Federal Agency for Cartography and Geodesy

BKG
Wir geben Orientierung.

Two Color SLR at the WLRS – Scope & Limitations

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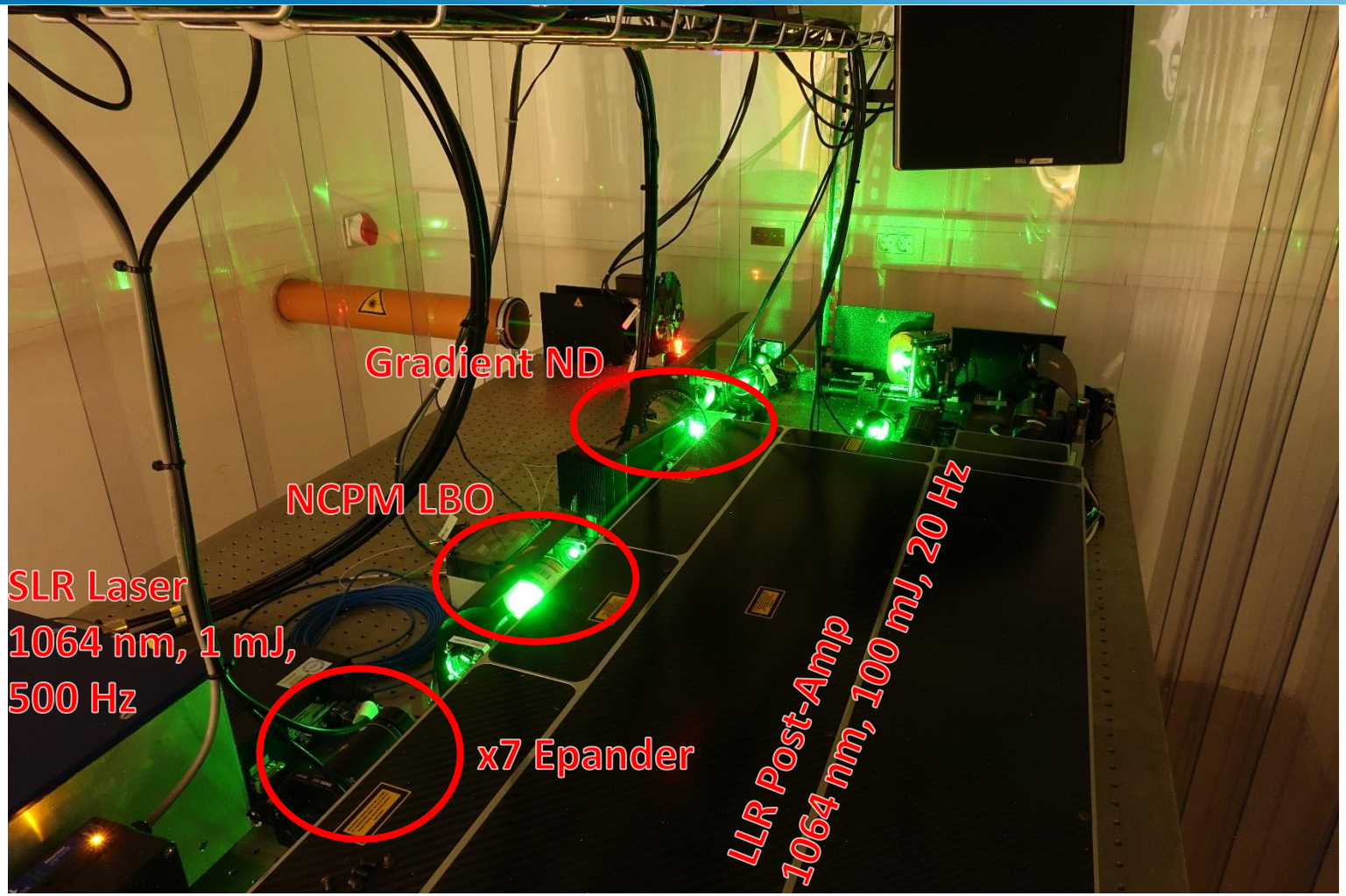
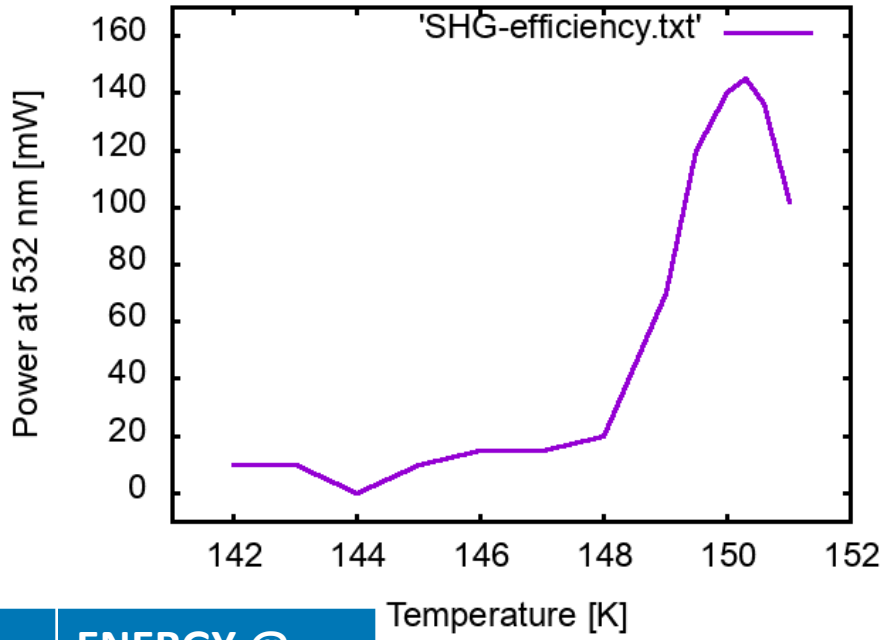
2022nd ILRS Workshop - YEBES

