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

(Thomas) <Varghese, Zagwodzki, Oldham>
NASA GSFC/ Cybioms Corporation, USA

Paper presented at the International Technical Laser Workshop 2012(ITLW-12),
Nov 5-9, 2012, Frascati (Rome), Italy

Acknowledgement:
In addition to the above authors, the Lageos 2 test team included: Peter Minott and Joe Dallas (From NASA GSFC) and Mike Selden (AlliedSignal); we thank them for their significant contributions.

Lageos 2- Scope of Satellite Test Revisit

1. Will the SLR Ranging accuracy of the space segment launched during the last 30+ years suffice for the next "30+" years of the space geodesy program?

2. Will the L1 and L2 Ranging accuracy meet the needs of GGOS in the future?
3. What did we learn from the extensive pre-launch L1, L2 lab measurements/ computations?
4. How do we exploit the best accuracy from a S/C with a "fuzzy" impulse response?

5. What ground based technologies and data processing techniques permit maximally leveraging the satellite capability / constraints, NOW and in the FUTURE?

Lageos 2 – Leveraging On-orbit Performance

Space Segment <FIXED>

- CCR → Point target in space → (Best Range accuracy, Reduced Lidar Cross-section);
- Array → "Fuzzy" Depth function → (Reduced Accuracy, Increased Lidar Cross-section);
- Array → Multi-parameter Dependencies;

How do we minimize ARRAY induced issues?

Ground Segment <CHANGEABLE>

- Type of TX (Laser Pulsewidth, Wavelength, Polarization)
- Type of RX (Detection and Signal processing Type, Detection Levels, …)
- Observing Geometry: Location of the RX in the FFDP and its variance;
- Data Edit / Processing Criteria & Modeling: Removing Skewness, Multimodal Distribution,.. etc.

Lageos 2 – Optical Characterization Approach

Measure/ Compute / Deduce the following and their dependencies for the Space environment

1. Target Impulse Response Function
2. Range Correction (RC) to Center of Mass (CoM)
3. Lidar Cross-section

1. CW Measurement/ Computation
   a) Illuminate the entire satellite/ individual Cubes using CW Lasers
   b) Measure the FFDP of contributing Cubes; Synthesize an Integrated Response of the satellite;
   c) Determine the temporal Response by (1) Convolving the Satellite Depth Function with GND system characteristics (2 convolutions) and (2) Compute Center of Mass (Com);
2. Pulsed Measurement/ Processing
   a) Illuminate the entire satellite using Short Laser pulses
   b) Image/ Measure the satellite response using multiple fast detectors;
   c) Compute the CoM from: (1) direct range measurement ; (2) waveform analysis

