Single versus multi-photon SLR using SPAD detectors

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Presented at

2017 ILRS Technical Workshop, "Improving ILRS Performance to Meet Future GGOS Requirements"
Riga, Latvia, October 02 through 05, 2017

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Key questions #1 – Session 3

- What are the factors that are currently limiting performance: data quantity and quality ?
- Return signal strengths and satellite return rates, single x multiple photons approach …….
- “never ending story…” in SLR

SLR systems performance comparison

- Based on *Quarterly Global Report Cards* published by ILRS www pages.
- Simple averages over 4Q 2016… 2Q2017 all 5 data centers
- Selected 6 SLR sites among the most productive:

1	Yaragadee	multi photon
2	Changchun	single – multi photon
3	Mt.Stromlo 2	single – multi photon
4	Herstmonceux	single photon only
5	Graz	single – multi photon
6	Matera	multi photon

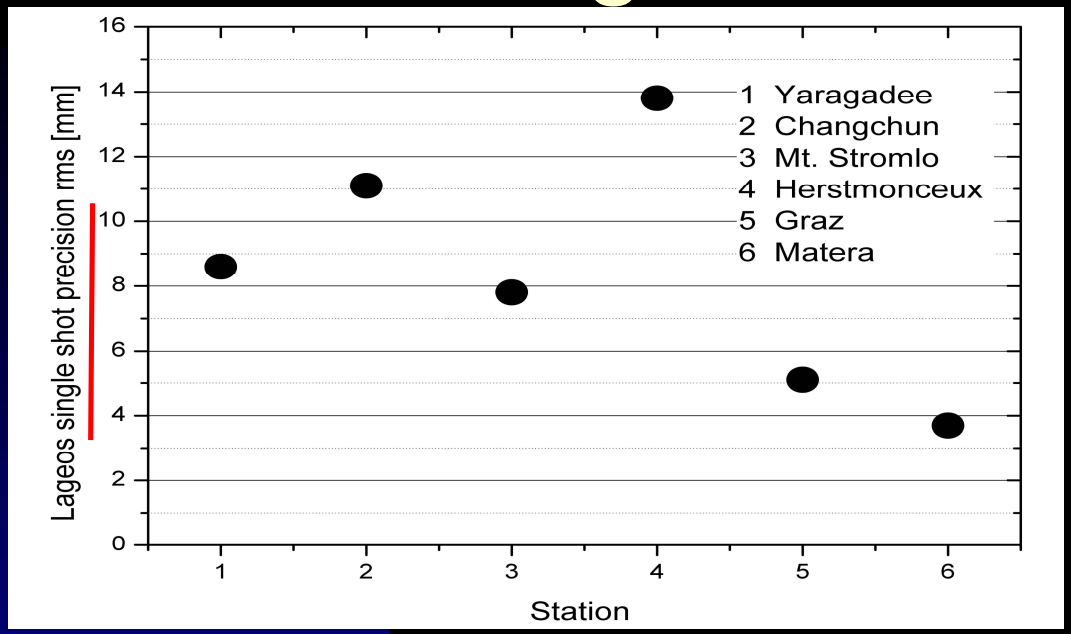
~ identical HW

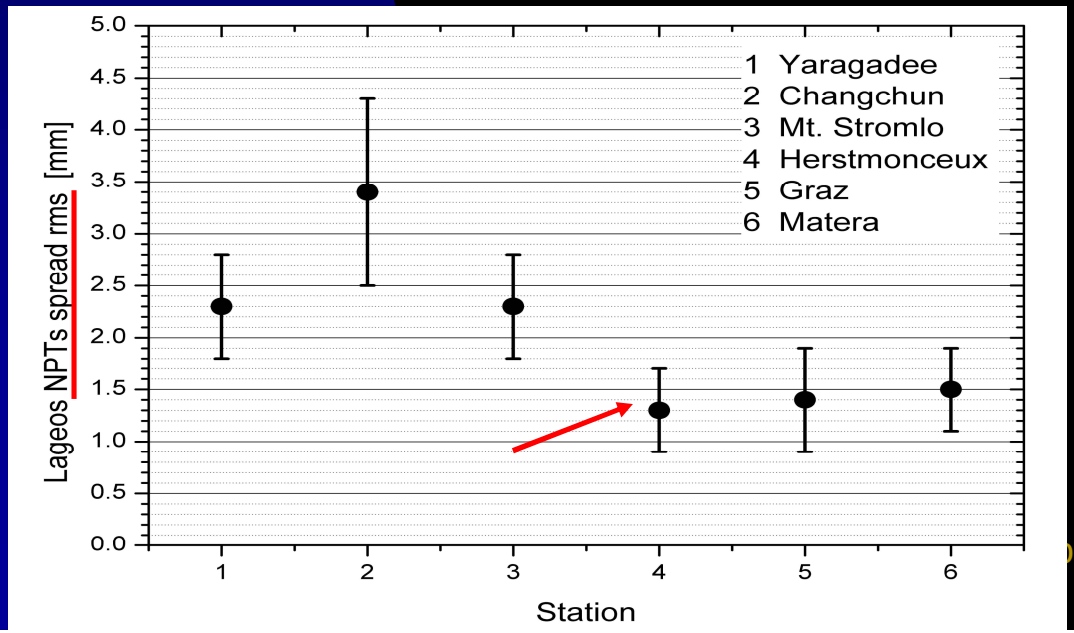
Table 2