Setup
- transmitter -



Setup
- operating modes -

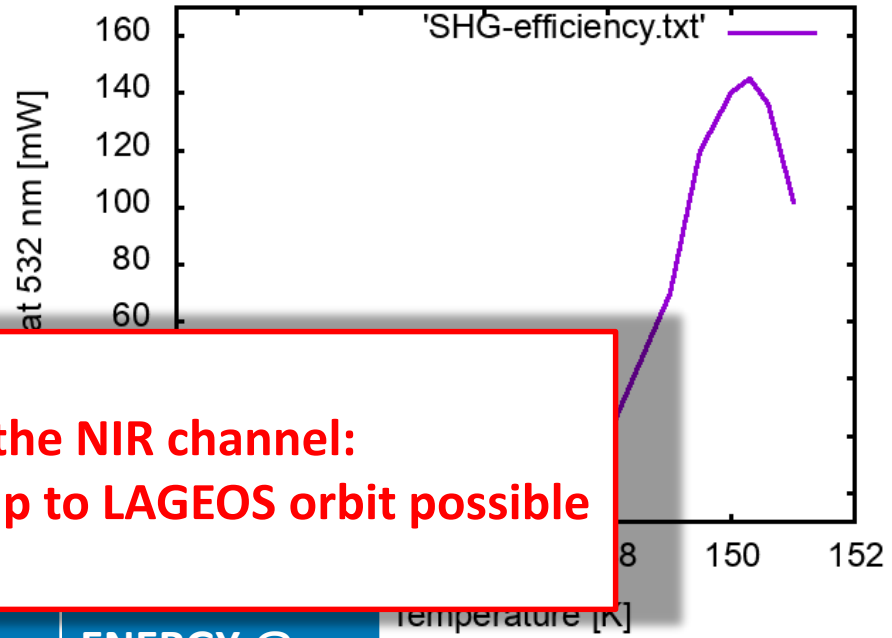
- 3 operating modes
- SHG temperature detuning to switch to two color SLR
- NCPM crystal -> no spatial walk-off
- Pointing offset < 1.5 arcsec
- ONLY 25% conversion efficiency



MODE	REP-RATE [Hz]	ENERGY @ 1064 nm [Hz]	ENERGY @ 532 nm [Hz]
SLR	500	~ 1.2	---
Two Color SLR	500	~ 0.9	~ 0.3
LLR	20	~ 75 & 50	---

Setup
- operating modes -

- 3 operating modes
- SHG temperature detuning to switch to two color SLR
- NCPM crystal -> no spatial walk-off
- Pointing offset < 1.5 arcsec
- ONLY 2!



To avoid losses in the NIR channel:
TWO COLOR SLR @ WLRS ~ up to LAGEOS orbit possible

MODE	REP-RATE [Hz]	ENERGY @ 1064 nm [Hz]	ENERGY @ 532 nm [Hz]
SLR	500	~ 1.2	---
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LLR	20	~ 75 & 50	---

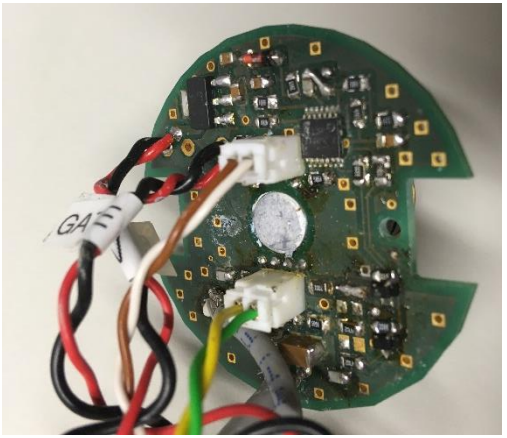
Setup
- receiver -

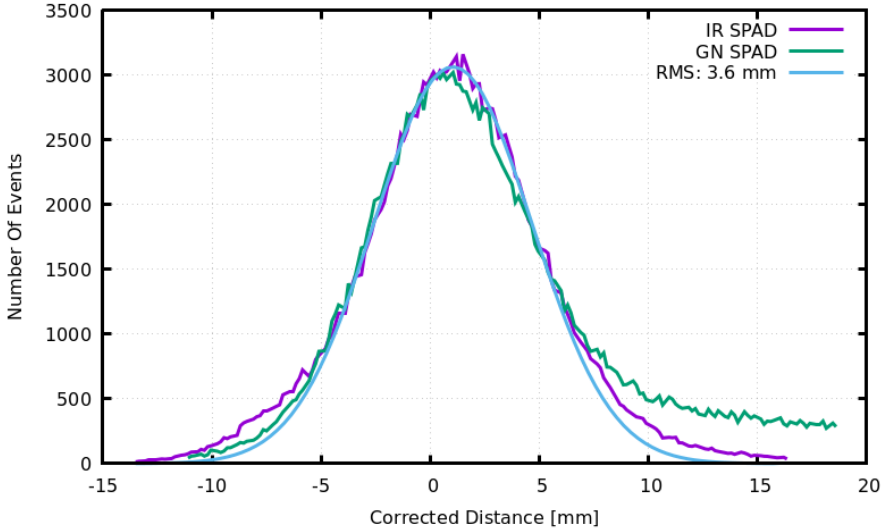
SAP300 (LaserComponents)

- SPAD (custom active quenching)
- ~ 100 V above breakdown
- Cooled to -15 °C
- Timing ~ 3.6 mm RMS
- QE ~ 85 %
- Dark Noise ~ 6.5 kHz

PGA-200-1064 (RMY Electronics)

