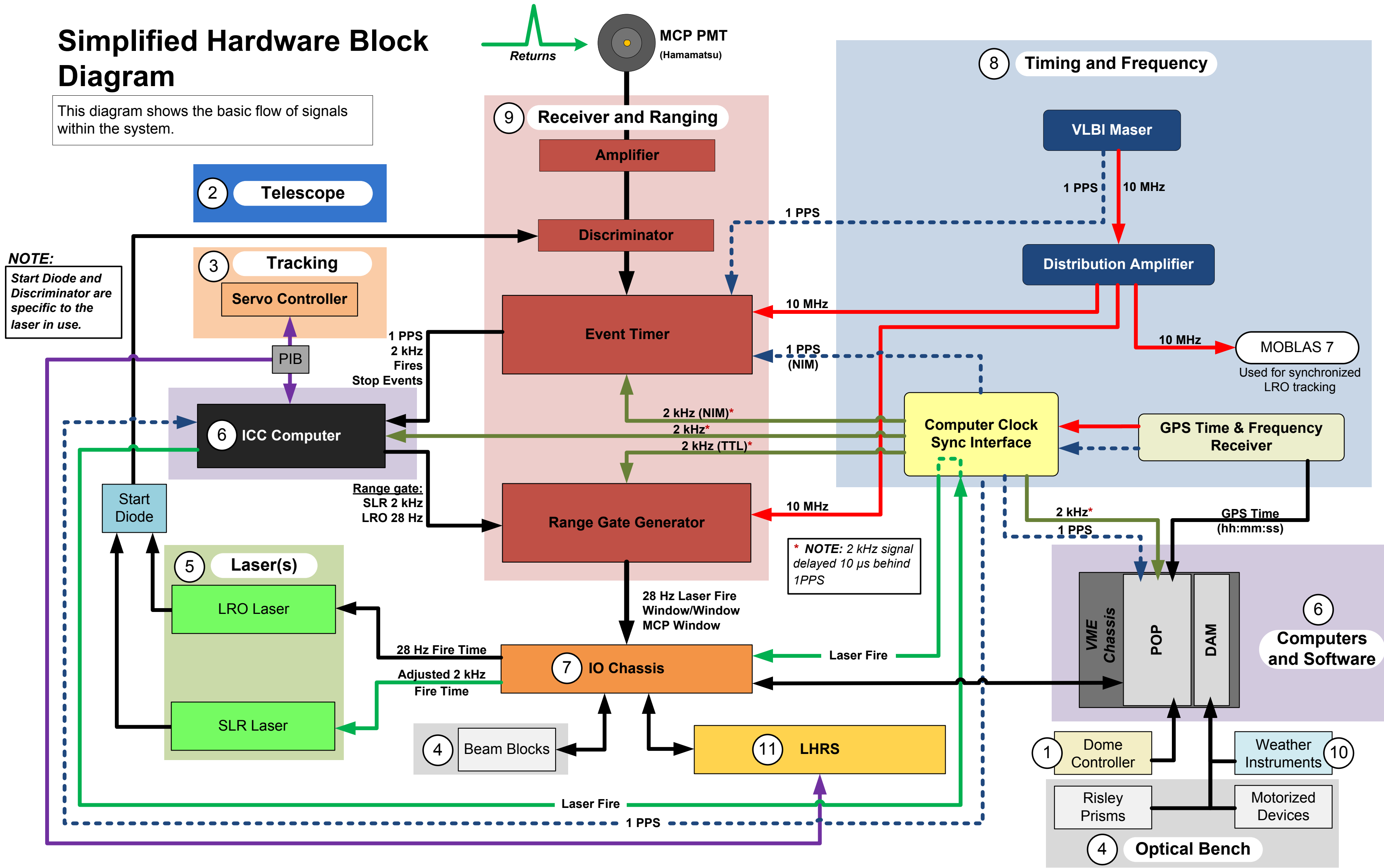


Telescope & mount

Weather instruments

Precipitation & visibility

Current System Block Diagram



Collocation between NGSLR & MOB-7

- **A majority of the ILRS satellites were tracked:**

AJISAI	LARES	GALILEO-103	GRACE-A
BEC	LARETS	GLONASS-109	HY-2A
BLITS	LAGEOS	GLONASS-115	SARAL
COMPASS-M3	LAGEOS-2	GLONASS-122	STARLETTE
CRYOSAT-2	JASON	GLONASS-123	STELLA
ETALON-1	JASON-2	GLONASS-124	TANDEM-X
ETALON-2	GALILEO-101	GLONASS-129	TERRASAR
GOCE	GALILEO-102	GLONASS-130	

