Status of the ACES retroreflector modification and the time transfer via Satellite Laser Ranging and optical fiber links

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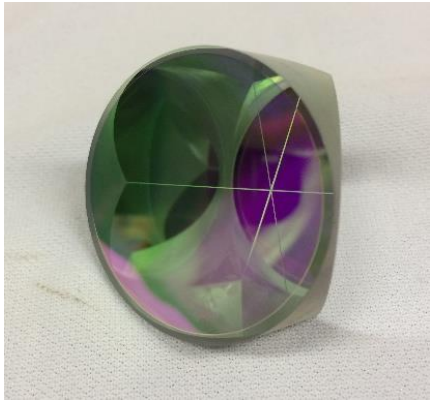
Content

- ACES retroreflector modification
- Optical link PTB – GFZ – ACES
- Optical link PTB – GFZ (– ACES) – Poland
- Updated detector at GFZ SLR station
- Updated GFZ SLR station system delay
- Updated GFZ SLR station time and frequency comparison stability

ACES Retroreflector modification

- Spacecraft automatically approaching and docking the ISS use predefined retroreflector pattern
- To avoid confusion, ACES retroreflector needs to be non-detectable for approaching spacecraft
- Thus an optical layer is added
- Layer is optimized for transmission at 532 nm
- Several higher wavelengths will not be transmitted
- However, this agrees with the ELT detector wavelength of 532 nm



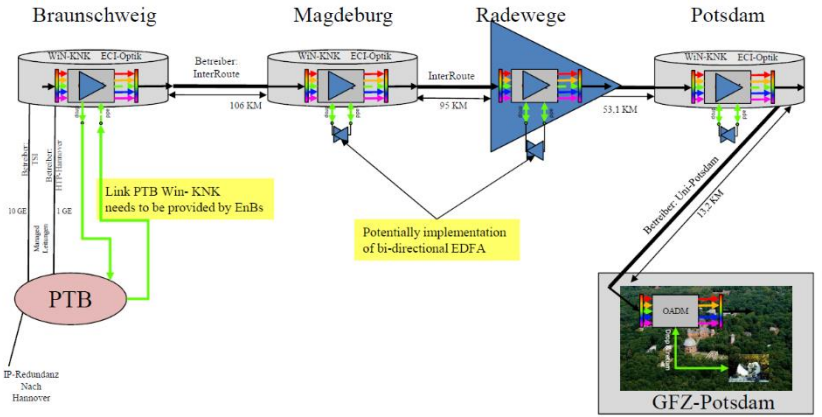
Modified ACES retroreflector with added optical filter layer. Layer is optimized for transmission of 532 nm. Reflector diameter is approx. 38 mm.

So 532 nm will be the wavelength for SLR to ELT/ACES

Optical link PTB – GFZ – ACES

- Ongoing discussion with DFN about an optical link
- Link can be established, negotiations about
  - For how long is the link required and possible
  - Where to put amplifiers (bidirectional EDFAs)
  - Costs and financing
- Transferring
  - 1.5 µm optical carrier frequency referenced to the PTB Sr-optical lattice clock to GFZ and conversion to 10 MHz locally at the station
  - Time is under discussion – UTC(PTB)?
  - Transfer of frequency (and time) to ACES via SLR to ELT and with that world-wide

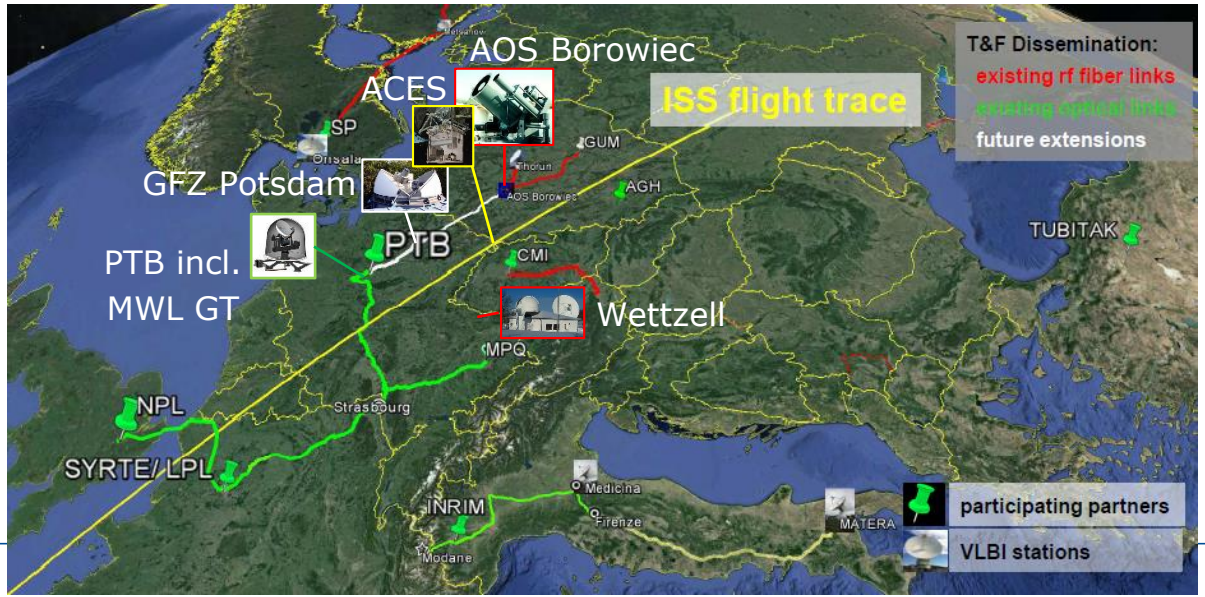
Example for an optical fiber link between PTB and GFZ. Here a link with one fiber is pictured. At best there is a second fiber available for comparison.