Site Information		DGFI Orbital Analysis				Hitotsubashi Univ. Orbital Analysis				JCET Orbital Analysis				MCC Orbital Analysis				SHAO Orbital Analysis			
Station Location	Station Number	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP
Baseline		**10.0**	**20.0**	**10.0**	**95**	**10.0**	**20.0**	**10.0**	**95**	**10.0**	**20.0**	**10.0**	**95**	**10.0**	**20.0**	**10.0**	**95**	**10.0**	**20.0**	**10.0**	**95**
Yarragadee	7090	3.3	14.9	3.0	100.0	2.0	7.1	1.5	100.0	2.2	14.0	3.0	99.3	2.2	17.2	2.9	98.8	1.9	7.8	1.5	93.7
Changchun	7237	4.5	24.1	5.2	99.9	3.1	27.5	5.4	100.0	2.1	33.3	7.3	95.9	2.9	21.0	5.4	97.3	4.5	27.2	9.1	94.7
Mount_Stromlo_2	7825	3.0	17.3	2.9	100.0	2.3	9.7	1.9	100.0	1.8	13.2	3.7	99.7	2.8	15.2	3.4	97.5	1.7	10.4	2.1	95.8
Herstmonceux	7840	1.8	10.8	2.3	100.0	1.0	6.5	1.3	100.0	1.1	10.3	2.6	100.0	1.6	10.3	1.9	99.7	0.8	6.5	2.8	97.7
Zimmerwald_532	7810	2.7	11.1	3.0	100.0	1.7	7.5	1.5	100.0	1.9	10.8	3.1	99.8	2.9	11.9	1.7	97.5	1.7	7.6		94.8
Wettzell	8834	3.0	13.1	6.5	100.0	2.3	8.9	6.2	100.0	1.8	12.2	5.9	99.6	2.5	10.5	7.4	98.3	1.6	10.9	8.2	95.0
Graz	7839	2.0	9.1	3.5	100.0	1.5	6.2	2.3	100.0	0.9	11.1	4.0	99.3	1.8	8.5	3.5	97.1	0.6	8.8	2.5	96.1

