High Quality, High Quantity Laser Ranging Data for the 21st Century: NASA's Next Generation Satellite Laser Ranging Network

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Abstract

A new generation of Satellite Laser Ranging (SLR) stations is in development by NASA's Space Geodesy Project. Since the 1980s, NASA's network of SLR stations has provided a large percentage of the global orbital data used to define the International Terrestrial Reference Frame (ITRF). This network is reaching end-of-life. Current sub-millimeter precision ranging requirements coupled with the ever-increasing number of satellites with retro-reflectors require a new network of SLR stations with exacting performance specifications. These are the Space Geodesy Satellite Laser Ranging (SGSLR) systems.

Following a successful prototype demonstration in 2013, SGSLR is being developed to produce a robust, kilohertz laser ranging system with 24/7 operational capability and with minimal human intervention. SGSLR's data must support the aggressive ITRF goals set by the Global Geodetic Observing System (GGOS), which are 1 millimeter position accuracy and 0.1 millimeter per year stability on a global scale.

This poster will show how the new SGSLR systems are designed to meet the GGOS performance goals, give the expected system performance, and show the initial planned deployment

Performance Requirements

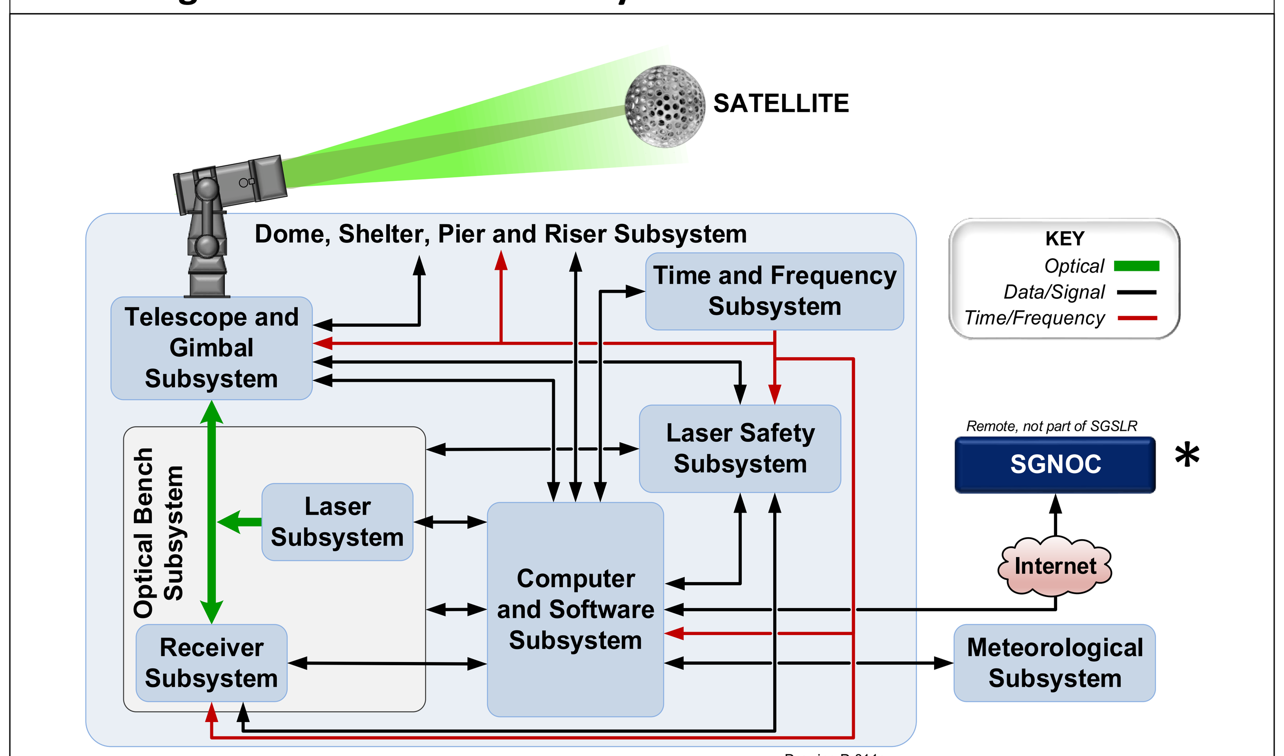
Quantity Requirements

- Annual volume of 45,000 LEO, 7,000 LAGEOS and 10,000 GNSS Normal Points

Quality Requirements

- Precision for LAGEOS Normal Points < 1.5 mm averaged over a one month period
- LAGEOS Normal Point range stable to 1.5 mm over 1 hour
- Over 1 year the RMS of station's LAGEOS Normal Point range biases < 2 mm
- Normal Point time of day accurate to < 100 ns RMS
- No introduction of any unquantified biases into the legacy SLR network

Block Diagram of the 9 SGSLR Subsystems



Subsystem Descriptions

