

## **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 successful five week collocation with the NASA SLR Network standard 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 collocated data for the LAGEOS and LAGEOS-2 satellites shows that, as predicted by theory, NGSLR is about 13 mm long when compared to the collocated MOBLAS-7 ranges. Furthermore, this range difference is very stable as confirmed by independent analysis performed with SLR Network generated orbits.*

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

### **Overview/Background**

The Next Generation Satellite Laser Ranging System (NGSLR) is a prototype for NASA's new Satellite Laser Ranging (SLR) systems (McGarry et al, 2011). This system was designed to provide millimeter level stability, robust day and night tracking of satellites from Low Earth Orbit (LEO) to Global Navigational Satellite System (GNSS) altitude, millimeter or better normal point precision on LAGEOS, and automated operations. In the coming years, this system will guide the build of the NASA Space Geodesy Program's new global SLR network replacing the existing NASA SLR Network (Merkowitz et al, 2011) which is part of the International Laser Ranging Service (ILRS) (Pearlman et al, 2000).

NGSLR was recently upgraded and demonstrated its performance capabilities during simultaneous ranging with the current NASA SLR Network standard, MOBILAS-7. This five week period of ranging, referred to as a collocation, consisted of ground calibration ranging and satellite ranging comparisons between the two systems. During the collocation NGSLR successfully demonstrated its performance and verified its design requirements.

**Figure 1.** NGSLR at the Goddard Geophysical and Astronomical Observatory with a list of its eleven major subsystems.

1. Shelter and dome
2. Telescope assembly
3. Tracking system
4. Optical bench
5. Laser
6. Computers & software
7. Laser safety system interface to software (IO Chassis)
8. Time & frequency subsystem
9. Receiver subsystem
10. Meteorological system
11. Laser Hazard Reduction System



### Recent Upgrades

To improve NGSLR's performance in some critical areas, we recently replaced our in-house built two kHz laser with a Commercial-Off-The-Shelf (COTS) laser from Photonics Industries (PI). This laser is more robust, has a narrower pulse-width (50 ps), and is easier to use and maintain.

The optical bench was redesigned and many of the components were replaced. The result is a system that has greater stability, is easier to align, provides greater optical isolation of the receiver from transmitter backscatter, and is capable of being completely automated.

Although many automation features were already implemented at NGSLR including many operator decisions, real-time signal processing, and aircraft detection, software and hardware upgrades were performed during this period that automated many additional parts of the system. These include the configuration of the laser safety system and the configuration of the optical bench components (neutral density filters, daylight filter, and receiver field of view). Automation that was completed or advanced during this upgrade period was the real-time signal processing, the automated decisions on sky conditions, automated target search and acquisition, and automated ground calibrations.

### Collocation Range Comparisons

During collocation, two SLR stations within close proximity range simultaneously to the same satellite and utilize the same calibration targets. The proximity allows for geometric comparison of the ranges without introducing any orbital analysis effects. Atmospheric differences are also minimized since both systems range through the same atmosphere. Ranges from one station are transformed to the origin of the other and a direct comparison is then made.

NGSLR is approximately 40 meters away from MOBLAS-7. Accurate surveys of both systems' origins and the ground calibration target locations were performed before and after the collocation and showed results which agreed to within the accuracy of the survey ( $\pm 1.5$  mm).

This collocation is unique in that it provided the first opportunity for direct comparison of ranges between a single photon detection SLR system (NGSLR) and a multi-photon system (MOBLAS-7). Theoretical analyses of the differences between these two types of SLR systems have been performed in the past and were discussed in a separate presentation at this Workshop (Clarke et al, 2013).