- SPAD (custom passive quenching)
- ~ 20 V above breakdown
- Cooled to -50 °C
- Timing ~ 3.6 mm RMS
- QE ~ 75 %
- Dark Noise ~ 180 kHz





Setup
- receiver -

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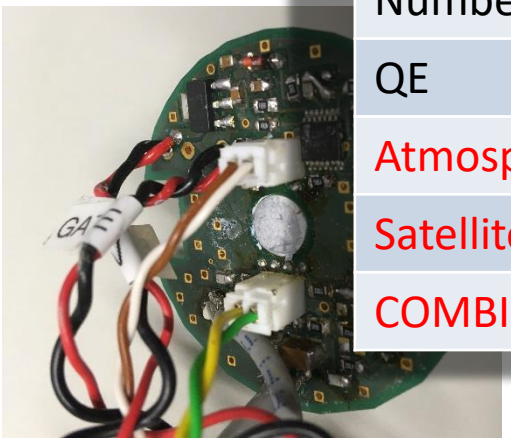
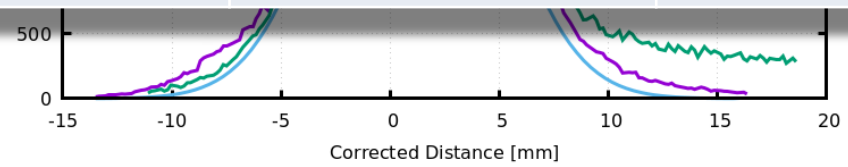
- QE ~ 85
- Dark No

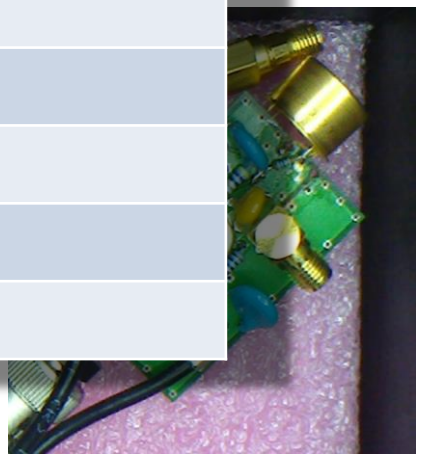
PGA-200-1064 (RMY Electronics)

- SPAD (custom passive quenching)
- ~ 20 V above breakdown
- Cooled to -50 °C
- Timing ~ 3.6 mm RMS

CHANNEL	GN	NIR
Laser	0.33	1
Number of Photons	0.5	1
QE	1	0.88
Atmosphere	~ 0.8 ?	1
Satellite	1	0.25 ?
COMBINED	**0.67 ?**	1