Timing & Frequency (T&F)
- GPS tie to USNO – heart beat of system
- Monitoring of timing using 2nd GPS
- Monitoring info supplied to software

Meteorological (MET)
- Pressure, Temperature, Humidity for data quality
- Horizontal Visibility, Precipitation, Wind, Sky Clarity for automation

Telescope and Gimbal
- Gimbal & Telescope Assembly **(GTA)** – pointing and tracking
- Visual Tracking Aid – used by operator

Optical Bench (OB)
- Transmit path, Receive path, Star Camera, Motion Control
- Software can automatically configure for all modes

Laser
- Provides health & diagnostic information to Software
- Repetition rate controlled by software

Laser Safety (LSS)
- NASA/ANSI compliant, Failsafe, Redundant, Highly responsive
- Provides information to Software on actions it takes and reasons why

Receiver
- Sigma Space Range Receiver **(SSRx)** – Precise signal timing coupled with angular offset info to optimize pointing
- Range Control Electronics **(RCE)** – sets range window and laser fire rate

Dome, Shelter, Pier, Riser (DSPR)
- Provides clean stable environment and protection from weather
- Software controls power through UPS units and can initiate system shutdown

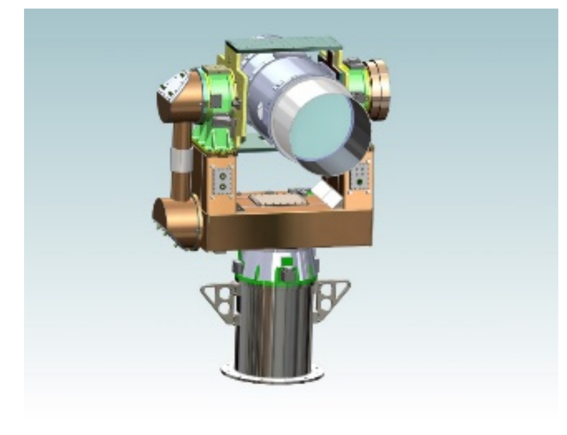
Computer and Software (C&S)
- Transfer and store data, process ranging data, perform operational decision making, generate and deliver science data product, and communicate with the SGNOC
- Support local, remote, and automated operations

**** Space Geodesy Network Operations Center (SGNOC)***
- Not an SGSLR subsystem but manages SGSLR stations
- Receives engineering data and distributes commands and schedules to the SGSLR stations

Key Elements for Performance and Automation

- **Telescope and Gimbal** designed for accurate pointing and low jitter, with high knowledge of invariant point location

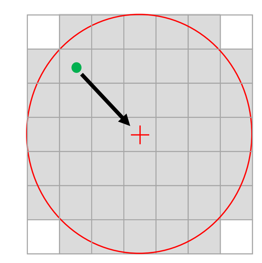
Absolute Pointing	≤ 3 arcsec RMS
Jitter	≤ 1 arcsec
Invariant Point* Knowledge	≤ 1 mm in 3D space