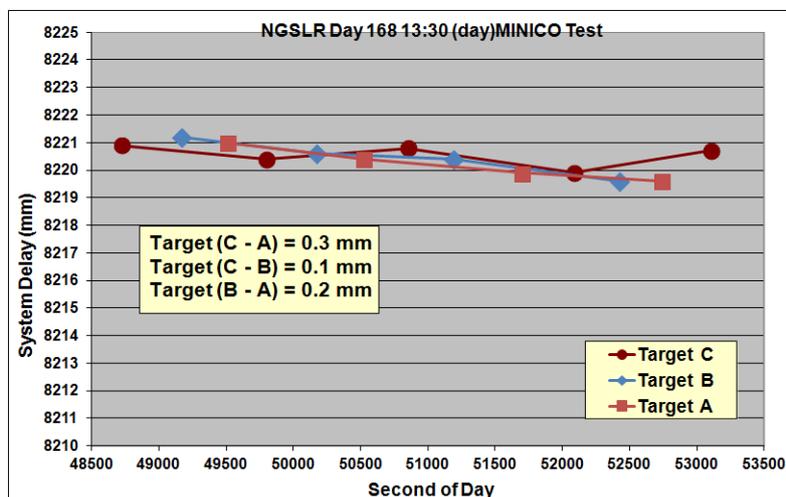
### Demonstrated Performance

In 2013 NGSLR successfully ranged to a majority of the ILRS satellite constellation, demonstrating its ability to perform day and night ranging to most of the LEO, both LAGEOS, LARES, COMPASS-M3 and many of the GLONASS and Galileo satellites. Because there are so many GNSS satellites tracked by the ILRS and because of the GNSS importance, the ability to track these satellites during daylight hours has become a very important capability for SLR stations. Weak signal links and/or solar background noise make it difficult for many SLR systems to range to the higher altitude satellites, such as GNSS, during the day.

Because of the shift schedule, over 80% of the collocation passes were taken during daylight. With the new PI laser and the upgraded optical bench, NGSLR tracking during daylight has proven to be almost as robust as at night, even for the GNSS satellites.

With our recent upgrades in place, ground calibrations have consistently shown stabilities at the  $\pm 1.5$  mm level (peak to peak) with standard deviations better than 1 millimeter over one to two hour periods. Ranging to two other ground targets at different azimuth locations shows the same stability as for the primary target and all provide consistent system delays over hour long periods.

**Figure 2.** Calibrations results from three ground targets. The targets are all to the East of the station with azimuth angles from about 40 to 90 degrees. The ranges from all targets show good agreement and stability over the hour long ranging. Each dot in the plot is a 5 minute normal point.



LAGEOS ranging is a critical component in the generation of the International Terrestrial Reference Frame (ITRF). Information on the LAGEOS mission can be found at: [http://ilrs.gsfc.nasa.gov/missions/satellite\\_missions/current\\_missions/lag1\\_general.html](http://ilrs.gsfc.nasa.gov/missions/satellite_missions/current_missions/lag1_general.html).

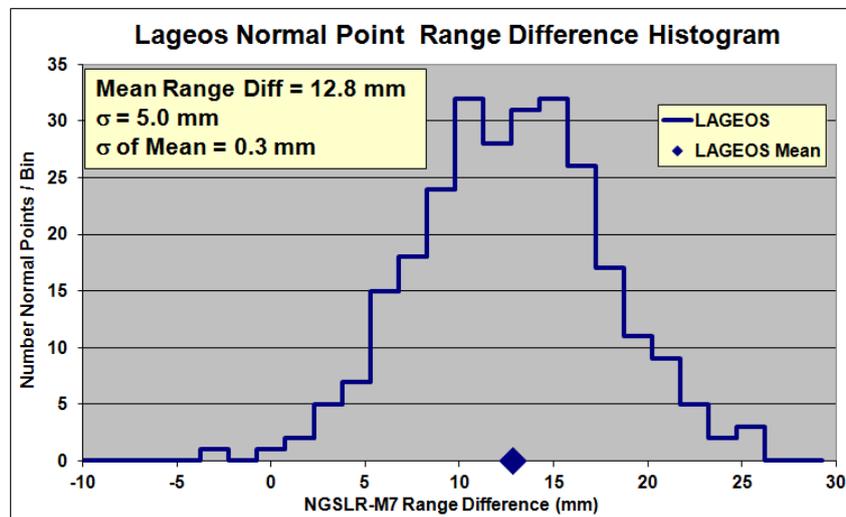
SLR ranging data products are called normal points which are the average of ranges to the satellite over a short period of time, typically five to thirty seconds for LEO, two minutes for LAGEOS, and five minutes for GNSS. Information on normal points can be found at: [http://ilrs.gsfc.nasa.gov/data\\_and\\_products/data/npt/npt\\_algorithm.html](http://ilrs.gsfc.nasa.gov/data_and_products/data/npt/npt_algorithm.html)

To provide the millimeter level ITRF of the future, SLR systems will need millimeter or better normal point precision on LAGEOS. Throughout the collocation NGSLR demonstrated normal point precision at the 1 millimeter level on both LAGEOS and LAGEOS-2.

