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Centre-of-mass Corrections of sub-cm-precision Targets, STARLETTE and LARES

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Abstract. *Recent enhancement in precision and repetition rate makes it possible and necessary to study the effects for small targets STARLETTE and LARES. Using kHz full-rate laser ranging data obtained at Herstmonceux and Potsdam, and comparing the residual profile with optical simulations, it is revealed that the center-of-mass correction can vary within 128 to 135 mm for LARES, and 75 to 82 mm for STARLETTE. The result of STARLETTE indicates that the current standard value 75 mm is applicable only to single-photon systems and it is too small for the worldwide average.*

Introduction

Otsubo and Appleby (2003) investigated the target signature effects for relatively large satellites such as LAGEOS, AJISAI and ETALON, where the system dependence of the centre-of-mass correction amounts to 1 cm to 5 cm. The measurement precision of state-of-the-art laser ranging systems is now in millimeters, and high repetition laser ranging systems are becoming common. Such enhancement in precision and repetition rate makes it possible and necessary to study the effects for smaller targets STARLETTE and LARES. Note that the STARLETTE satellite is followed by its twin STELLA, optically identical, and therefore the study on STARLETTE is automatically applicable to STELLA.

Optical property of STARLETTE and LARES

The STARLETTE satellite, one of the long-lasting artificial objects, was launched in 1975. Its twin, STELLA, was launched in 1993. They are spherical satellites of 24 cm diameter and equipped with 60 coated reflectors. The LARES satellite, the newest among the spherical geodetic satellites, was recently launched by the VEGA rocket in 2012. Its diameter is 38.4 cm, and has 92 uncoated reflectors.

An uncoated reflector has a narrower acceptance angle than a coated reflector. Therefore, although LARES is larger than STARLETTE, the two satellites have nearly the same amount of target signature effects.

For each type of the reflector, the active reflection area a and the reflectivity e are numerically computed covering every possible angle of incidence. Rather than precisely modelling the far-field diffraction pattern, we express the intensity I using the following formula:

$$I \propto a^p e$$

where the exponent p is an empirical parameter to be fitted with the observation.

It is now possible to construct an optical response function assuming a certain p value, for any angle of incidence toward a satellite. To build an average response functions, we computed more than 10,000 ones taking an angle of incidence approximately 2 degrees apart to the next.

Empirical determination of response functions

To determine the p parameter, the residual distribution of single-photon laser ranging is useful because it can retrieve the average shape of a response function (Otsubo and Appleby, 2003).

In this study, we collect full-rate residual data from two single-photon stations, Herstmonceux, UK, and Potsdam, Germany. They often switch the laser systems, but we adopt data obtained by a kHz laser system. In addition to STARLETTE, STELLA and LARES, we also obtain BLITS data from Herstmonceux and GRACE data from Potsdam. These satellites have almost negligibly small target signature effects, and therefore the residual distribution profile is used as a raw system noise. The convolution of the system noise profile with the target's optical response function is the *modelled* residual distribution that is to be compared with the *observed* residual distribution.

Fig. 1 and Fig. 2 are the case of Herstmonceux and Potsdam, respectively. The best-fit p