SLR systems performance comparison # 1

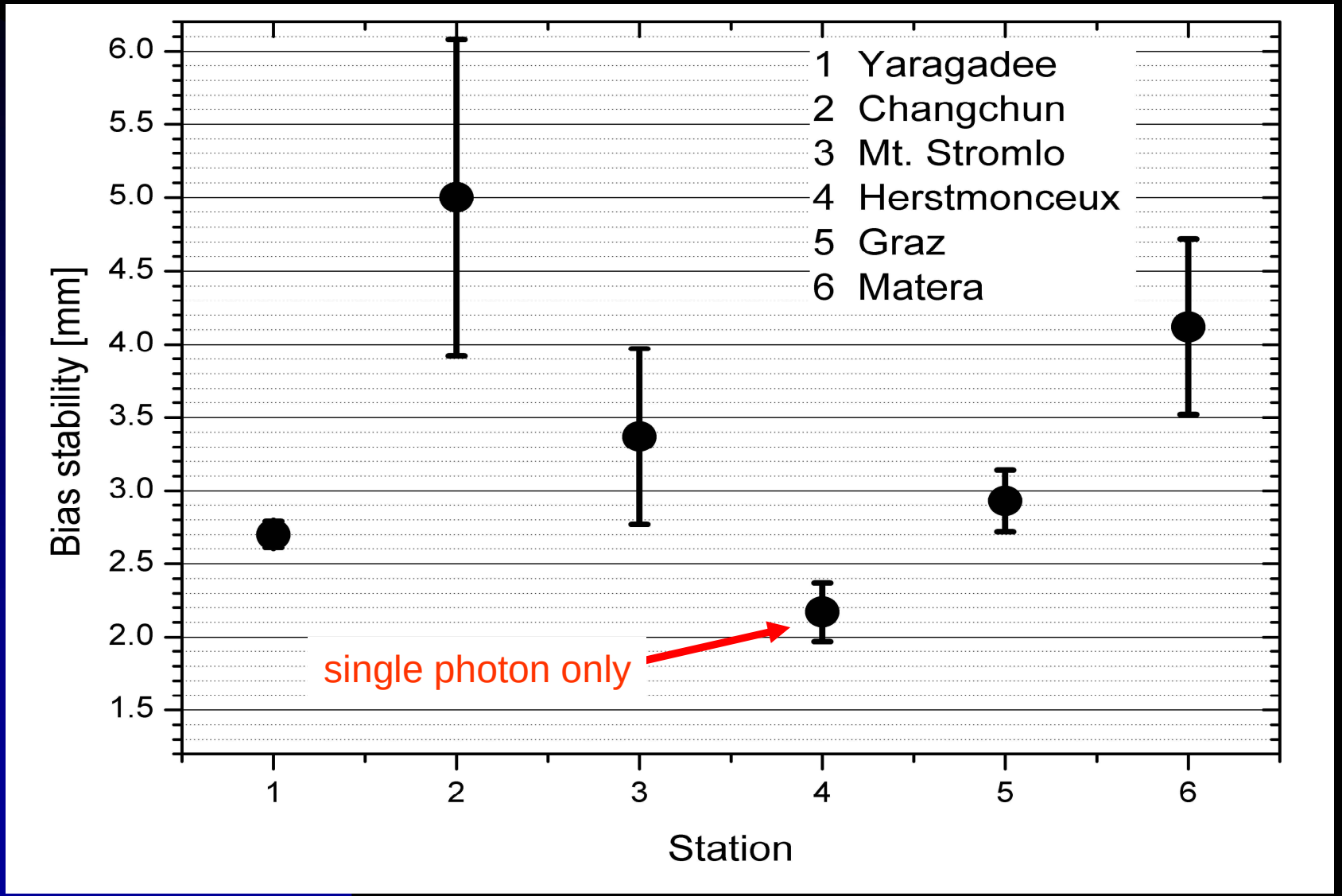
Lageos Precision





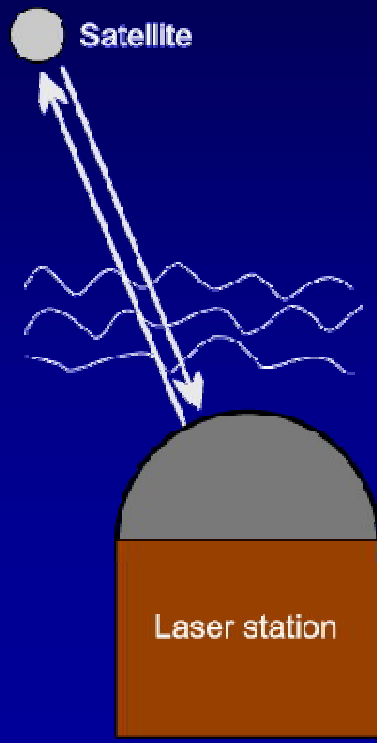
- Stations 2,3,4,5 are using C-SPAD detector by F.Koidl, Graz

SLR systems performance comparison # 2
Bias long term stability



Workshop goals #2

Prochazka et al, 19th ILRS Workshop, Matera, 2015



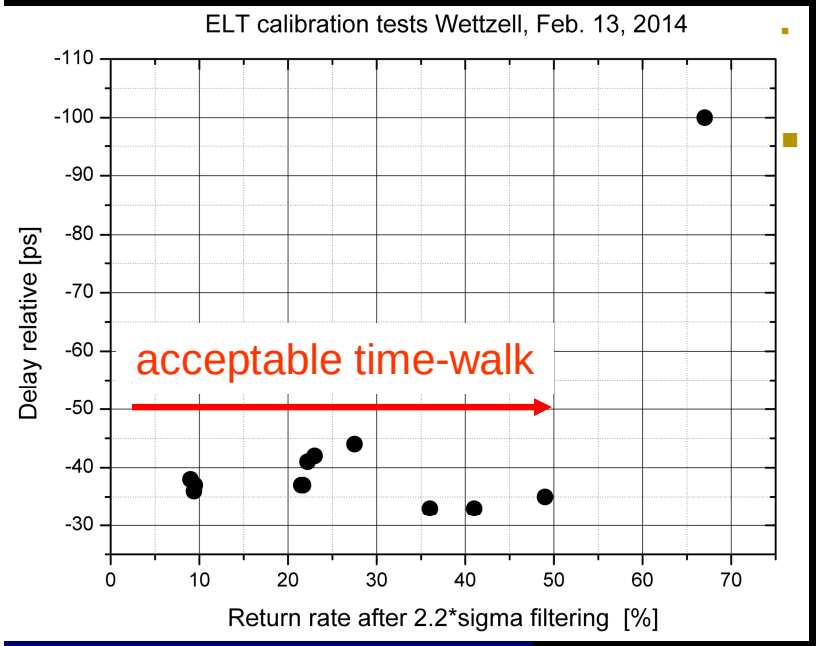
- “What changes in procedures and processes would give the stations greater ability to detect biases ? “
- ANSWER
  “1 photon only “ approach