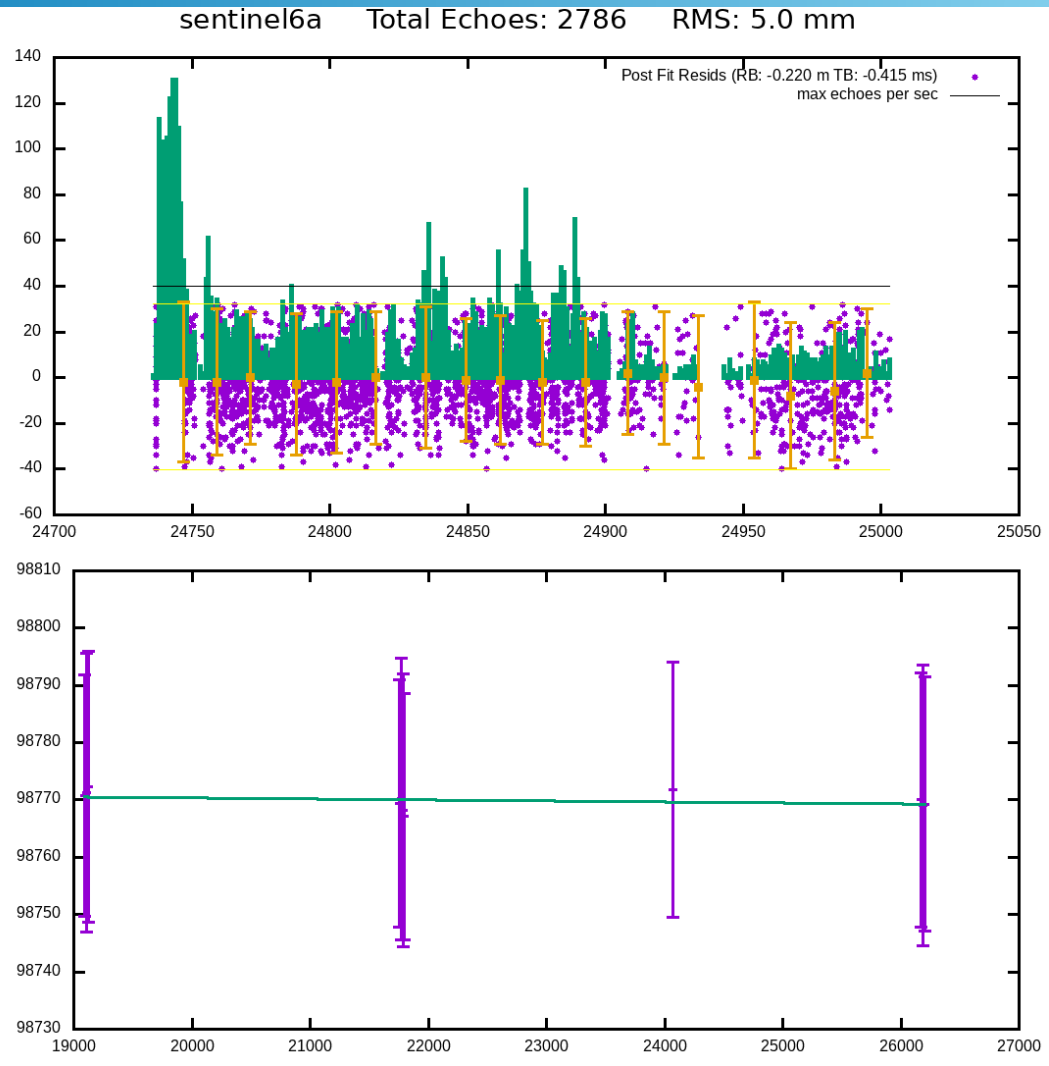






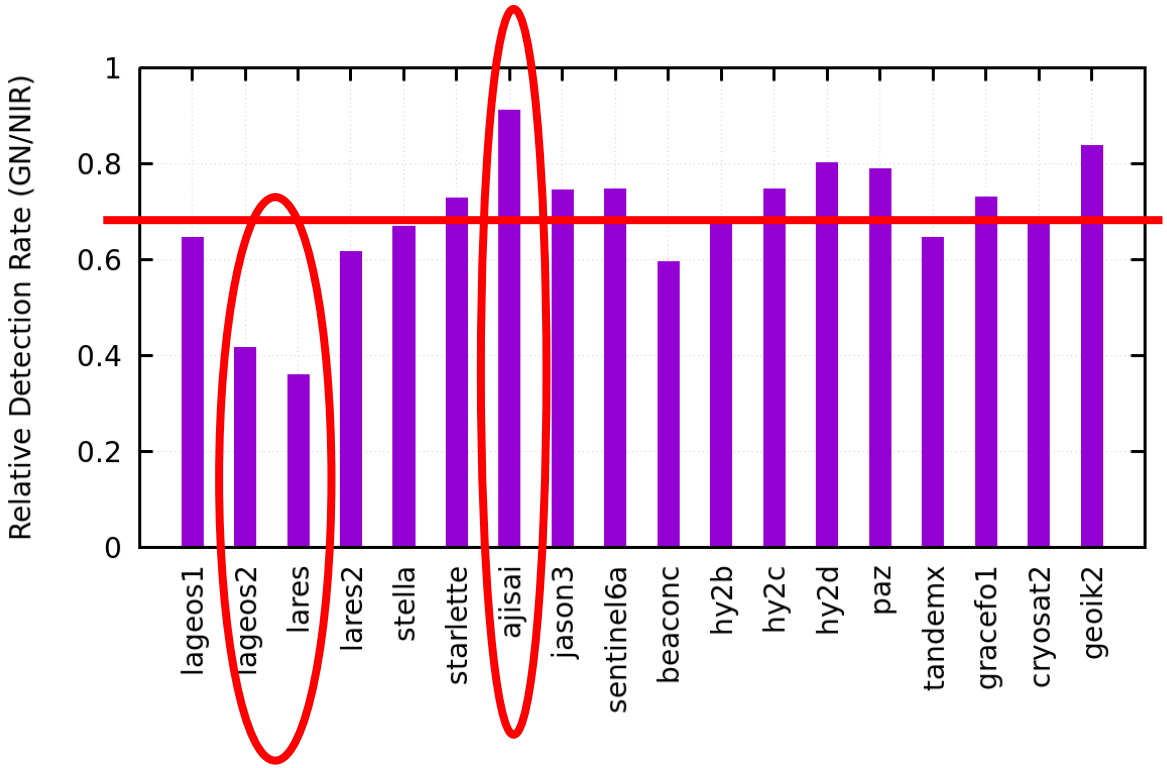
Setup
- summary -

- Two color SLR operational since 08/2022 (up to LAGEOS orbit)
- Total >3500 NPs up to now
- Focus on 1064 nm channel
  - Echoe rate control (< 10 %)
  - Telescope pointing
- Fully automated operation
  - Reproduceable algorithms
  - Automated echoe extraction & NP generation
  - No human interaction
- Relative detection efficiency expected to be < 67 percent



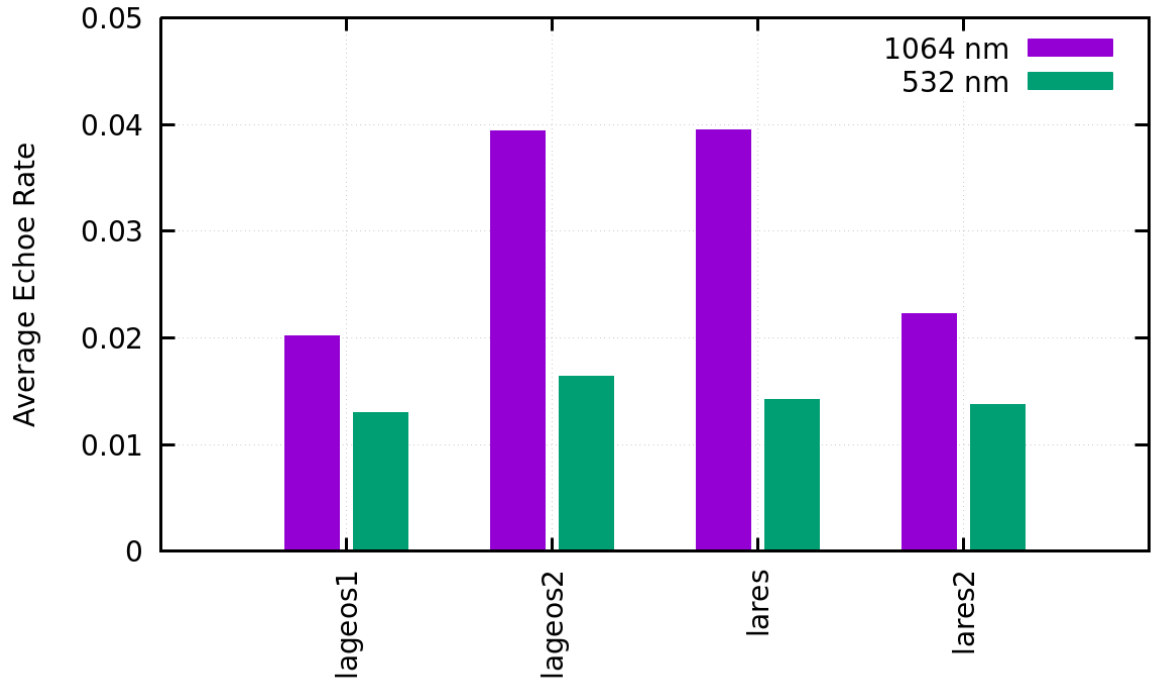
Two Color Ranging
- Relative Detection Rate (GN/NIR) -