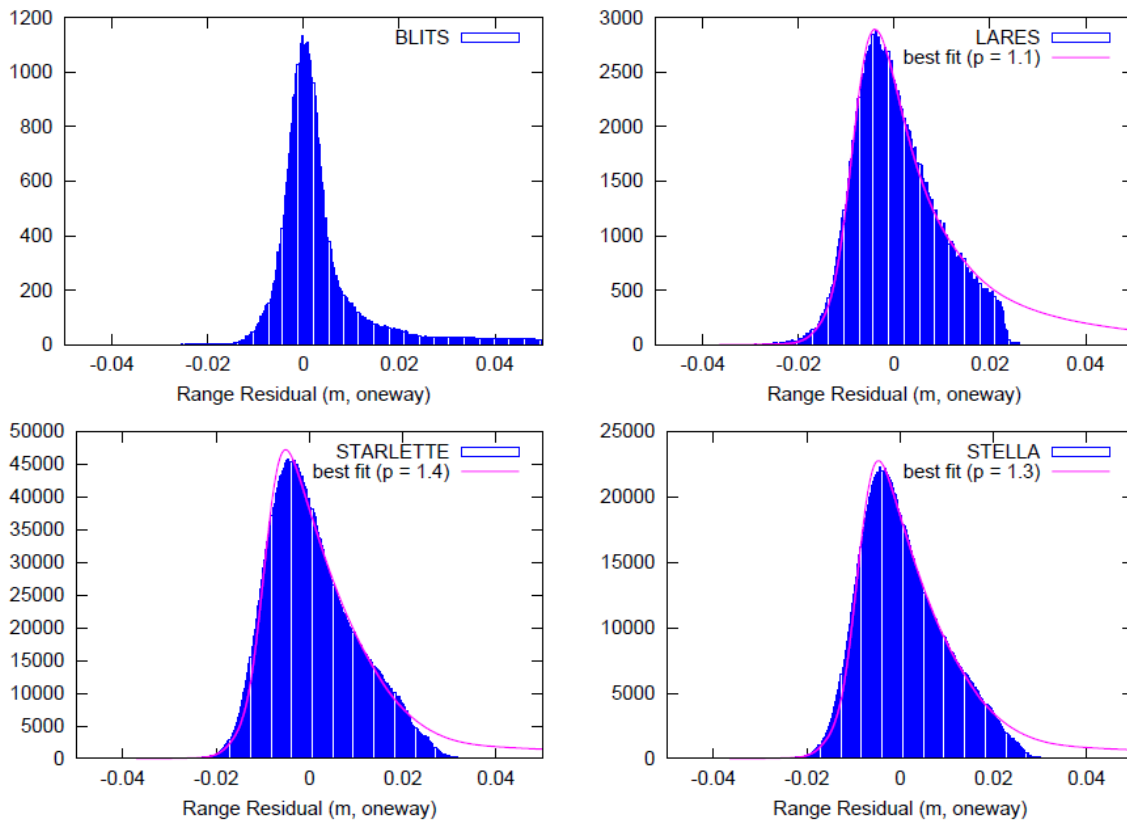


Figure 1. The residual distribution of Herstmonceux full-rate data (2009-2012) with the best-fit optical response functions.