- **Robust daylight ranging, including GNSS.**
- **Ground calibration stability RMS < 1 mm for up to 2 hours.**
- **Normal point precision on LAGEOS ~ 1 mm.**
- **Good ranging comparison with MOBLAS-7. Fundamental difference between single photon and multi-photon ranges seen in collocation data – which is predicted by theory.**

- **Collocation period:**
May 29 to July 5, 2013.

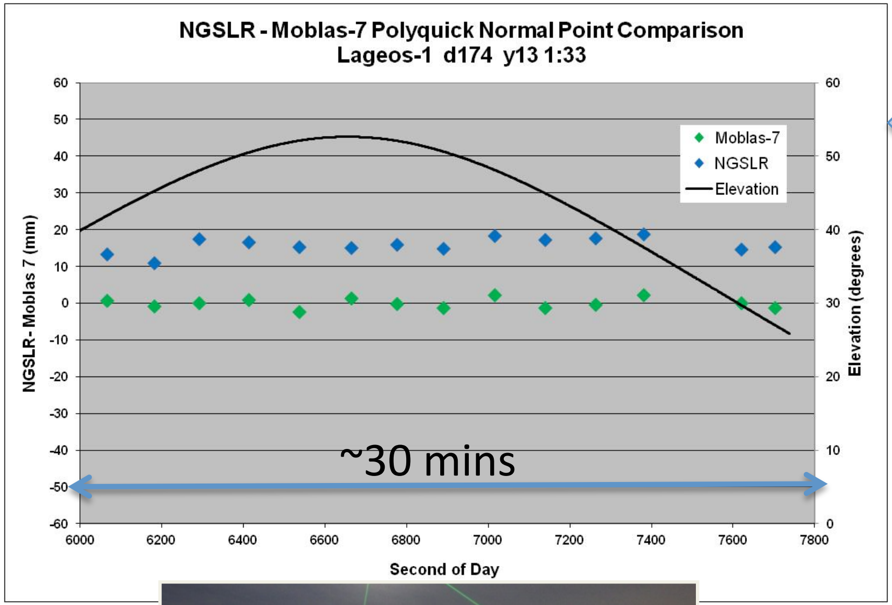
- **Collocation passes:**

	%
Passes with MOB-7	69%
Passes in daylight	82%

	Number
TOTAL	**121**
LAGEOS-1/2	35
GNSS	16
Collocated LAGEOS	28
Collocated GNSS	5

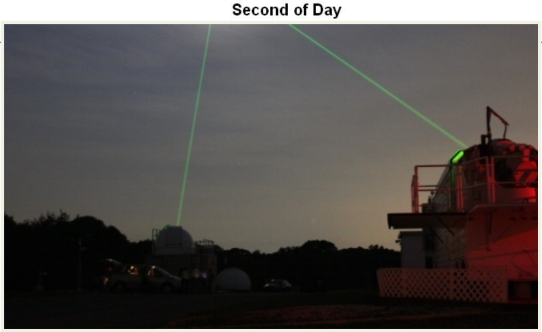
See Horvath/Clarke poster for details

System Performance during Collocation



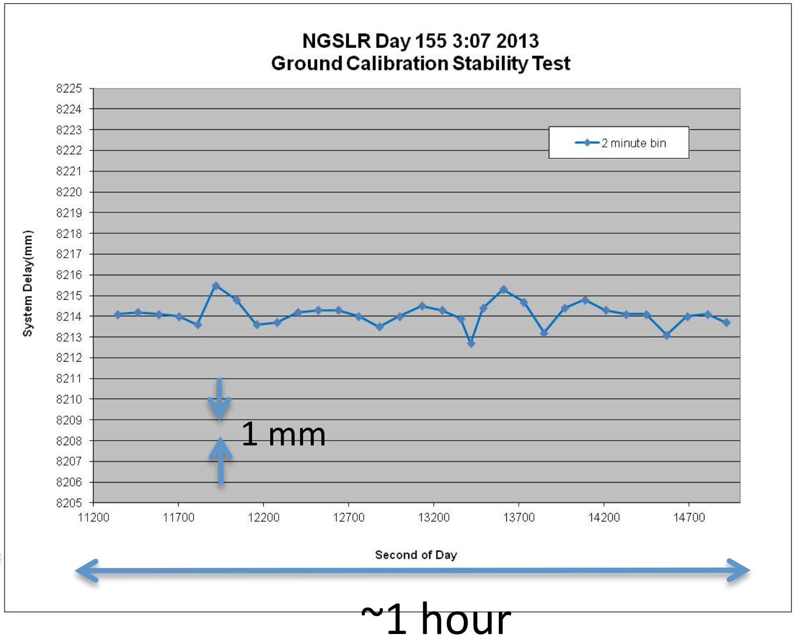
Ranging to LAGEOS satellite:

- LAGEOS normal point period = 2 mins
- NGSLR points in blue; MOB-7 in green
- Good ranging comparison between the two systems. NGSLR ranges are long compared to MOB-7 due to difference between single and multi-photon systems, as predicted by theory.



Ground calibration stability over hour:

- 2 min averages for system delays
- Stable to ~ +/-1 mm. RMS = 0.6 mm



Single Photon vs Multi-photon Ranging

John Degnan analysis ("Effects of detection threshold and signal strength on LAGEOS range bias," Proceedings of 9th Workshop):

- For single photon detection thresholds with small signal strengths, the distribution of the range data has the shape of the convolution of the satellite signature and the instrument impulse response, and the same centroid.
- At higher signal strengths the range centroid is shifted away from the satellite centroid toward the leading edge of the pulse, resulting in a signal strength induced bias.

Theoretical LAGEOS range difference between single photon (NGSLR) & multi-photon (MOB-7) systems:

John Degnan: **13 mm** (bias between (bias between 0.1 and 5 pe detection)

Fan Jianxing / Yang Fumin: **10 mm** (bias between 0.1 and 4 pe detection)

Otsubo / Appleby (2003 Koetzting): **6 to 9 mm** (CoM correction difference)

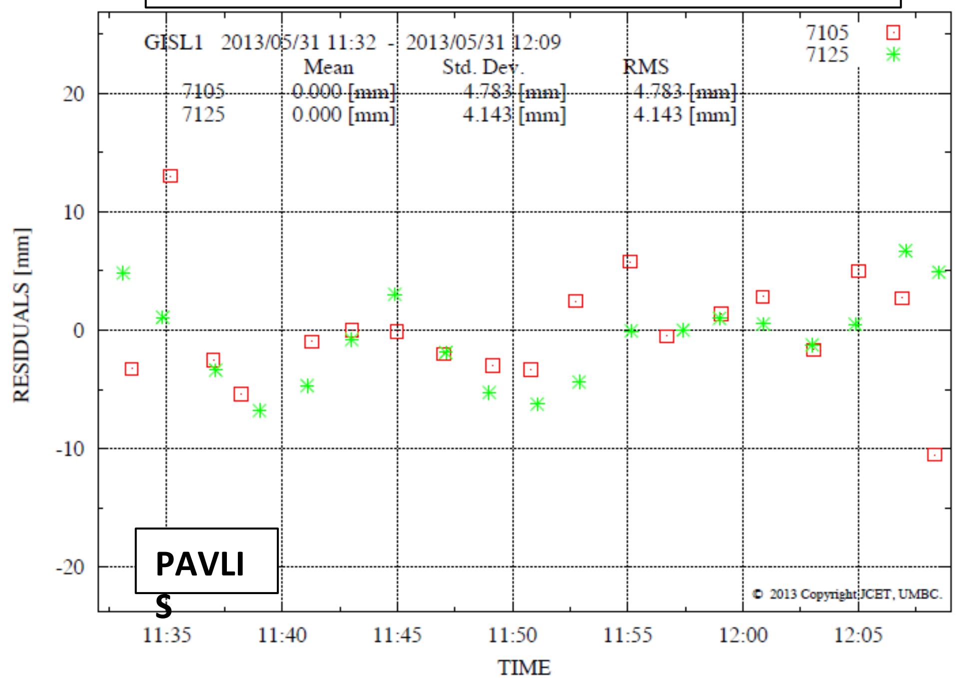
Ranging Comparison to the Network

- NGSLR was originally post-processed with a 1.8*sigma edit filter to use the peak of the data distribution. After collocation revealed that this sigma editing filter caused a bias in the data, the data was then processed with a 3*sigma edit for a very close representation of the centroid of the data. Because of the large amount of noise, some of the weaker passes (which are viable with a 1.8*sigma edit) are no longer viable. Some changes in our post-processing in the future, however, may allow us to pick the weaker passes back up.