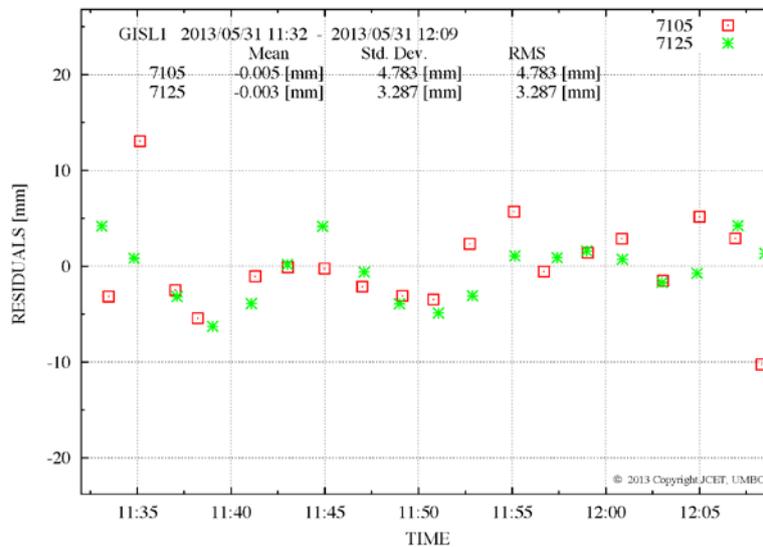
Because of the Poisson nature of the receive events, multiple photon returns will bias the receive time earlier than for single photon returns (Degnan, 1994) (Fan et al, 2001). This implies a fundamental range difference between systems that limit their receive events to the single photon level (NGSLR) and conventional systems that regularly receive multiple photon returns (e.g. MOBLAS-7). The mean range measured by single photon systems coincides closely with the centroid of the satellite impulse response while the mean of multiple photon returns tends to move toward the surface of the satellite. This difference becomes larger with a broader satellite target signature such as that of LAGEOS. Analysis of the theoretical difference between NGSLR and MOBLAS-7 (Clarke et al, 2013) predicts that NGSLR ranges should be ~13 millimeters longer than MOBLAS-7's. Our comparisons during collocation show NGLR ranges to LAGEOS and LAGEOS-2 to be 12.8 millimeters on average longer than MOBLAS-7's. See Figure 3. In addition, after removal of the mean pass bias between the two systems, plots of normal points from both systems show very good agreement between the individual points through the passes. See Figure 4.

Independent analysis by the ILRS Analysis Working Group Chair compared NGSLR collocation data against orbits generated from the ILRS network data and confirmed our analysis of NGSLR's performance (Pavlis et al, 2013).

**Figure 3.** Histogram of the range differences between NGSLR and MOBLAS-7 for all collocation passes. The mean of the histogram shows NGSLR ranges long from MOBLAS-7's by 12.8 mm which is in good agreement with theory.



**Figure 4.** Individual normal points from NGSRL (7125 in green) agree very closely to those of MOBLAS-7 (7105 in red) after the mean pass bias has been removed.



## Current Status

NGSLR is currently performing satellite laser ranging under operator control while we work to complete the automation of the system. Much of the system is now automated, but work continues on the automated satellite acquisition, software sky-condition-based decision making, and the final beam divergence automation. We expect these to be completed this year. In addition, closed loop tracking and a health and safety subsystem still need to be implemented to produce a fully automated system.

After approximately one year of laser ranging in the current configuration, NGSRL data will be analyzed for long term trends. Data will be released to the ILRS periodically over the coming year.

## The Future of NASA SLR

NASA's Space Geodesy Program plans to build a new SLR Network with systems based upon the NGSRL concept, completing eight to ten systems in the next decade. NGSRL has been developed over many years, and system requirements and restrictions have changed during this period. As a result, certain subsystems are now obsolete, no longer needed, or are otherwise not optimum. Therefore the new NASA SLR systems (SGSLR) will not be exact replicas of the NGSRL prototype, but will be an improved version designed to meet the current requirements.

Future NASA SLR systems must be automated. Whether these systems will be able to perform tracking without an operator or with a remote operator will depend upon regulations from the US Government's Federal Aviation Administration (FAA). These regulations are currently undergoing revision and there is some potential for reductions in the current restrictions on SLR operations in the United States.

Many of the new SLR systems will replace legacy SLR systems at the same sites. There will be some period of overlap in operations between old and new before the legacy systems are removed. A majority of the new systems are planned to be located in close proximity to other SGP geodetic techniques, such as Very Long Baseline Interferometry (VLBI), GNSS receivers, and DORIS beacons.

## Summary

NGSLR has verified its performance requirements during 2013, concluding this effort with a successful five week collocation with MOBLAS-7. Ground calibration stability was better than one millimeter and LAGEOS normal point precision was on average one millimeter. Daylight ranging was robust, even to GNSS satellites, with a majority of the collocation data taken during daylight. The comparison between NGSLR and MOBLAS-7 ranges gave the first opportunity for a direct comparison of single-photon detection systems and multi-photon systems, and showed very good agreement with prior theoretical predictions.

## Acknowledgements

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