Precision, Accuracy, Stability → sub millimeter corrections

Lageos 2 – Pulsed Measurement – Parameter Space

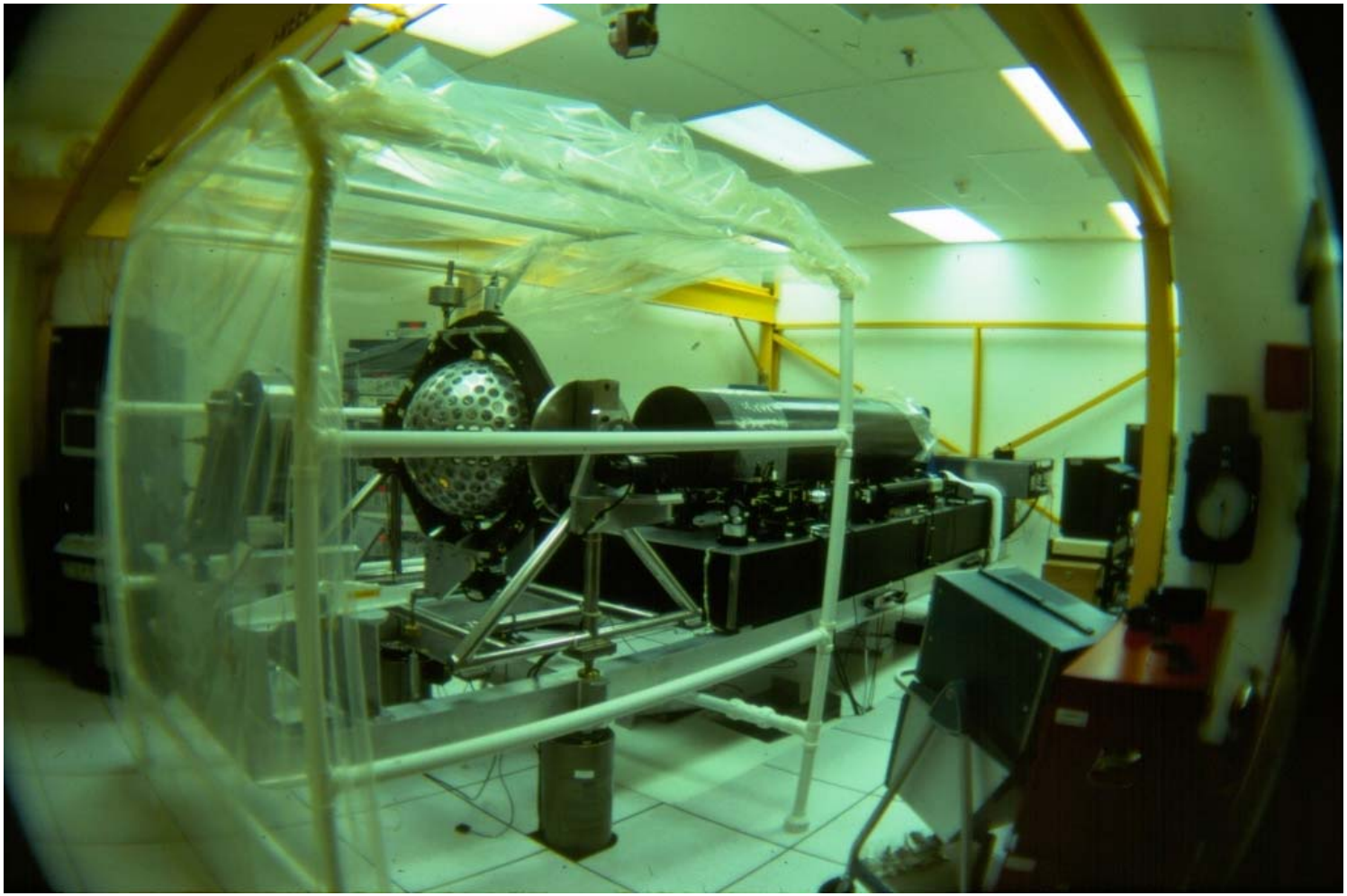
				Pulsed				
TX	TX	TX	S/C (θ,ϕ)		FFDP	FFDP	RX	Receiver
Pulse width	λ	Polarization	Orientation		Whole	Piecewise	Type	Signal
20 ps	355 nm	Horizontal	60		Annulus	0	Centroid	Low
30 ps	355 nm	Vertical	61			45	Peak	High
25 ps	532 nm	Circular	62			90	Half Max	
37 ps	532 nm		63			135	CFD	
67 ps	532 nm		64			180		
128 ps	532 nm		65			225		
	1064 nm		66			270		
			67			315		
			68			360		