Optical link PTB – GFZ (– ACES) – Poland

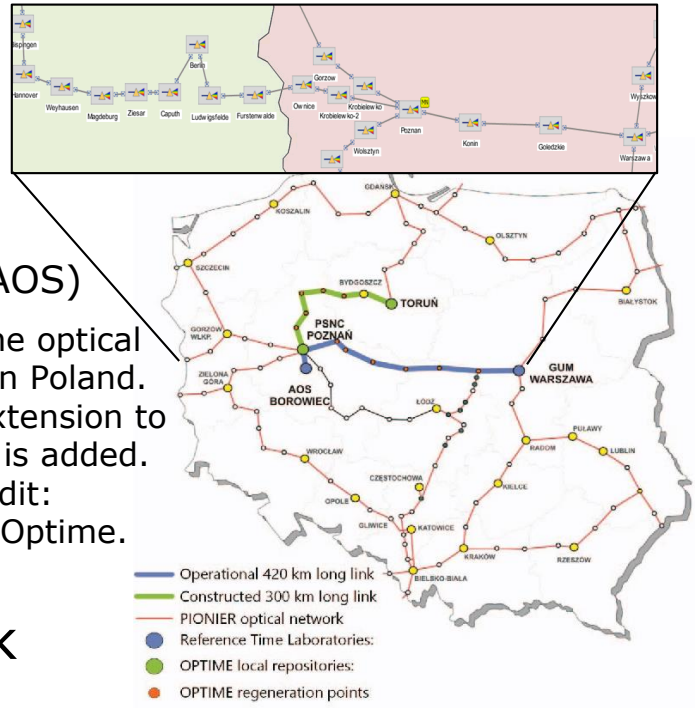
- Broader picture
  - Connecting the existing Polish network to the existing EU network also via SLR

Connecting the existing Polish and EU fiber network from PTB to AOS via GFZ with fiber and SLR. Stations like Wettzell could also be connected via SLR. Credit: EURAMET, ESA, GFZ, NASA, AOS, BKG.



Optical link PTB – GFZ (– ACES) – Poland

- Idea
  - Extending optical link from PTB to GFZ to Poland
- Why connect the Polish network?
  - Cs-Fountain and SLR Station @ AOS Borowiec, UTC(AOS)
  - Cs-Fountain @ PSNC Poznan
  - Sr-optical lattice clock @ Torun
  - Cs clocks @ GUM, UTC(GUM)
- Possible clock comparison via fiber
  - PTB – AOS/PSNC/Torun
- Further, comparison of fiber and SLR link
  - (PTB –) GFZ – AOS vs. (PTB –) GFZ – ACES – AOS

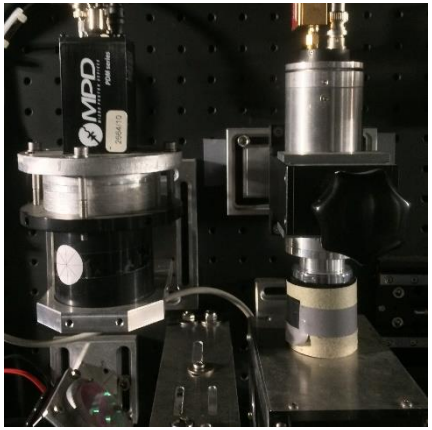


Map of the optical network in Poland. Possible extension to Germany is added. Credit: Pionier, Optime.

