IDENTIFYING SINGLE RETRO TRACKS WITH A 2KHZ SLR SYSTEM-SIMULATIONS AND ACTUAL RESULTS

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Introduction.

This is a abbreviated version of the original paper. For the complete paper see the SPWG website 'http://nercslr.nmt.ac.uk/sig/signature.html'.

The new 2kHz SLR system at Graz can generate single photoelectron histograms in a short period of time. Plots of the range residuals vs time show how the return pulse shape varies during a pass. Many satellites, including Lageos, appear to show single retro tracks. Computer simulations have been used to calculate return pulse shapes as the viewing angle on the array changes. Plots of the simulated data look very similar to plots of the actual data. The simulations indicate that the tracks can be single retros for small arrays, or groups of closely spaced retros for large arrays.

Data collection and processing.

The 2kHz SLR system at Graz uses a CSPAD detector. The system can operate in either a multi-photoelectron mode or a single photoelectron mode. If the system is operating in a multi-photoelectron mode, the range measured is basically the leading edge of the pulse.

For high satellites like LAGEOS, the system operates in a single photoelectron mode because of the low signal strength. The return pulse shape is the probability function for obtaining a photoelectron. The return pulse shape can be plotted by making a histogram of the range residuals using a large number of returns. The Graz system takes data so rapidly that it is possible to plot single photoelectron histograms in a very short period of time. Plotting the range residuals vs time shows a plot of the pulse shape vs time.

For low satellites with strong signal strength one would not expect a plot of the data to show the pulse shape since the system is measuring only the leading edge. In fact, there are large variations in signal strength for low satellites so that there is a significant fraction of single photoelectron data even for low satellites. The result is that the data often shows the pulse shape even though the average signal strength is fairly strong.

Computer simulations.

The return pulse shape from an array can be computed using program RETURN which is described in Appendix A and Appendix C of Reference 1. This program has been used to compute return pulse shapes for various satellites as the viewing angle on the array changes. Successive pulse shapes are plotted using a gray scale plotter. This give a visual representation that is very similar to the plots of the range residuals vs time.

LAGEOS-1

a.- Plot of the actual data

Figure 1 shows a plot of data from a LAGEOS-1 pass. There are tracks clearly visible in the data. Since LAGEOS-1 is spinning very slowly, it is not possible to use the photometry of the solar reflections from the front face of the cube corners to determine the orientation of the satellite. Since the orientation is unknown it is not possible to do a computer simulation for the actual conditions of the data.
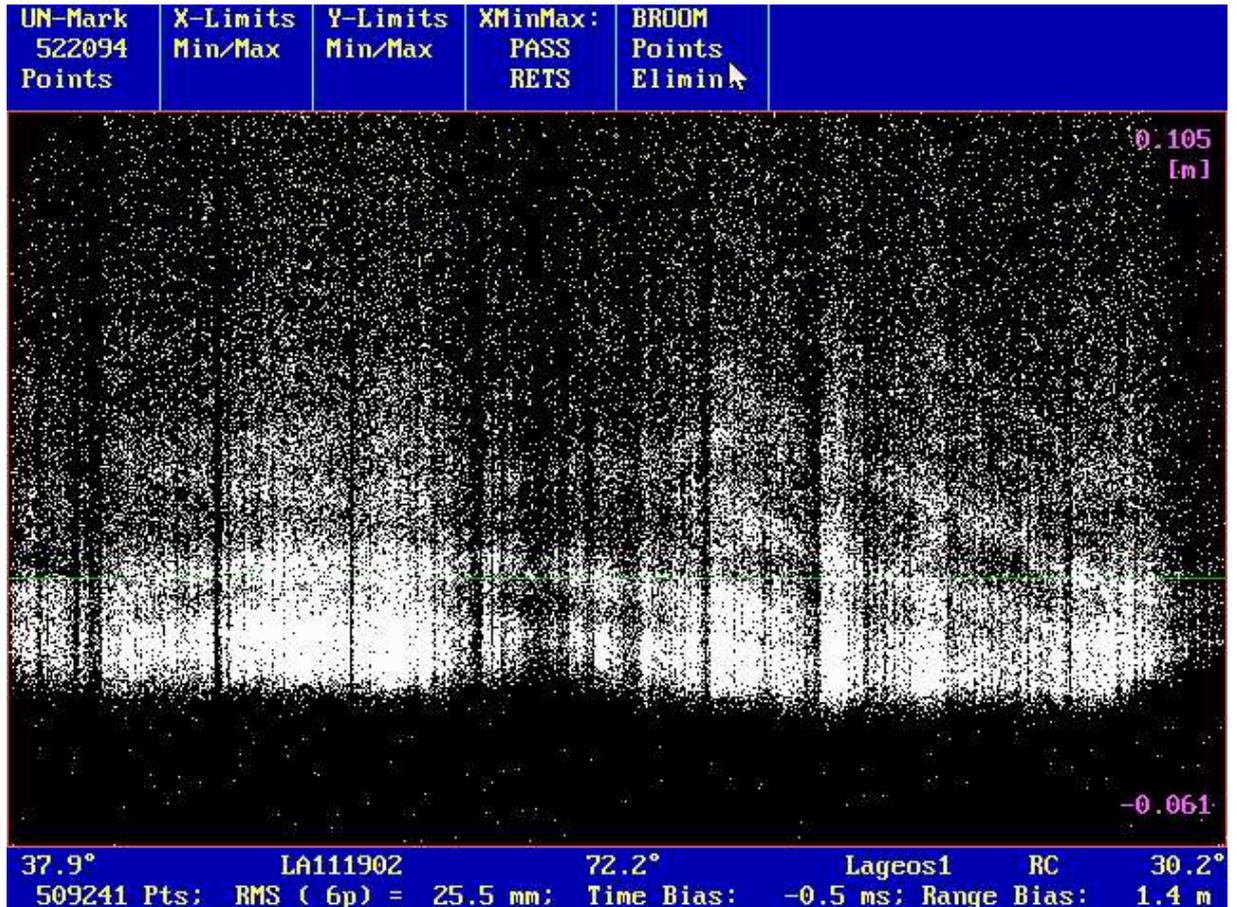