Lageos 2 – Pulsed Laboratory Measurement

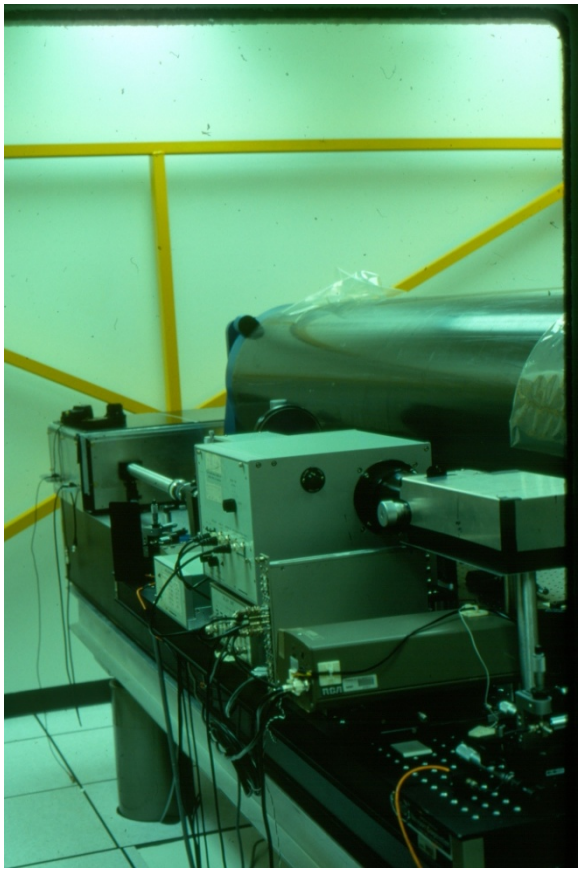
Approach: Measure temporal response of the S/C by illuminating the S/C with a diffraction limited pulsed laser beam and instrumentation – Complex Expt to setup, validate, and sustain at that time;

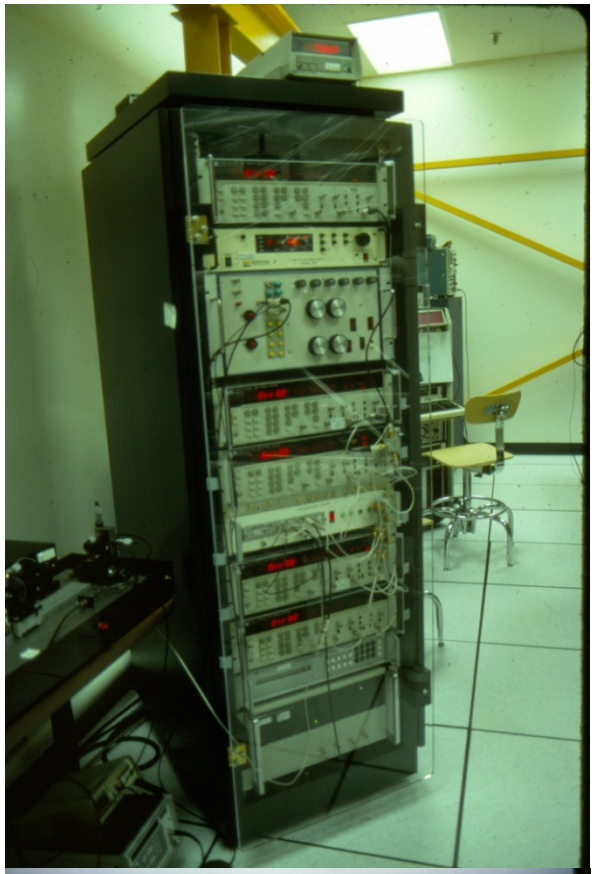
- Laser Transmitter (Nd:YAG)
  - 2nd harmonic <532nm> output of the of YAG laser;
    - Pulse width, <30, 60, 150 ps>; Polarization, <Linear, circular>
  - 3rd harmonic <355nm> output of the of YAG laser;
    - Pulse width, <20, 30 ps>; Polarization, <Linear, circular>
- Laser Receiver
  - Streak Camera + Frame Grabber + Optical Cal + Processing → 2ps resolution, accuracy;
  - MCP-PMT + CFD + TIU stack + Optical Cal + Processing → 2ps accuracy, stability over the range of the depth function of the S/C;
- Receiver FOV
  - Measure within the annular region of 32-38 μradians OR limit to 6 μradian using a pinhole