* Intersection of axes for the telescope, from where the range is measured

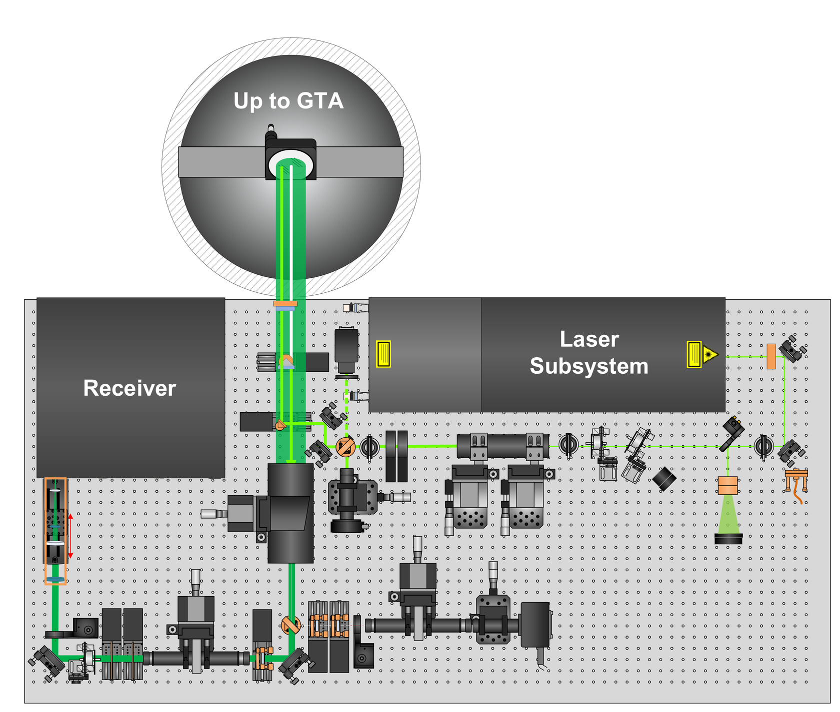
- **Pixelated Detector** allows for correction of angular errors and higher signal to noise ratio per detector element

7x7 MCP-PMT Detector Array	*1.6 mm Pixel size*
	<1 kHz noise per pixel
	High QE
	Negligible dead space
Sigma Space Timer Card	*52 Channels with single shot precision of 3.45 ps*



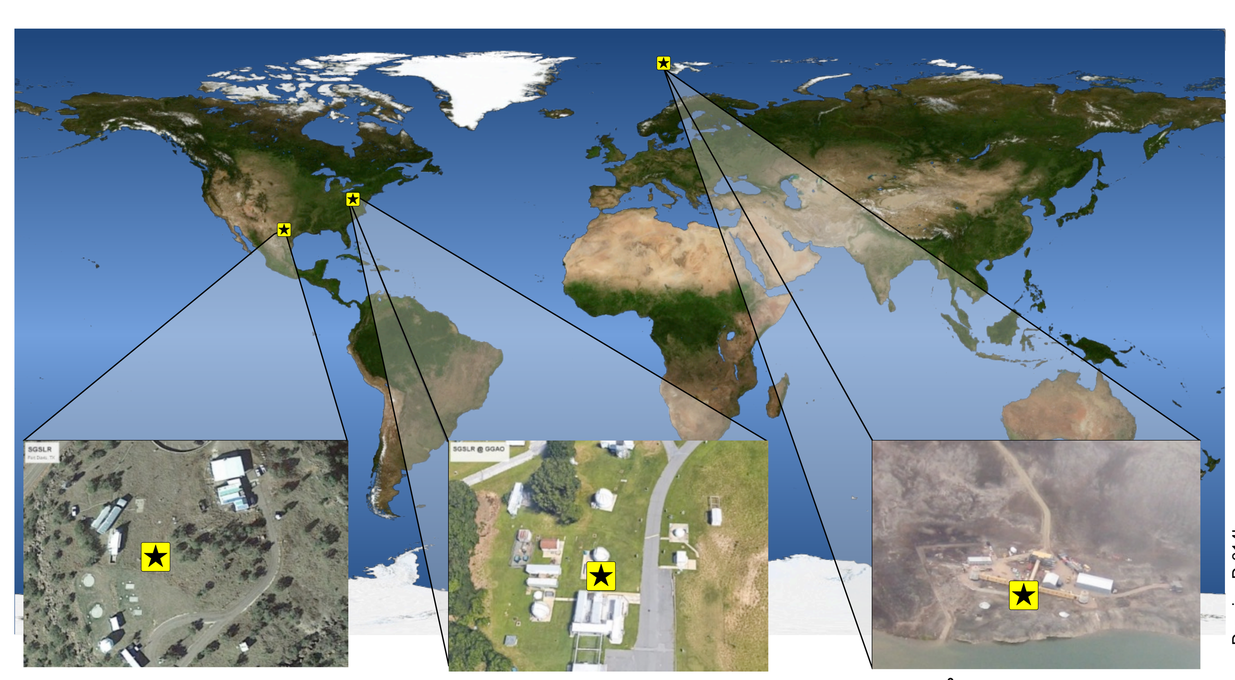
- **Computer and Software subsystem** designed for remote operations and expansion into a fully automated station with little human interaction, including automated satellite tracking, star calibration, weather & cloud detection, and real-time decision making