Figure 1. Plot of data from a night time pass of LAGEOS-1 with about 500 k returns.

b.- Simulated LAGEOS data.

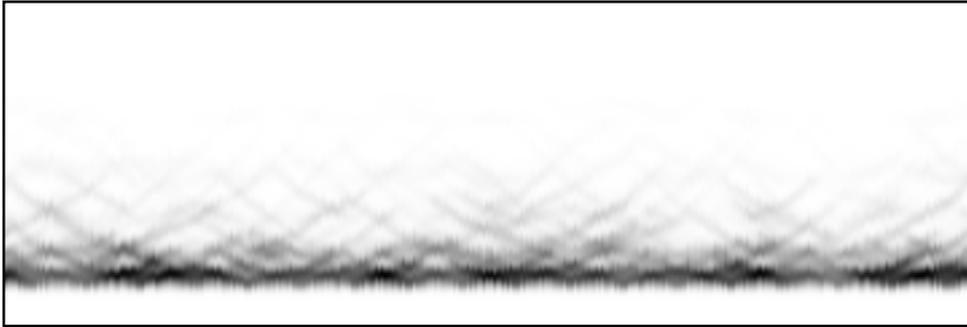Figure 2a. 90 deg angle with the spin axis (equatorial)

Figure 2b. 30 deg angle with the spin axis.

Figure 2c. 0 deg angle with the spin axis (polar). (See SPWG website)

Figure 2 shows inverted gray scale plots of the simulated data for three different angles with respect to the spin axis. The horizontal axis of the plot is one complete revolution (360 deg). The vertical axis is .28 to .55 meters (two-way).

There are 32 cube corners in each of the equatorial rows and this is reflected in the structure of Figure 2a. At 30 degrees incidence angle there is no well defined periodicity because the signal is the sum of rows having different numbers of cube corners.

The transmitted pulse width is 10 ps for the Graz laser. However, the rms noise in actual laser ranging is about 20 ps, probably due to atmospheric effects. This is roughly equivalent to having a 40 ps transmitted pulse in terms of pulse spreading. In Figure 2, the input pulse is 40ps FWHM to simulate the rms system noise of about 20ps.