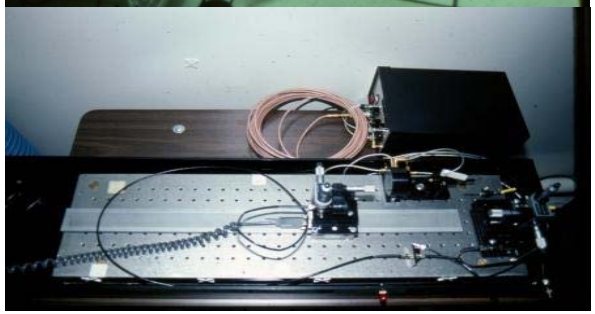
Lageos 2 – Laboratory Measurement



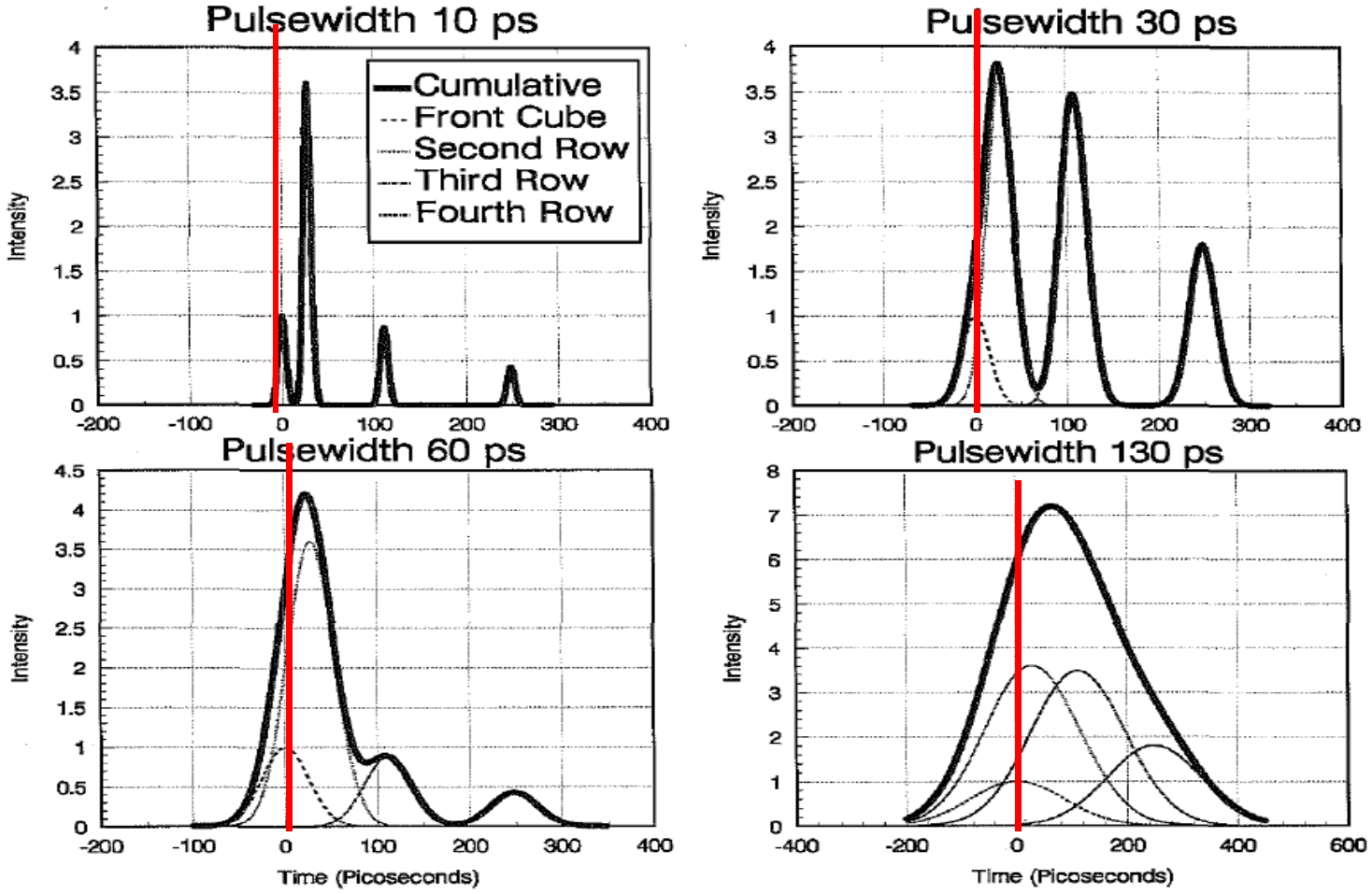
Lageos 2 – Pulsed Measurement - Instrumentation