- => missing time walk effects
- => reducing target spread problem

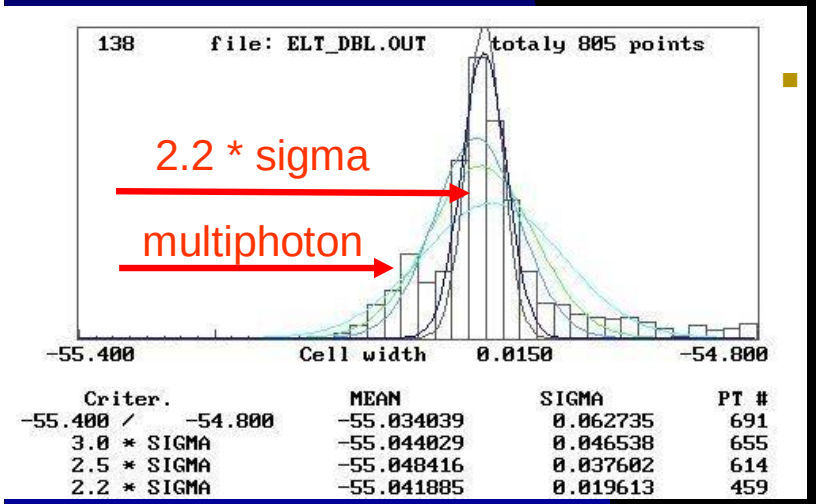
Key questions #2 – Session 3

- For single photon "..The current philosophy is to reduce return rate to about 10% to try to capture primarily singles".
- "What would we lose if we expanded the capture rate to 20%, 30% or more? "
- Two key issues
  - Echo signal detector response
  - Target response

Key questions #2 – Session 3
SPAD DETECTOR RESPONSE



GOOD NEWS
Using 10 ps laser pulse @ 532 nm
SPAD detector can operate up to 50% rate with negligible (< 1mm) time walk when applying 2.2*sigma data editing
(J.Kodet, J.Eckl, Wettzell, 2014)

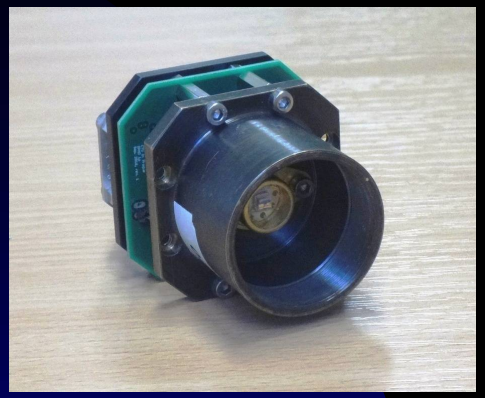


Criter.	MEAN	SIGMA	PT #
-55.400 / -54.800	-55.034039	0.062735	691
3.0 * SIGMA	-55.044029	0.046538	655
2.5 * SIGMA	-55.048416	0.037602	614
2.2 * SIGMA	-55.041885	0.019613	459

BUT
This feature can be utilized for ideal targets only, laser time transfer or one way ranging.

Echo signal spread by target depth will cause a significant time walk for rates > ~ 15 %

New single photon only SPAD detector for SLR



- SLR and laser time transfer ground segment

- 200um TE3 cooled SPAD
- New control circuit (8 GHz bw)
- Output pulses fall times ~ 40 ps
- Low noise for kHz reprates

- **Jitter (single shot)** **1.5 mm rms**
- **Low temperature drift** **< 70 fs/ K**
- **Timing stability TDEV** **< 80 fs @ hours**

- Field version is under construction now.
- More details on the Poster

CONCLUSION

- Answers to several key questions:
- Single photon only approach is providing the best bias stability and the lowest NP spread while maintaining high station Lageos productivity (Herstmonceux).
- Echo rates up to 50% can maintain sub-mm biases using < 10ps lasers and zero depth target.
- New SPAD detector provides 1.5 mm single shot jitter and extremely high timing stability and low drift.
- My dream – zero target signature geodetic satellite (uncoated Luneburg sphere on ~ Lageos orbit)