The simulation in Figure 2b looks similar to the plot of the actual data in Figure 1. There is no way to do a plot for the actual conditions since the orientation of the satellite is unknown.
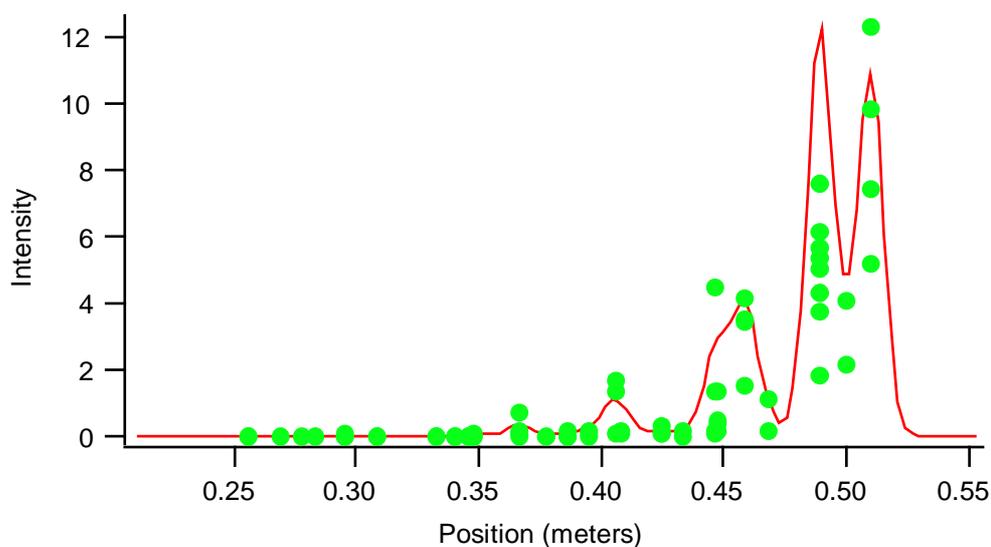
c.- Simulated pulse shape.

Figure 3. Plot of pulse shape at a single orientation with a 40 ps transmitted pulse. The red curve is the incoherent pulse shape and the green dots are the reflectivity of individual cubes at their position in the pulse. The positions of the individual retros and the plot scale of the pulse

are multiplied by a factor of two because of the two way travel time. The range correction would be half the mean position of the pulse.

The pulse shape in Figure 3 gives the appearance of showing individual retroreflectors. However, the green dots showing the positions of the active retroreflectors shows that the peaks are actually the result of looking at groups of retroreflectors. There are 4 peaks in Figure 3. This is roughly consistent with the number of peaks evident in Figure 1 showing the actual ranging data.

TOPEX.

a.- Actual TOPEX data

There are a number of tracks evident in Figure 4. Since TOPEX gives a very strong signal it is somewhat surprising that the tracks from retros far from the leading edge are clearly visible in the plot. The explanation is that there is always a certain percentage of single photoelectron returns which can be from anywhere in the pulse.
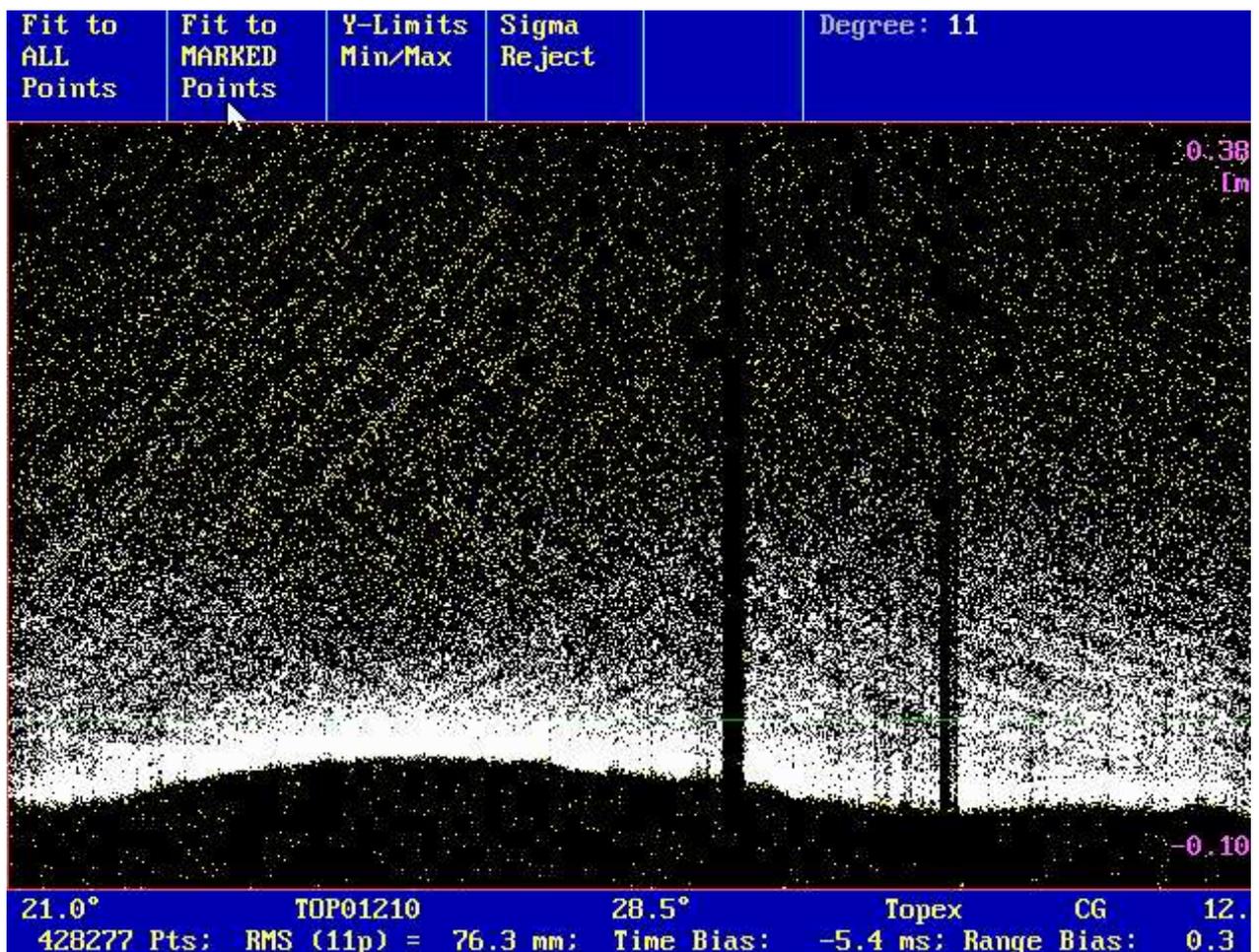