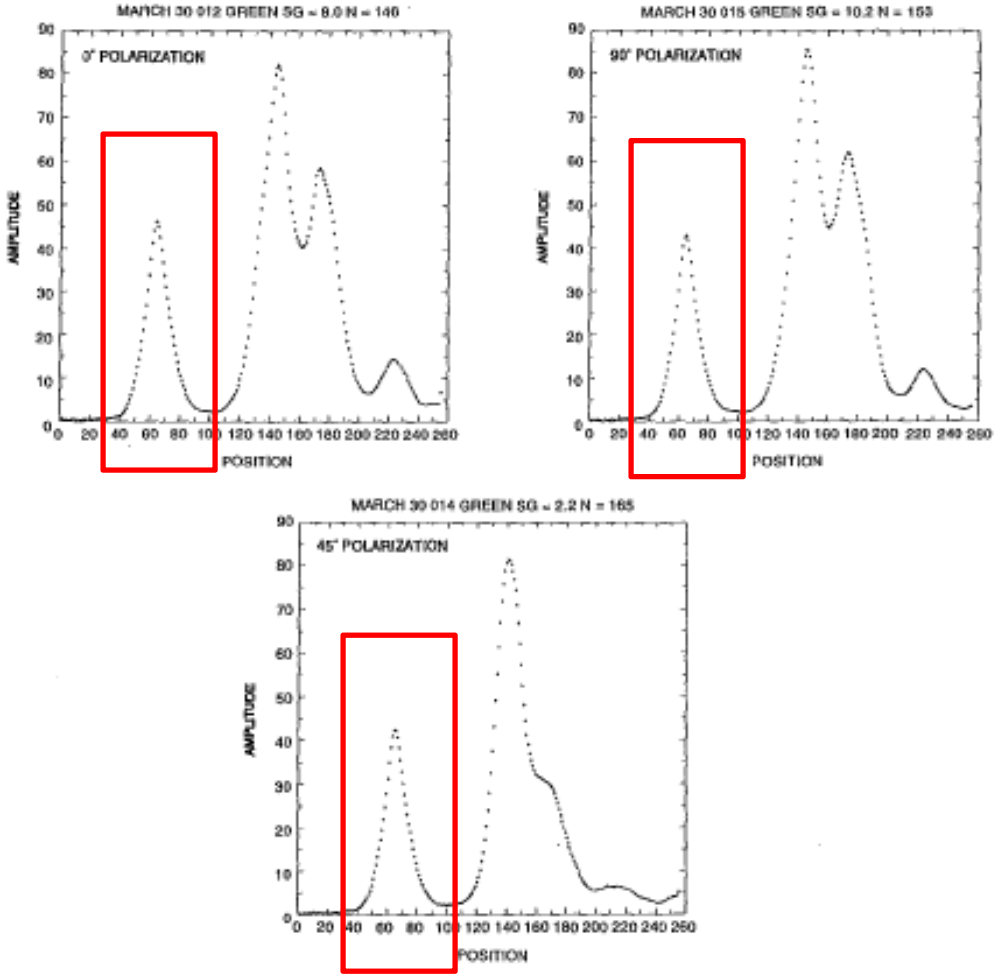


Lageos 2 – Temporal Response - Simulation



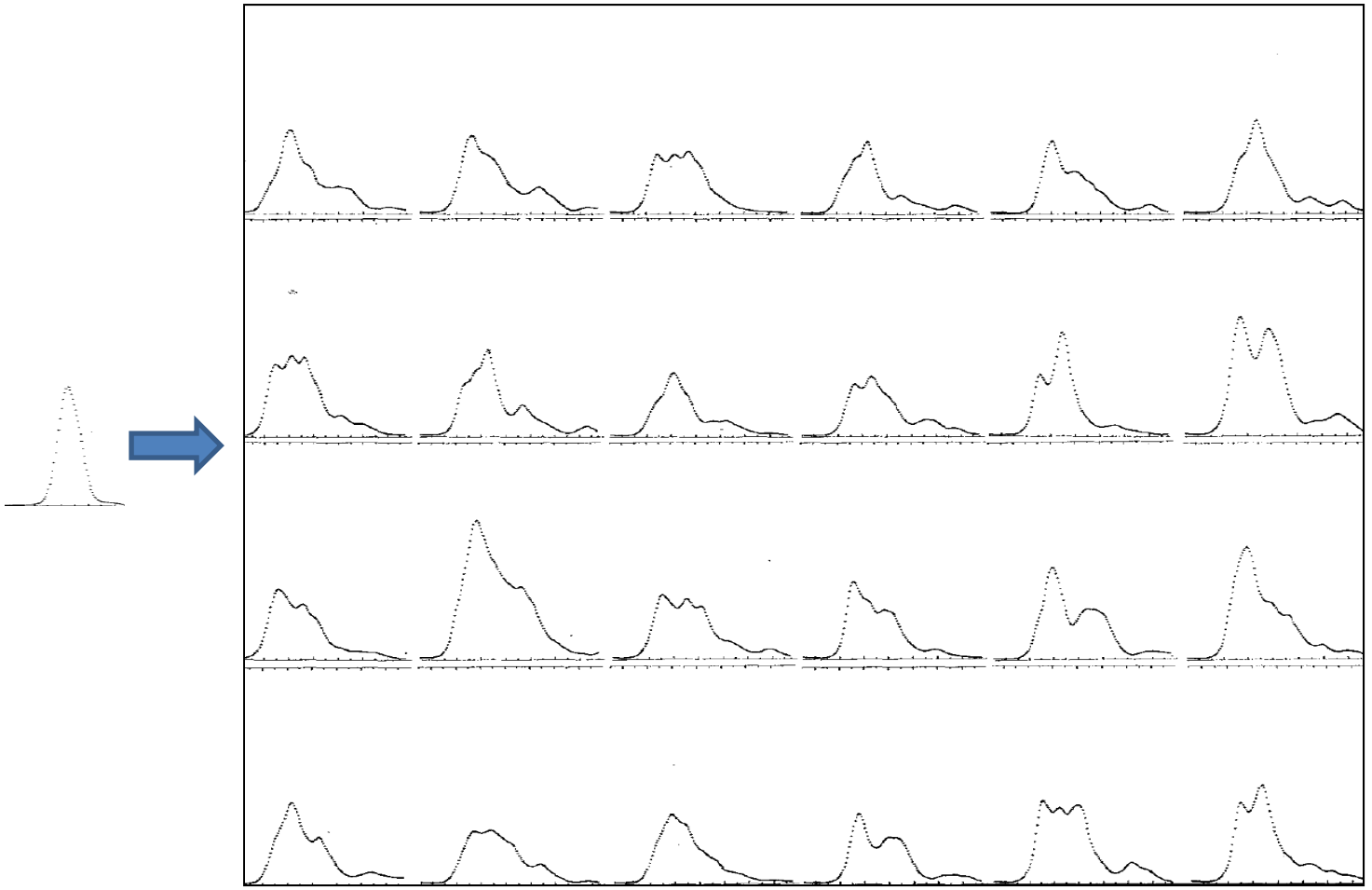
1. Simulation of Satellite Return for various Pulse widths;
2. Orientation is the polar region; shorter pulses have fully resolved temporal response