- **Optical Bench subsystem** fully automated for:
  - Divergence control
  - Laser point ahead
  - Receiver field of view control
  - Beam power and quality measurements
  - Real time decision making
- **Laser Subsystem**
  - 2 kHz
  - 532 nm
  - Variable pulse frequency to avoid transmit/receive collisions



- The **Laser Safety Subsystem** includes sensors and cameras to prevent accidental laser exposure to aircraft and personnel
- Laser Safety Interlock and KBRwyle Laser Hazard Reduction System for aircraft (where allowed)

Locations of Initial Deployment

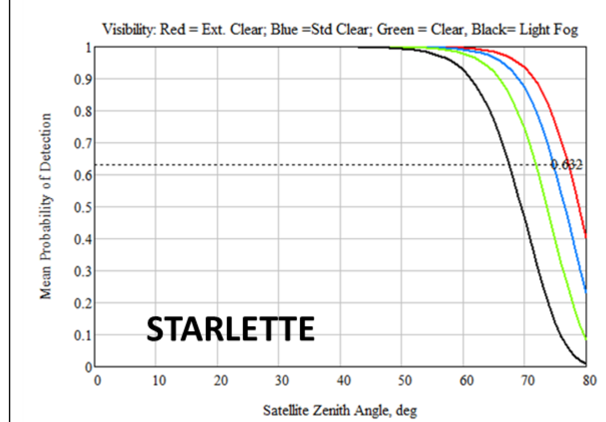


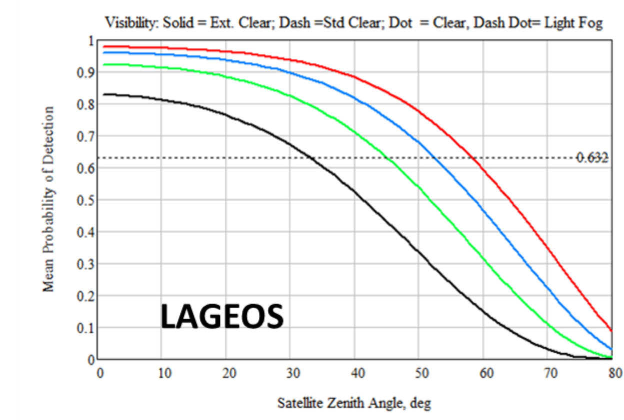
Construction has begun at each site
First Station (TX) scheduled for deployment in 2020