Figure 4. Plot showing about 400 k returns from TOPEX.
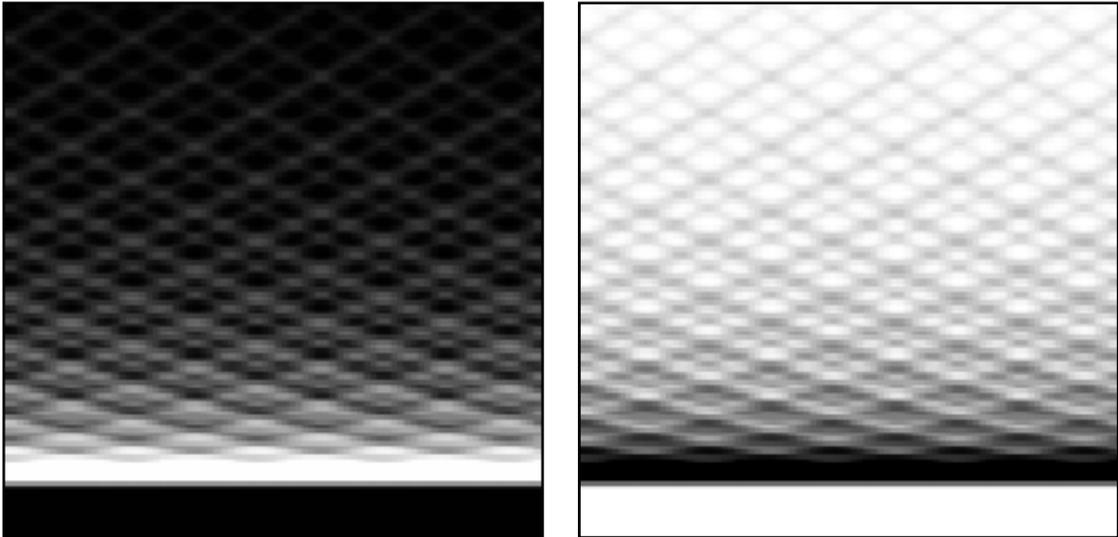
b.- Simulated TOPEX data.

Figure 5. Simulated data for a 24 degree rotation of the satellite about the symmetry axis. The angle from the symmetry axis is 40 deg. The vertical axis is .55 to 1.188 meters (two-way) and the horizontal axis is 0 to 24 degrees rotation about the symmetry axis.