- Collocation analysis by Clarke shows NGSLR ranges long from MOBLAS-7's by **~13 mm**. Analysis done only on normal points that overlapped.

- Comparison of NGSLR data to orbit generated from SLR Network by Pavlis (using all normal points) shows NGSLR long by **~16 mm**.

NGSLR & MOB-7 normal points after mean range difference removed



See Clarke/Degnan and Pavlis talks for more details

System Automation Status

Automation that is complete

- The system automatically downloads predictions and schedule.
- The schedule is automatically followed (except for star calibrations which are started manually when needed). The operator can override to go to another target if desired.
- Star calibrations, once started, are completely automated.
- All system configuration changes between satellite tracking, ground calibration, and star calibration are done automatically by the software based on the target.
- Ground calibrations are completely automated, including setting ND filters to get correct return rate from the ground target, and calculating the system delay.
- Risley prisms are controlled by software to point the transmit ahead of receive.
- PRF is changed by software to prevent collisions between outgoing and incoming pulses.
- Real-time signal processing appears to be working well (LEO to GNSS).
- System automatically generates normal points and transmits hourly.
- System can be controlled remotely via RAT (but currently must be within NASA intranet).

Automation that is nearing completion

- Automated search and find a satellite.
- Cloud coverage automated decision process (change targets, close dome, etc).
- Beam divergence control (based upon satellite).

System Automation Plans

Work in 2014

- Automated search, cloud decisions and beam divergence control will be completed.
- Our current design of closed loop tracking will be implemented and tested.

Future NASA SLR Systems

- Must be fully automated. Along with automated tracking, the system must monitor voltages & temperatures of equipment and make decisions on closing of the dome shutter and shutdown of equipment. Operator is only there to press the laser enable button (US Government regulations) – and we are preparing for a time when we may not need this.

- Must be remotely controllable from specific facilities.

- Must be able to interact with new SGP IGSOC (Integrated Geodetic Site Operations Center). The IGSOC will serve as NASA's "Geodetic Internet" for SLR, VLBI, and GNSS and enables global geodetic infrastructure connectivity. It connects with all the NASA stations and CDDIS.

- From a remote connection to the IGSOC, everyone should be able to view tracking status and results in real-time.

NGSLR Performance Summary

We have satisfied the NASA SLR requirements and demonstrated at NGSLR:

- Robust daylight and night ranging from LEO to GNSS.
- ~ 1mm normal point precision for LAGEOS.
- Ground calibration stability RMS < 1 mm for up to 2 hour periods.
- Successful collocation with MOBLAS-7. Good comparison of ranges between MOBLAS-7 and NGSLR. Fundamental difference between single photon and multi-photon systems has been shown at NGSLR where ranging results follow theory.
- Semi-autonomous system operations. Some operator interaction is required by US Government regulations and is also still needed to close the tracking loop. However, the system now performs fully autonomous target selection and autonomous system configuration changes on the optical bench for different satellites, ground calibrations, and star calibrations.
- Automated aircraft avoidance radar blocking of laser beam.

The Future of NASA SLR

- Future NASA SLR systems (SGSLR – Space Geodesy Satellite Laser Ranging) will be built on the NGSLR concept.
- We will be completing automation and other work on the prototype in 2014.
- Some engineering development will still be needed before the operational systems can be built. The new SLR systems will not be just a replication of NGSLR.
- We are currently working on the solicitation of proposals for the new SLR network build.
- We expect to begin production of the new systems in 2015, subject to funding availability.
- NASA's Space Geodesy Program plans to produce 8 to 10 systems over a 10+ year period.
- All new systems will be built, tested and collocated at Goddard before being shipped to their final location.
- Each legacy system is expected to remain operational until a new system is in place such that a proper hand-off can be made.
- The majority of new systems will be located with VLBI, GNSS and DORIS where possible.