Updated detector at GFZ SLR station

- Successful optimization of the beam alignment in August 2018
- Improved signal rate and precision
- The Spad also improves
  - Station delay stability
  - Frequency comparison stability
  - Time comparison stability

GFZ Potsdam station detector package. The Spad is on the left and the PMT on the right side.

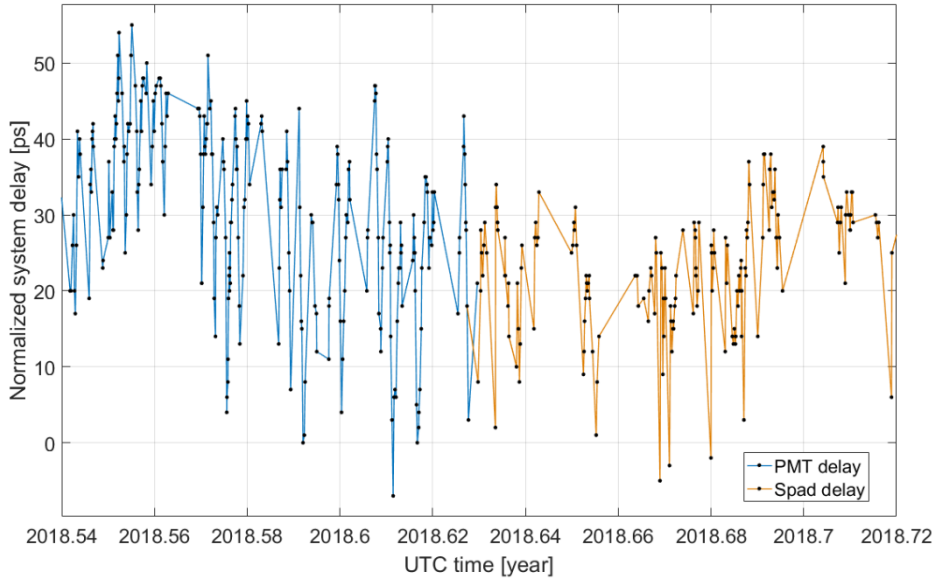


Comparison of GFZ Potsdam station detector parameters.

	Spad	PMT
Quantum efficiency @ 532 nm	40 %	8 %
Data precision @ calibration	12 ps	48 ps
Applied filtering criteria	2.0 σ	2.5 σ
Active area diameter	0.1 mm	5 mm

Updated GFZ SLR station delay

GFZ Potsdam system delay over time for the PMT and the Spad detector.
The delays from both detectors have been normalized for comparison.

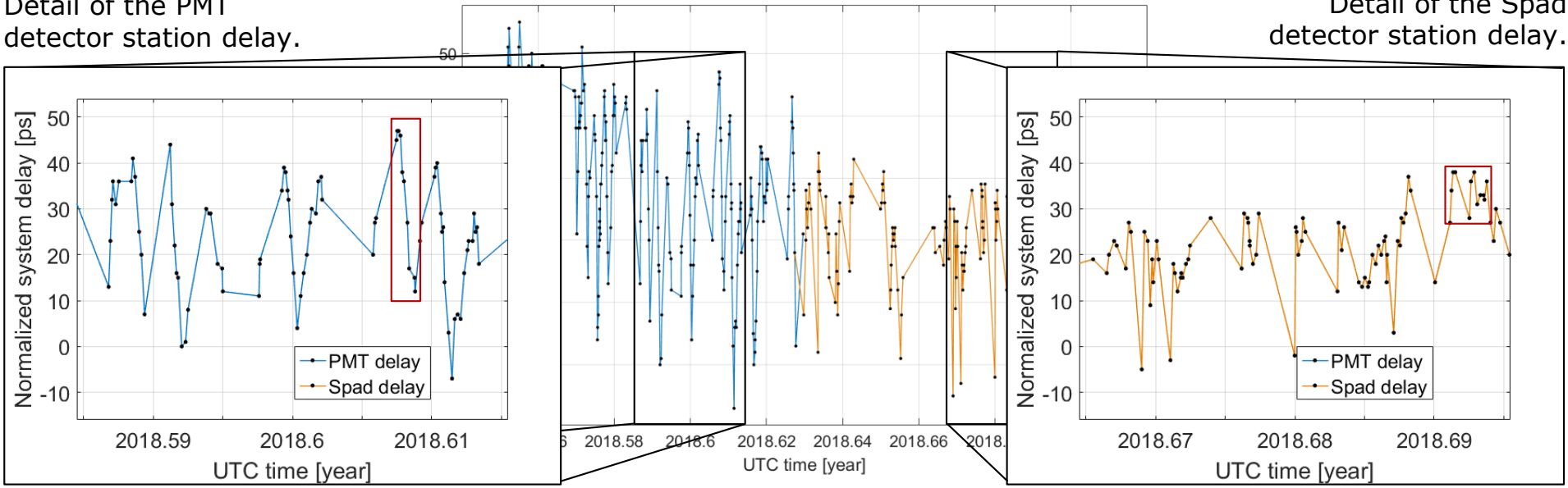


Updated GFZ SLR station delay

GFZ Potsdam system delay over time for the PMT and the Spad detector.
The delays from both detectors have been normalized for comparison.