The simulation shows the structure in much more detail than the actual data. If the TOPEX data were all single photoelectron it should show the structure in more detail.
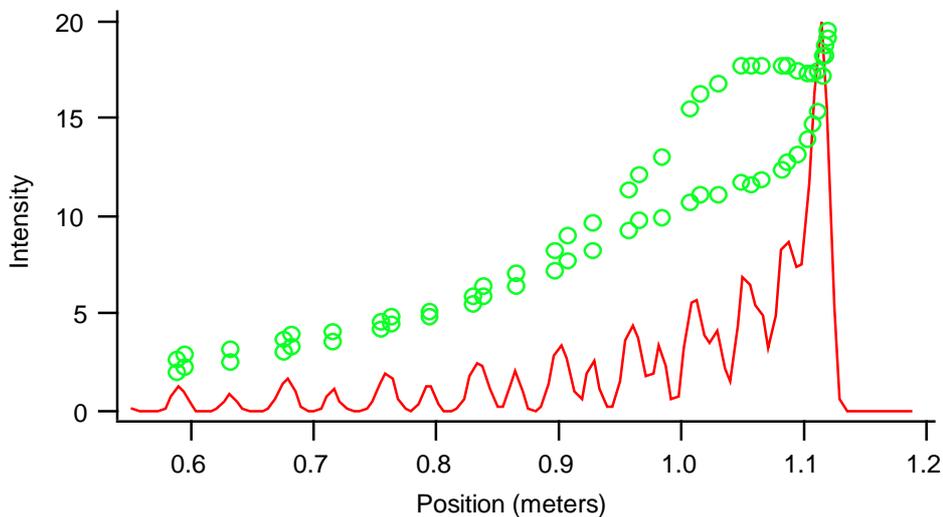
c.- Simulated TOPEX pulse shape.

Figure 6. Pulse shape and distribution of retoreflectors for TOPEX. The incidence angle on the array is 40 degrees. The horizontal axis is two-way meters. The pulse has been truncated below .55 meters to preserve resolution in the plot. The pulse actually starts below 0. meters. The input pulse is 40ps HMFW to simulate the 20ps rms noise in the receiver.

There is more than one retroreflector contributing to each peak. The part of the pulse between .6 and .9 meters shows that the peaks correspond alternately to 2 and 4 retroreflectors.
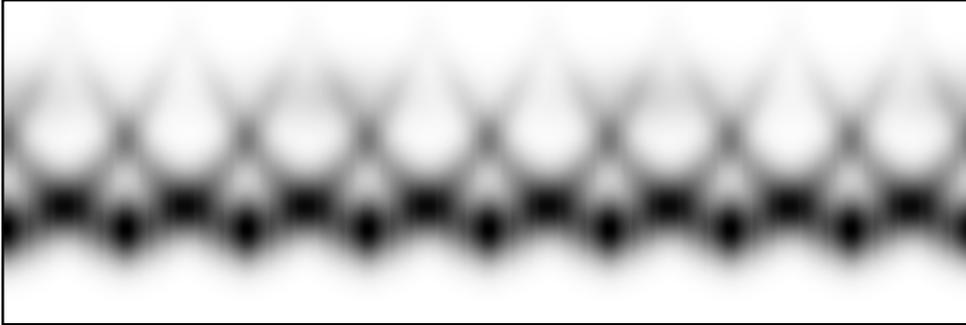
ERS, ENVISAT