- Determination of relative detection rate in the lab (calibration) difficult, depending on diffraction pattern & filter transmission



Two Color Ranging
- Absolute Echoe Rate (geodetic Sats) -

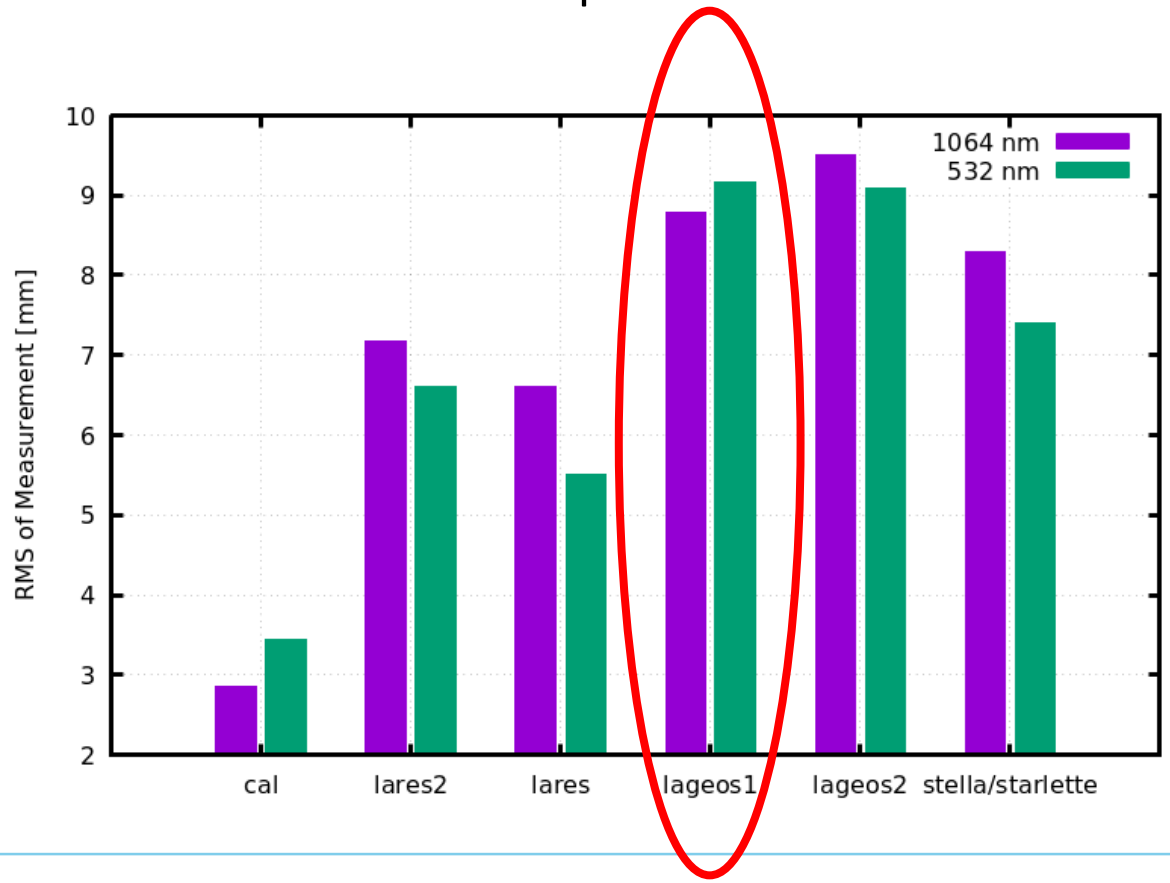
- Based on evaluation of echoe rate in 1 sec time intervals
- Echoe Rate adjustment based on 1064 nm channel



- LAGEOS1 similar to LARES2 (GN & NIR)