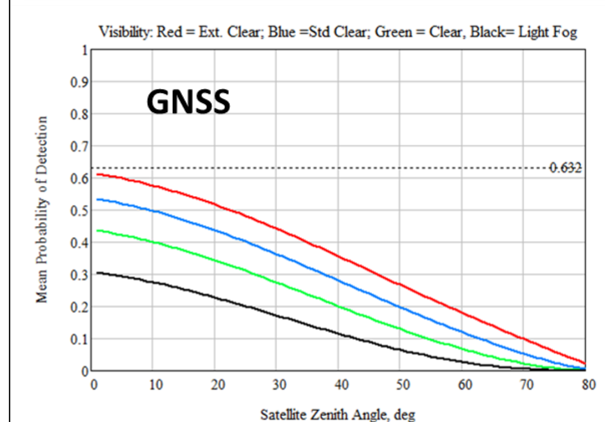
Reference

McGarry, J. F., Hoffman, E. D., Degnan, J. J., Cheek, J. W., Clarke, C. B., Diegel, I. F., ... & Patterson, D. S. (2018). NASA's satellite laser ranging systems for the twenty-first century. Journal of Geodesy, 1-14.

Expected System Performance







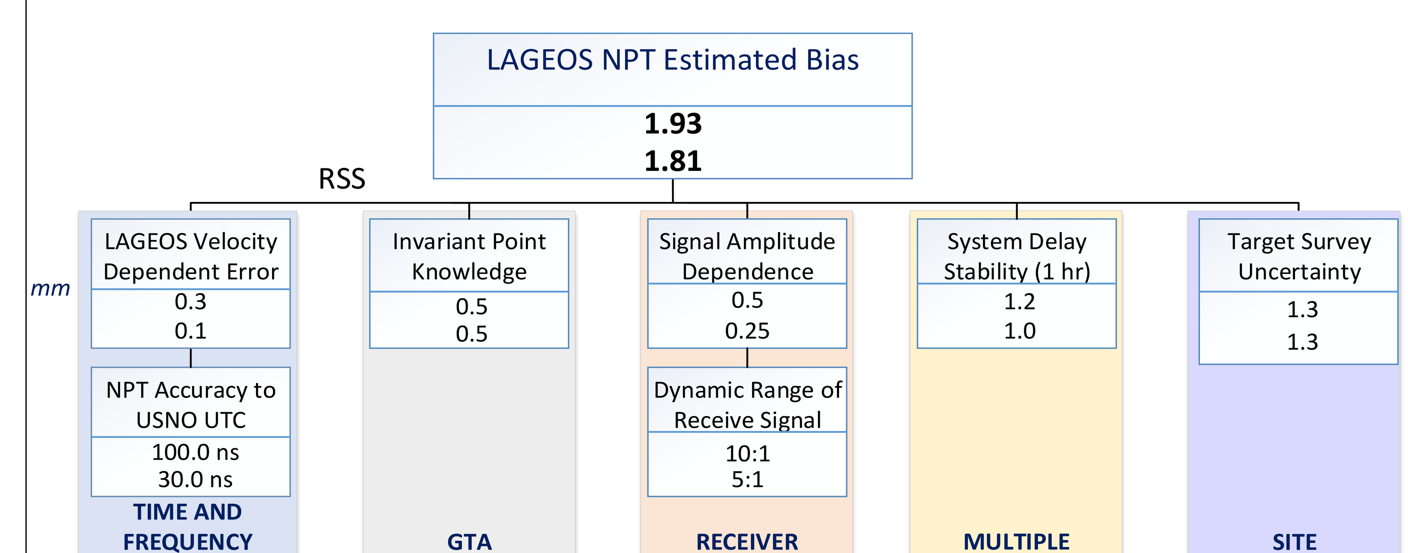
28 arc second full divergence (STARLETTE & LAGEOS)
14 arc second full divergence (GNSS)
2 arc second pointing offset
2 arc second RMS jitter
Includes effects of scintillation and beam wander
Poor site – at sea level