a.- Simulated data

Figure 7. Simulation of pulse shape from ERS and ENVISAT which are identical arrays. The horizontal axis is from 0 to 360 deg (one revolution). The vertical axis is from .046 to .119 meters. Polarization is irrelevant since the cube corners are coated. The velocity aberration is (0,35) microradians. The input pulse width is 40ps FWHM to simulate the 20ps rms noise. The ERS type arrays have a pole cube and 8 cubes tilted at a 50 degree angle with respect to the symmetry axis. The incidence angle on the array is 40 degrees. The figure shows 8 similar segments as the array rotates through one complete revolution. The first 1/8 of the simulated data looks similar to the actual data in Figure 8.
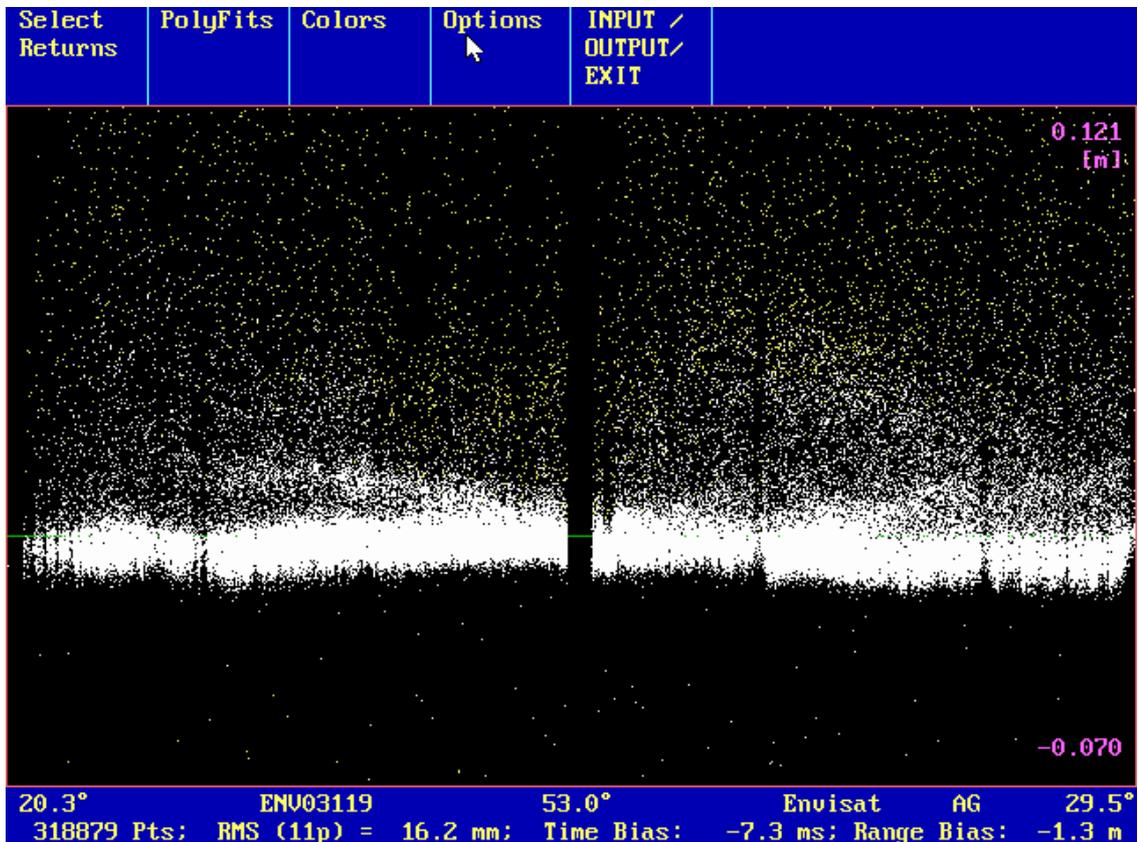
b.- Actual ranging data.

Figure 8. Plot of about 300 k data points from ENVISAT. The data shows evidence of a second track in parts of the plot.
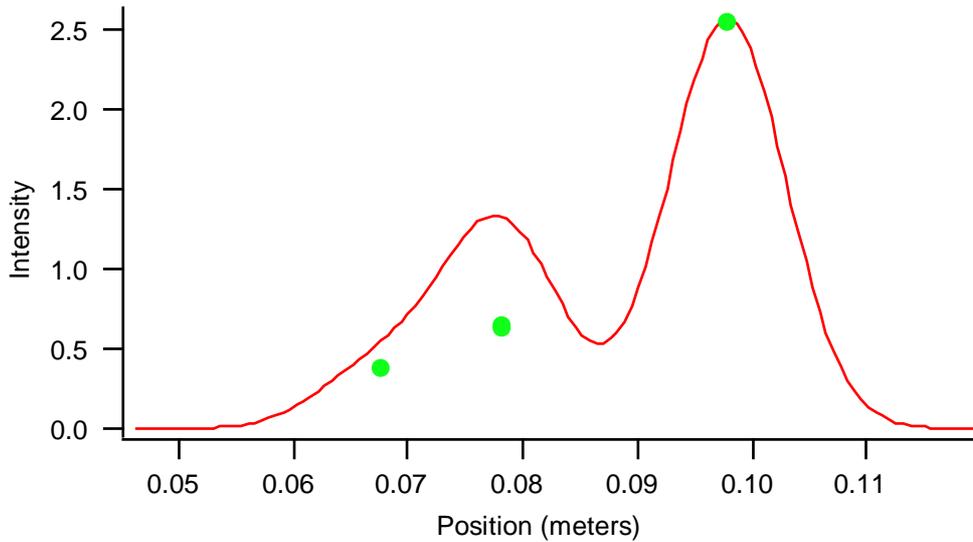
c.- Simulated return pulse shape.