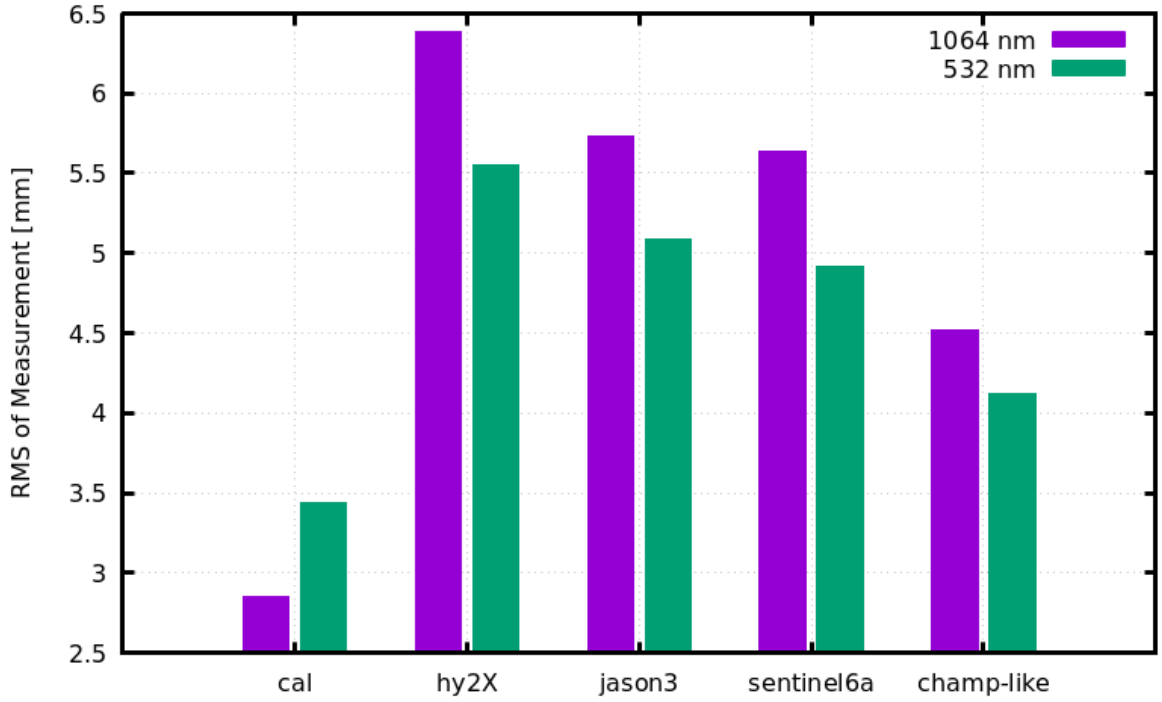
Two Color Ranging
- RMS (geodetic Sats) -

- Average RMS of NormalPoints based on RGO-algorithm (2.2 sigma clipping)
- RMS of 532 nm channel better except for LAGEOS1



Two Color Ranging
- RMS (LEOs) -

- NP RMS of 532 nm channel better for LEOs



Atmospheric Delay
- Basics -

- Requirements on detection delay measurement between both detection channels challenging:

$$\Delta R(1064\ nm) = \underbrace{\frac{f_{Gr}(1064\ nm)}{f_{Gr}(532\ nm) - f_{Gr}(1064\ nm)}} * \Delta R(532\ nm, 1064\ nm)$$

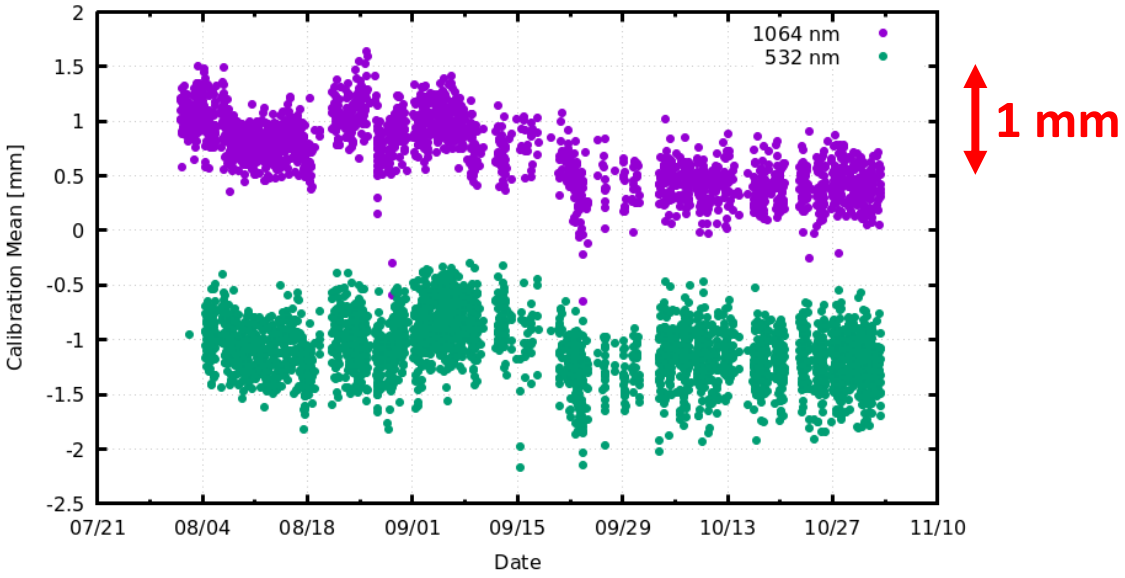
Scale factor ~20 → 0.3 ps two-way precision for 1 mm absolute

- Using single differences (simultaneous detections) most straight forward, Residual calculation based on IERS tropospheric delay model:

$$Residual = (ToF(1064\ nm) - ToF(532\ nm)) - (IERS(1064\ nm) - IERS(532\ nm))$$

Calibration Stability

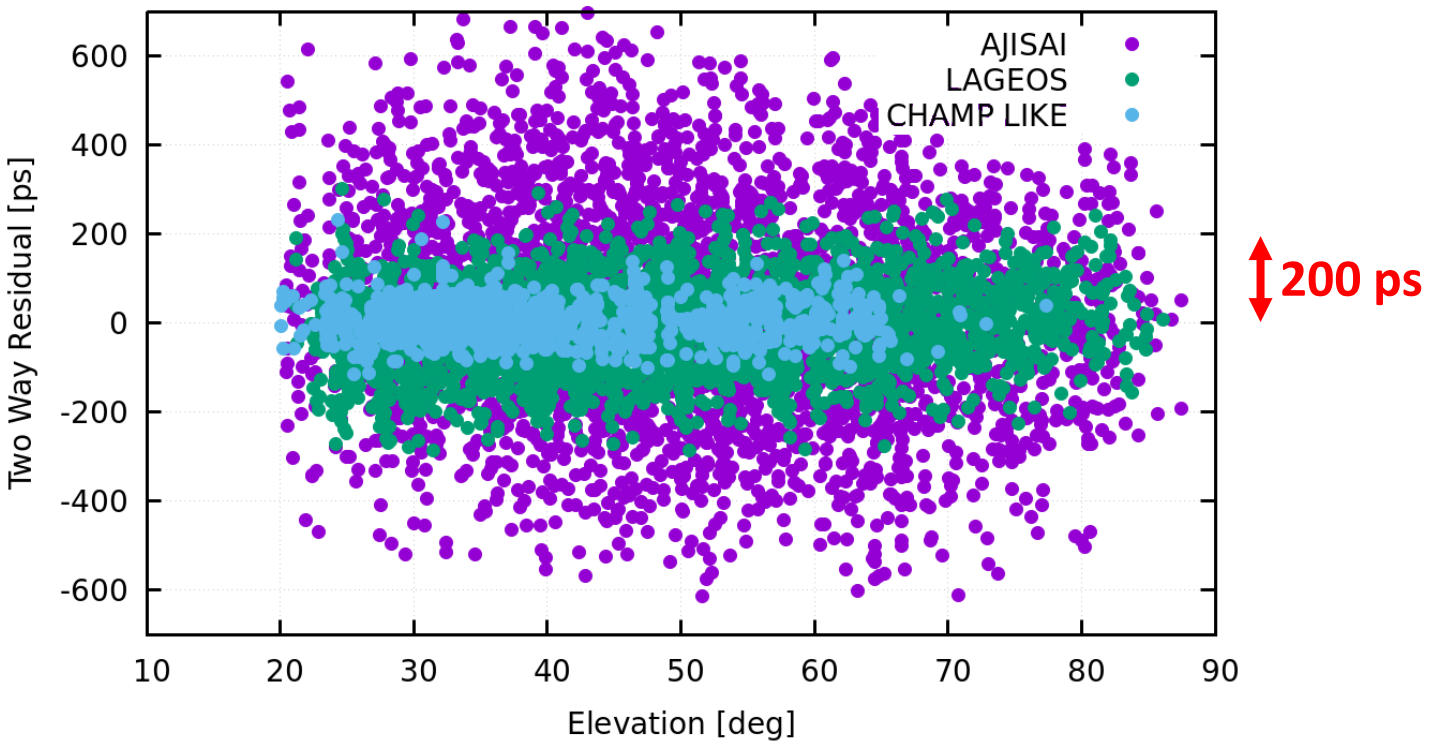
- High relative stability in both detection channels for two color SLR mandatory, if averaging is neccessary



- Absolute calibration delay stability < 1 mm
- Relative stability well below 1 mm

Atmospheric Delay
- Preliminary Results -

- Two way residual based on single-differences & IERS delay model



- For satellites with signature more sophisticated method neccessary

Conclusion

- Two color SLR up to LAGEOS orbit @ WLRS
- Focus on 1064 channel
- Eyesafe operation only for 1064 nm channel possible
- No discrepancy in relative detection rate for most satellites

  THEORY: <67 Percent ↔ REALITY: 60 – 80 Percent
- Internal QC not passed, yet (Calibration – Satellite RMS discrepancy)

- What is the difference between LAGEOS1 & LAGEOS2?
- What shall we do with the data?

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Thank you for your kind attention!

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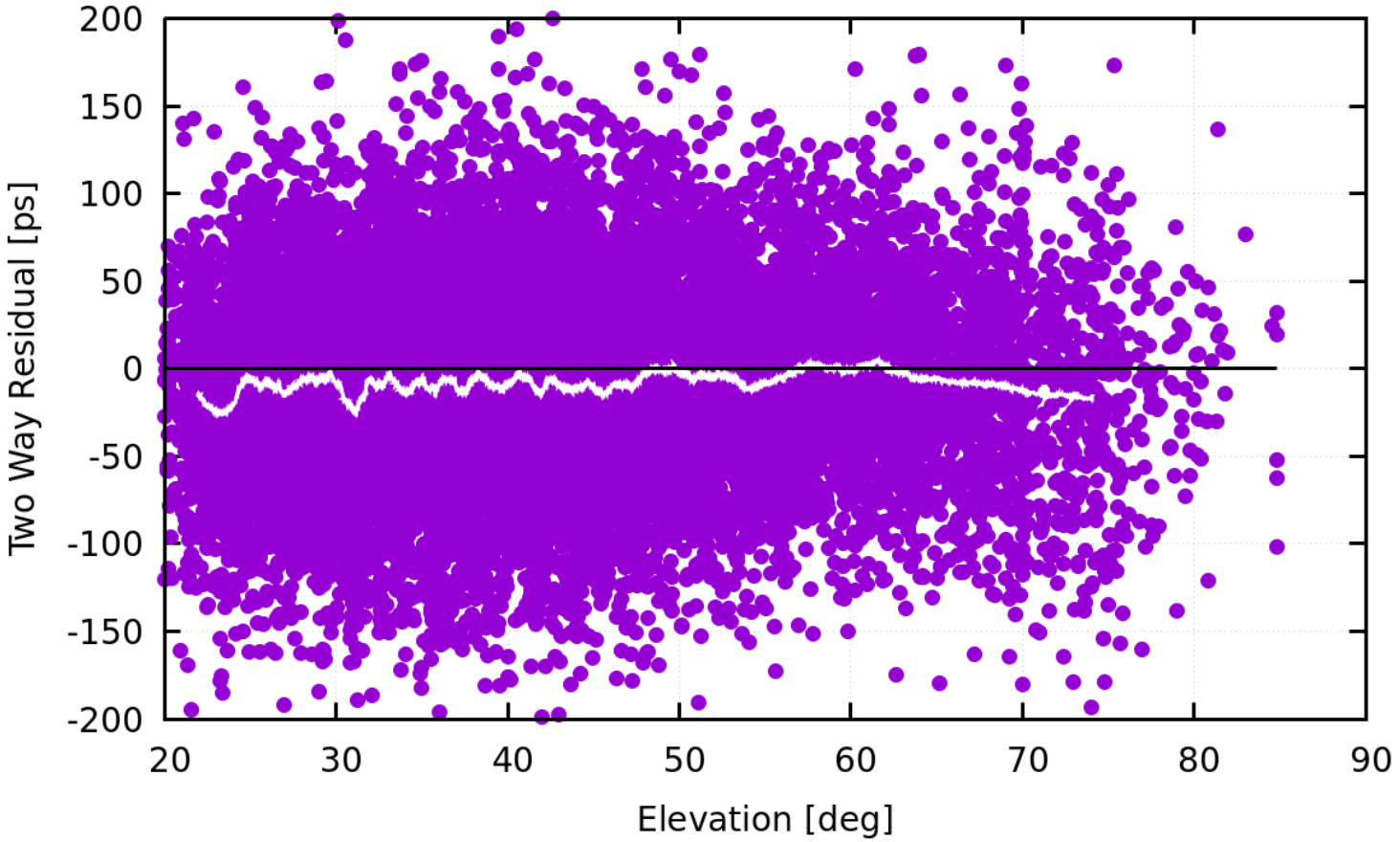
Laser Safety Aspects