Red = Extremely Clear (V=60 km)
Blue = Standard Clear (V=23.5 km)
Green = Clear (V=15 km)
Black = Light Haze (V=8 km)

Site ID	Station Number	LEO NP Totals	LAGEOS NP Totals	High NP Totals	LAGEOS Average Precision (mm)	JCET Long Term Stability (mm)
YARL[1]	7090	176,683	20,634	21,986	1.9	2.5
GODL[2]	7105	76,554	7,666	3,052	2.0	3.5
CHAL	7237	69,438	7,235	14,735	0.8	4.1
STL3	7825	78,089	7,218	3,984	1.9	1.5
GRZL	7839	75,714	5,468	18,016	0.2	1.8
HERL	7840	38,592	7,018	6,069	1.9	1.2
WETL	8834	46,509	5,053	12,683	1.6	3.0
SGSLR(20°)	@7105	53,400	7,400	12,200	<1.5	<1.8
SGSLR(10°)	@7090	200,000	18,500	26,400	<1.5	<1.8
Requirement		45,000	7,000	10,000	<1.5	<2.0

Projected SGSLR annual NP data volume[3]:
(20°) 50% weather outage, 16% other outage, 40% data collection when active, min 20° elevation
(10°) 14% weather outage, 16% other, 40% data collection when active, min 10° elevation

[1]YARL has 14% weather outage and tracks to 14° elevation
[2]GODL has 50% weather outage and tracks down to 10° elevation
[3]Precision and stability numbers for SGSLR are based upon SGSLR analysis and NGSLR (prototype) performance



- Based on simulations and empirical data collected from the NGSLR prototype
- SGSLR Requirement is less than 2 mm

KEY
Error Source
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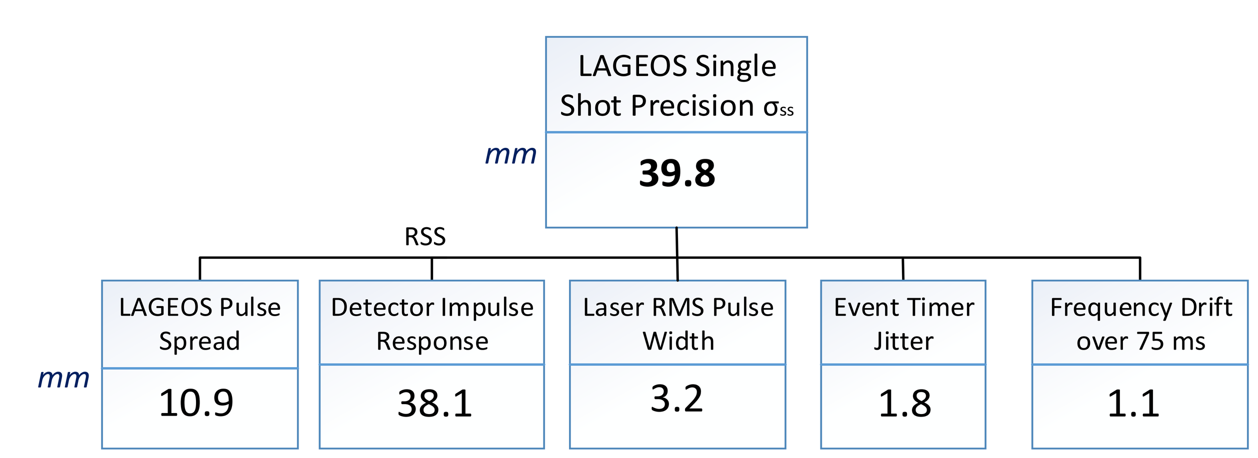

Single Shot Precision

$$\sigma_{NPT} = \frac{\sigma_{ss}}{\sqrt{N}} = 1\ mm \Rightarrow N = 1586 \Rightarrow \frac{N}{2000\ Hz * 10\%\ return\ rate} = 7.9\ seconds$$

Normal Point Precision   Number of Observations

A normal point for LAGEOS must be acquired within a **2 minute** time bin