Figure 9. Pulse shape (red curve) and position of cube corners (green dots). The middle dot is actually two cube corners at the same distance. The first retro in the table is the closest one in the ring of 8. The next two are the adjacent cubes in the ring. The last retro is the pole cube.

JASON 1 (see SPWG website)

LAGEOS-2

Plots of tracking data from LAGEOS-2 do not show the kind of tracks shown in Figure 1 for LAGEOS-1. This is an unexpected result since the arrays are identical except for the placement of the infrared cube corners. The explanation has to do with the rotation rate. The rotation rate of both LAGEOS satellites decreases with time. The rate for LAGEOS-1 is very low since it has been in orbit since 1976. On the other hand, the rotation period of LAGEOS-2 is a few minutes.

For LAGEOS-1 the incidence angle on the satellite will change as a result of the orbital motion even if the satellite is not rotating. However, it is possible to accumulate a lot of data before the incidence angle changes significantly. For this reason the plots of the data show the variations in the pulse shape. For LAGEOS-2 the incidence angle changes too rapidly to allow the accumulation of enough data to form a good single photoelectron histogram at each orientation.
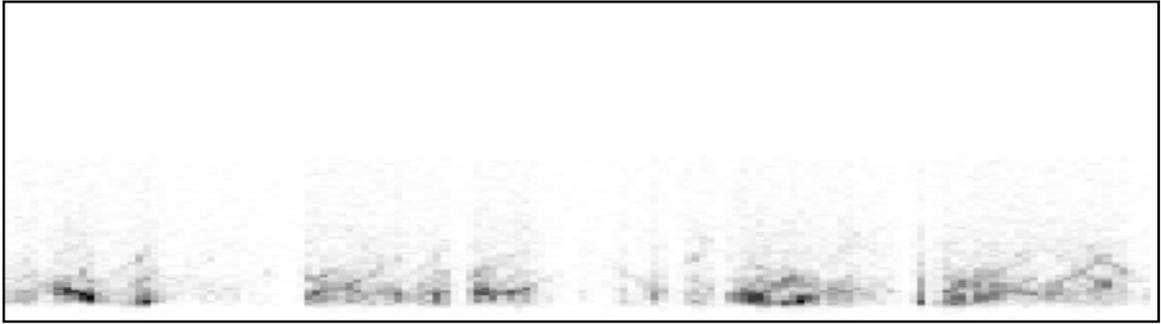
Figure 11. (see SPWG website)

Figure 12. Plot of measured LAGEOS-2 data from 60730 to 60873 sec (143 sec interval).

Figure 13. (See SPWG website)

Being able to see tracks in LAGEOS-2 data is basically a question of signal to noise. In order to improve the signal to noise ratio, some LAGEOS-2 data has been averaged by creating bins that are one second long and 20 picoseconds in range. The results are displayed as gray scale plots in Figures 11, 12, and 13. There are gaps in the data and the structure is still not as clear as one would like. However, there are places in each of the plots that appear to show the same kind of structure seen in the simulated data of Figure 2b.

A new method of applying range corrections.

The fact that the Graz data is capable of taking enough data to create a histogram of the pulse shape in a reasonably short period of time suggests an alternative way of correcting the range for the geometry of the retroreflector array. If the orientation of the array is know, it is possible to compute the positions of the individual retroreflectors along the line of sight and calculate the return pulse shape using the intensity of the reflection from each cube corner. This can then be compared to the measured pulse shape to determine the range correction to the center of mass. This is discussed in detail in the appendix.

Reference

1. "Retroreflector Array Transfer Functions" by David A. Arnold, 94 Pierce Road, MA 02472-3035 617-924-6812, Proceedings of the 13th International Workshop on Laser Ranging, October, 2002, Washington, DC. Also available on the website of the Signal Processing Working Group of the ILRS at http://nercslr.nmt.ac.uk/sig/signature.html

Appendix (See SPWG website)