Salient Results relevant for Next Generation Space Geodesy from the Pre-launch Lageos-2 Optical Testing / Analysis at NASA GSFC

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Abstract:

Next Generation Space Geodesy techniques are expected to significantly augment the International Terrestrial Reference Frame (ITRF) capability to sub-millimeter accuracy. This means that Satellite Laser Ranging (SLR) must have millimeter ranging accuracy across the SLR Ground and Space segments. To examine the Laser Geodynamic Satellite (Lageos) potential for millimeter ranging, a thorough investigation of the extensive pre-launch Lageos 2 test results was conducted. These results from the Far Field Diffraction Pattern (FFDP) measurement, under pulsed and continuous wave laser measurements, provide deep insights into the satellite temporal response for various ground segment configuration and data processing conditions. This paper highlights the salient results from the satellite temporal response study for the realization of millimeter space geodesy.

Introduction

Lageos 1 and 2, with its long history of geodetic ranging and stable time series, provide the firm basis for the SLR contribution to ITRF. These satellites are designed to be point-mass objects in space with large mass to area ratio to enable Precision Orbit Determination (POD). These should also behave as point optical targets in space to get the best ranging accuracy. However, Lageos has range accuracy issues from not being a point optical target due to its Laser Retro-reflector Array (LRA). The "Fuzzy Range Depth Function" of the LRA and its strong dependencies on the SLR system configuration requires further study, if millimeter accuracy ranging is needed from Lageos.

Space Segment Considerations

The geodetic satellites operating today were launched during the last 3 decades. These are in orbit and cannot be physically changed. Satellites are expensive to manufacture and launch. It is critical to examine the relevance, suitability, and adaptability of the current satellites for future high accuracy applications. Key questions include:

1. Will the SLR Ranging accuracy of the current space segment, launched during the last 30+ years, suffice for the next 30+ years of the space geodesy program?
2. How do we exploit the best ranging accuracy from a geodetic satellite with a "fuzzy" impulse response?
3. What ground based technologies and data processing techniques permit overcoming the satellite constraints?

In the context of the above questions as well as the emerging need for higher range accuracy, Lageos 2 pre-launch NASA GSFC test data/ results [1] were examined in detail. Following sections describe some of the key findings.

Laboratory Test Results

Lageos is a spherical satellite (diameter =600mm) with a dense population of Total Internal Reflecting (TIR) corner cubes (426). The satellite may be thought of as having polar (north and south) and equatorial regions. There is no LRA optical symmetry except about the poles of the satellite and along the latitude. It is oriented along a preferred spin axis in its orbital plane and the spin rate is different for Lageos 1 and 2. A ground-based SLR station will see different regions of the satellite in a typical track. It will also see a dynamic temporal response that varies depending on whether the ground station line of sight is along the polar, equatorial, or in between regions. For a plane wavefront illuminating the satellite, the Lidar returns from the cubes will coherently interact to generate a complex dynamic target impulse response [2] in the Far Field Diffraction Pattern (FFDP). Fig.1 illustrates the return waveforms from the lab measurement of a ~40 picosecond (ps) linearly polarized laser pulse input to the satellite for various satellite orientations. The return waveforms from the satellite were captured using a streak camera with a 2 ps temporal resolution (and comparable accuracy), with the input pulse always on the sweep serving as a reference. The coherent interaction is evident from the temporal variations of the retro-reflected pulses from the satellite.

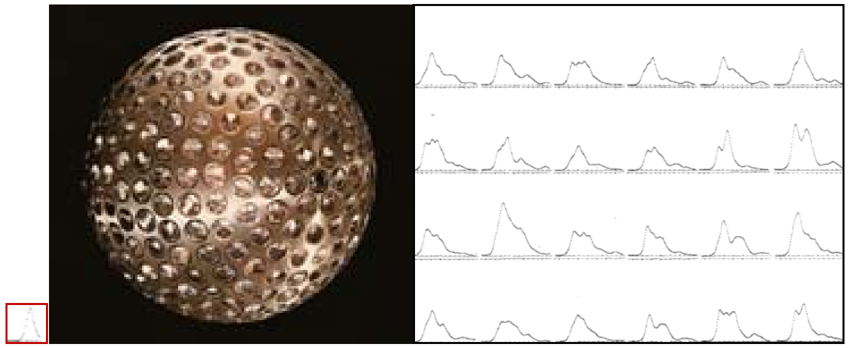

Fig. 1: Laboratory Measurement result illustrating the temporal response for a short laser pulse ~40ps)

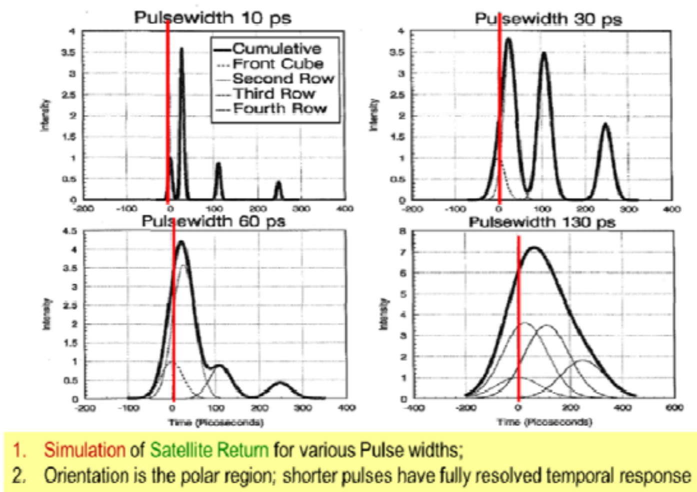

Fig. 2: Simulation of the pulse spreading at the polar region vs. pulse width for various pulse widths.

Fig. 2 shows a temporal simulation of the polar region (for different laser pulse widths) for a single instance of the phasing of the returns in the FFDP. This response will vary depending on the phasing of the return pulses and will generate complex pulse profiles analogous to the experimentally measured waveforms of Fig.1. The shorter pulses will have the least amount of temporal overlap and ensuing coherent interaction. The polarization state of the input pulse also showed a strong effect on the retro-reflected pulses. As expected, circularly polarized light showed a symmetric near Gaussian Range Correction (RC) distribution, unlike linearly polarized light.

Conclusion

Based on the Lageos 2 test results, one can envisage a ground station configuration that is capable of millimeter SLR accuracy. For this, millimeter (precision and accuracy) ranging electronics needs to be combined with a short (<10ps) circularly polarized laser. The detection should be operating on the leading edge of the retro-reflected pulse to minimize the LRA effect. This SLR configuration will resolve the satellite cubes that are differentially placed to an incident plane wavefront ≥1mm yielding a high resolution multimodal range residual data, which can then be digitally corrected to a single mode. Alternately, tight data editing may be applied to remove the asymmetric trailing edge of the range residual distribution to yield higher normal point accuracy at the expense of some data loss to truncation.

Note: Contributions of P. Minott, J. Dallas, and M. Selden, during Lageos testing at NASA GSFC, are gratefully acknowledged.

References

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2. Millimeter accuracy constraints on Lageos satellites and effective Ground Station solutions; Varghese, et.al. (to be published).