Lageos 2 – RC due to Temporal Broadening



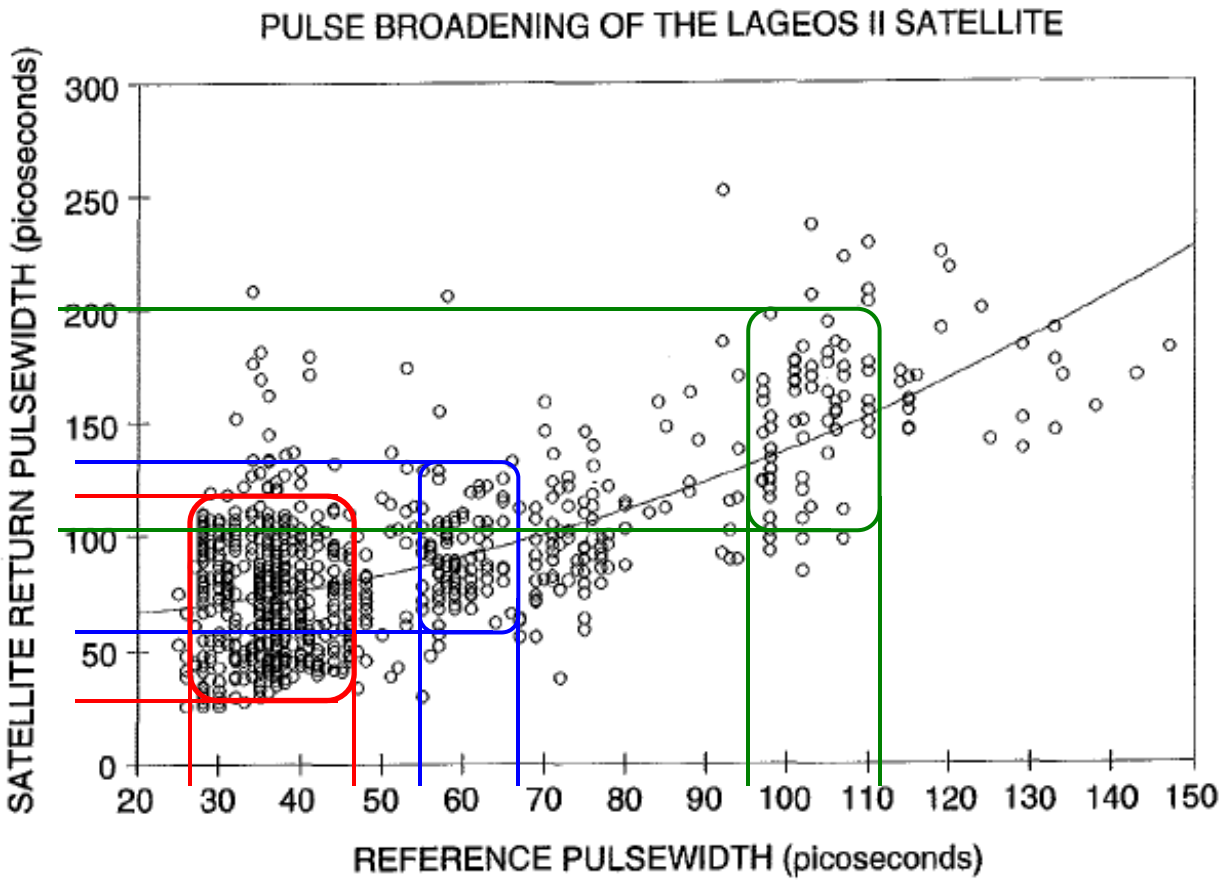
1. Measured Satellite Response (vs. Polarization) using a Streak Camera with 2ps resolution;
2. Reference Pulse is shown in RED Box taken in the same sweep;

Lageos 2 – Effect of Pulse Spreading



1. Reference Pulse and Satellite (random orientation) Return on a Streak Camera;
2. Effect of coherent Interaction through the complex structure seen in the waveform;