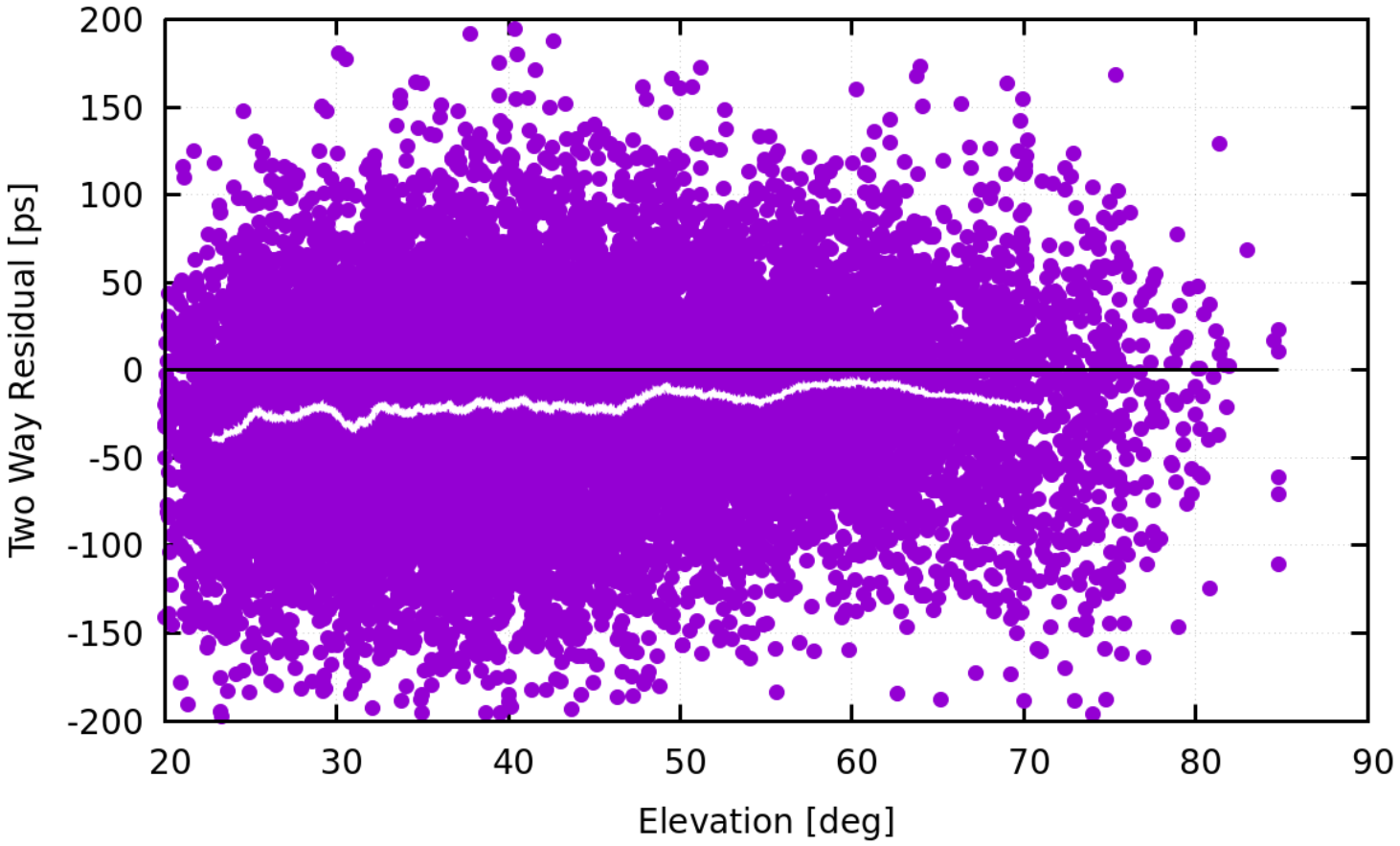
- Monostatic Telescope setup -> low laser energy density -> eyesafe ranging @ 1064 nm feasible
- Laser classification @ telescope output according to DIN EN 60825-1 (Ingenieurbüro Goebel GmbH)
- Classification based on „naked eye“-condition & „binokular“-condition

MODE	7 mm Aperture	50 mm Aperture	Laser Classification
SLR	1	3R	1M
Two Color SLR	1	3B	1M
LLR	3B	3B	3B

Marini Murray



IERS


Two Way Residual [ps]
200
150
100
50
0
-50
-100
-150
-200
20
30
40
50
60
70
80
90
Elevation [deg]

Two Color Ranging
- Echoe Rate (LEOs) -

- Similar CCR arrays behave similar