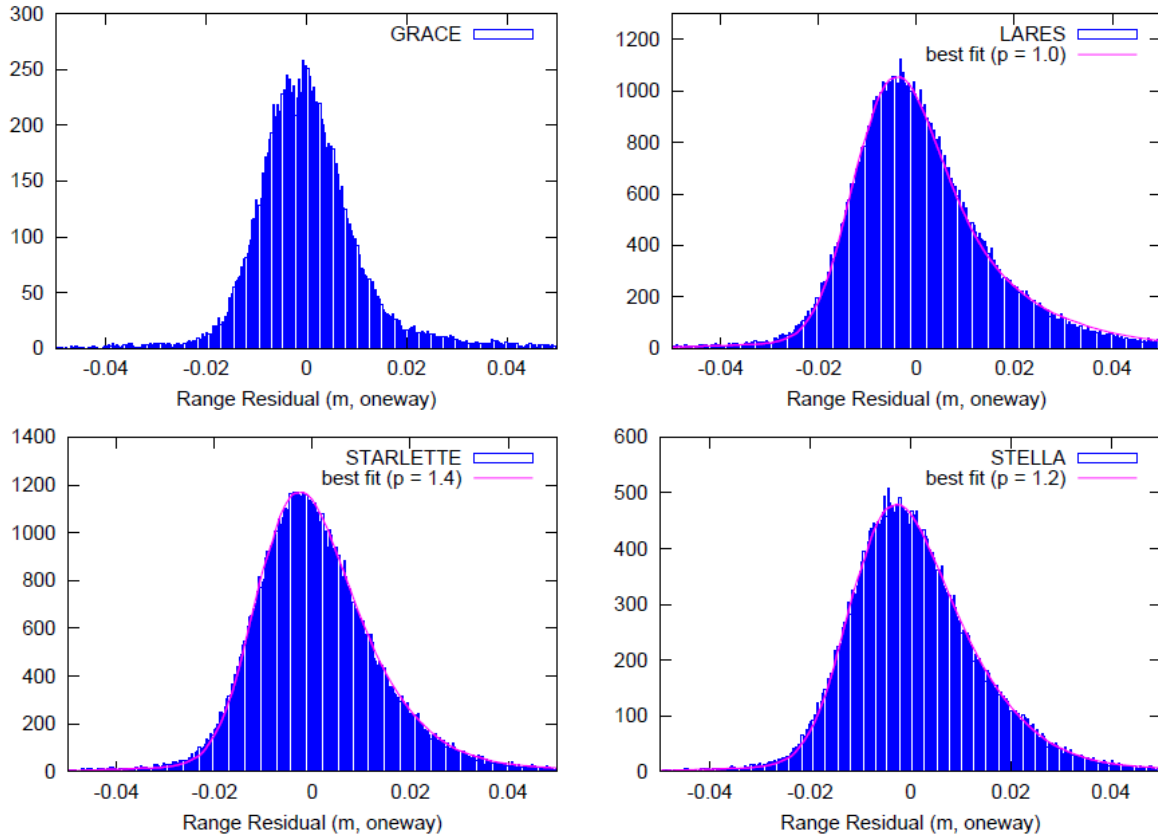


Figure 2. The residual distribution of Potsdam full-rate data (2013) with the best-fit optical response functions.

parameters are 1.0 to 1.1 for LARES, and 1.2 to 1.4 for STARLETTE and STELLA. The agreement is remarkable. The impact to the centre-of-mass correction is slightly less than 1 mm if the parameter p changes by 0.3, so the agreement here is well below 1 mm.

Note that we did not observe significant difference between STARLETTE and STELLA.

Compared with LARES, the twin, STARLETTE and STELLA, are spinning slowly, and the angle of incidence does not change during a pass. As a result, there is a pass-by-pass variation observed in residual distribution profiles, and, therefore, we have to accumulate a number of passes to obtain the average profile.

Centre-of-mass corrections

We can determine the centre-of-mass corrections of these satellites using the empirically estimated p values. The detailed process is still ongoing project, but we can here show the possible range following the procedure given by Neubert (1995) and also by Otsubo and Appleby (2003).

Using $p = 1.1$ for LARES, the centroid falls at 127.5 mm. Assuming iterative 3.0- and 2.5-sigma rejection of outliers, the centre-of-mass corrections for a single-photon system goes to 129.6 and 131.0 mm, respectively. Those of a multi-photon detection system are dependent on an average intensity (number of photons) and a laser pulse width, and they fall within 128 to 135 mm.

Using $p = 1.4$ for STARLETTE, the centroid falls at 75.0 mm, exactly the same as the standard value (Arnold, 1975). After 3.0- and 2.5-sigma clipping, the centre-of-mass correction for a single-photon system goes to 75.5 and 76.7 mm, respectively. The range of multi-photon systems is 75 to 82 mm. It should be emphasized here that when the standard value is the minimum among the possible range. It is likely that the actual worldwide average value has been 3 to 5 mm larger.

Summary and Future Studies

The target signature effects of small spherical satellites, LARES and STARLETTE, are investigated. The system dependence of their centre-of-mass corrections is 7 mm at maximum for the both cases, which should not be ignored for millimeter precision analysis.

The result of STARLETTE indicates that the current standard value 75 mm is too small in general for STARLETTE and also for STELLA. There should be an impact to the terrestrial reference frame scale and to the gravity constant (GM) of the Earth.

References

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