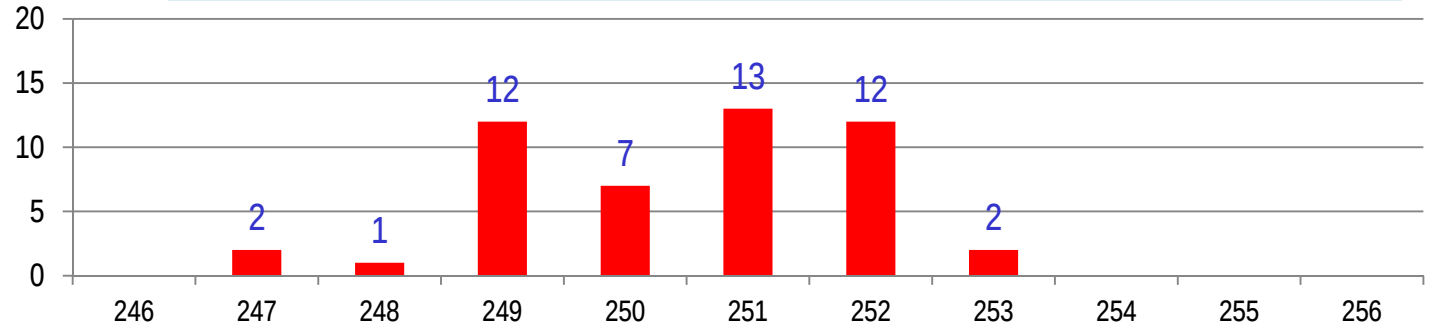
Lageos 2 – Pulsed Measurement- Temporal Broadening



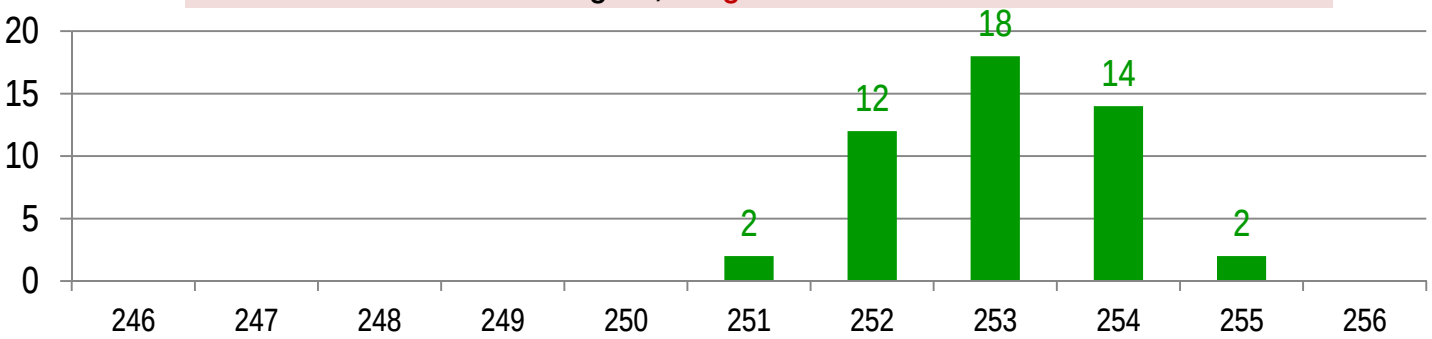
4 different pulse widths → 30, 37, 60, 105ps
Broadening of the pulse width (FWHM) by as much as 100ps

Lageos 2 – RC vs. Polarization – SLR Receiver

Range Correction (mm) vs. Satellite orientation Histogram for the Equatorial Region for a 130ps pulse; LINEAR POL. weighted Mean =250.5mm



RC vs. Sat. orientation for the Equatorial Region for a 30ps pulse; CIRCULAR; Pinhole = 0 degree; weighted Mean RC = 253.04 mm



- There is a significant difference in the RC dispersion for Linear vs. Circular Polarization;
- More importantly, the RC correction is symmetric for Circular case vs. Linear Polarization

Lageos 2- Preliminary Inferences!

- What did we learn from the extensive pre-launch L2 lab measurement/ computation?
  - NPT level Range Accuracy at the level of ±1 mm is possible;
  - Parameter dependencies can vary to the tune of +/- 3mm under ordinary conditions;
- How do we exploit the best accuracy from a S/C with a "fuzzy" impulse response? What ground based technologies and data processing techniques permit maximally leveraging the satellite capability?
  - High Power, High rep rate lasers (PW <10ps for minimal /NO coherent interaction) guarantee strong link to the closest cube; use detectors on the leading edge to minimize array effect;
  - Remove Linear Polarization variability/ skewness by using Circularly polarized light;
  - Choose high speed millimeter ranging electronics to resolve multimodal distributions;
  - Liberal editing, Modeling, Pre/Post Filtering, and Shifting to remove skew from the data;