Detail of the PMT detector station delay.

Detail of the Spad detector station delay.



Daily change ≈ 40 ps

Daily change ≈ 10 ps

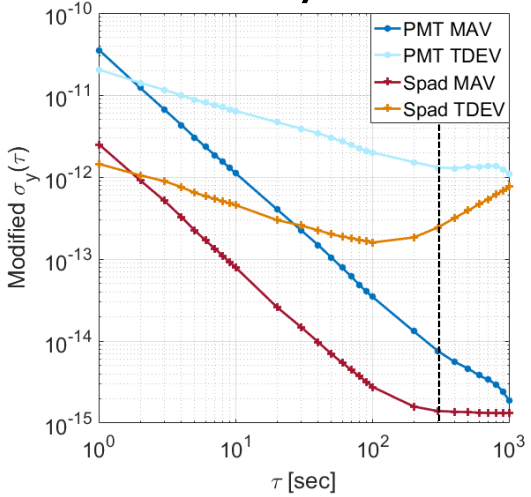
Updated GFZ SLR station time and frequency stability

- Spad allows for a better time & frequency comparison stability
- ELT detector stability measured in 2010 is met & outperformed

Achievable stability with the Spad:

$<10^{-14}$ after 40 s
$<2\times10^{-15}$ after 150 s

1 ps after 2 s
<200 fs after 50 s



POT3 station time and frequency transfer stability for the PMT and the Spad. Time deviation (TDEV) is given in seconds. Approx. max SLR pass length (≈ 5 min) to ISS/ACES/ELT is shown with the dashed line.

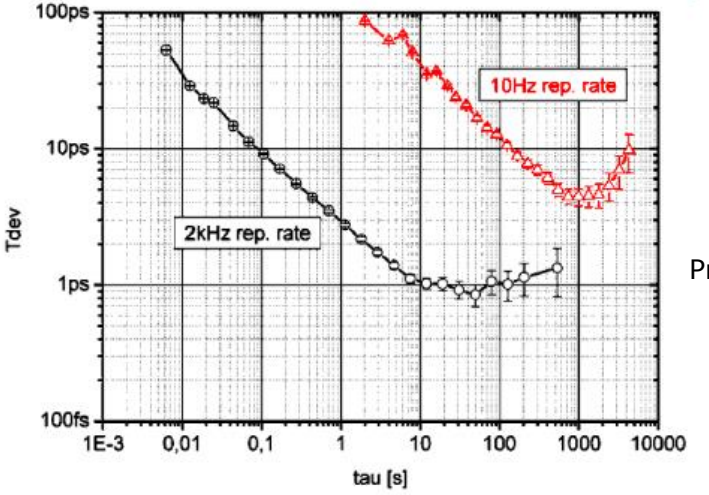


Fig. 5. The timing resolution and stability (T_{DEV}) of the ELT photon counting detectors together with the entire laser ranging signal loop. The upper curve (triangles) corresponds to the 10 Hz repetition rate operation and modest resolution timing system. The lower curve (circles) corresponds to the operation with repetition rate of 2 kHz and the top performance laser ranging system (SLR Graz, Austria).

Prochazka et al. (2010).

Summary

- Optical filter layer is added to the ACES retroreflectors
- 532 nm will be the wavelength for SLR to ELT/ACES
- Talking to DFN about the details of the optical PTB to GFZ link
- Discussion about extension of this link to Poland
  - Comparison of PTB clock to various clocks in Poland
  - Comparison and validation of fiber optical and SLR link between GFZ and AOS Borowiec
- Compared to the PMT, with the Spad at GFZ Potsdam station the
  - Performance is improved (signal rate), Measurement precision is reduced
  - System delay stability is better (10 ps per day)
  - Frequency comparison stability is better ($<10^{-14}$ after 40 s, $<2x10^{-15}$ after 150 s)
  - Time comparison stability is better (1 ps after 2 s, <200 fs after 50 s)

Thank you!