

European Laser Timing

current status, expected performance and future challenges

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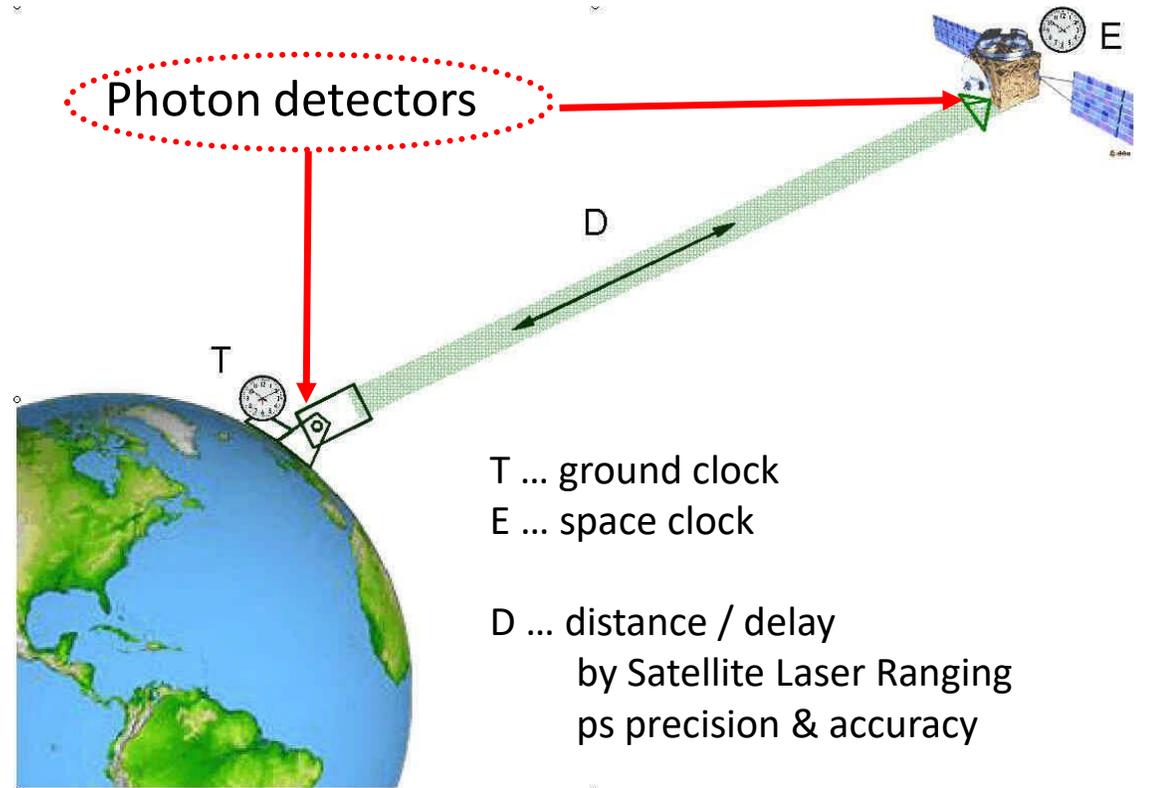
presented at :

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2 Technical University Munich, Germany

Laser Time Transfer ground – space principle



- n Relying on available technology and SLR ground segment
- n Sub-ps precision limit
- n Propagation delay in space fully compensated by SLR !!

- n WHY Single photon approach ?
- n NO analog signal processing => simple & precise
- n => systematic errors ~ 10 ps level
- n => precision TDEV < 1ps @ 100s

ELT Detector Flying Unit

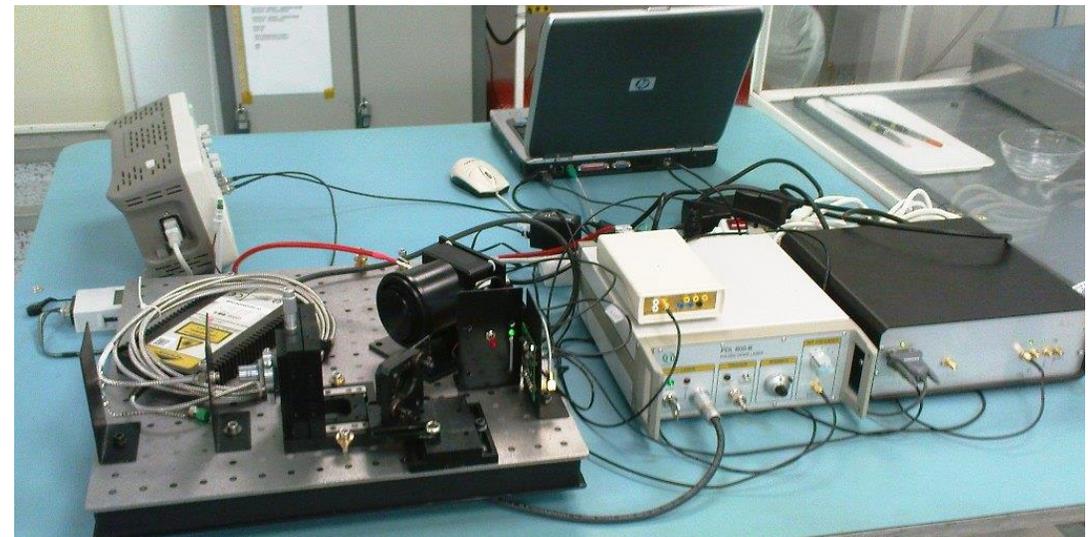


- ELT detector package flying unit (2 x) completed, tested, calibrated, delivered
- Output signal cables grounding modifications after EMC tests
=> output signals modifications
- New measurements of detection delays needed and completed

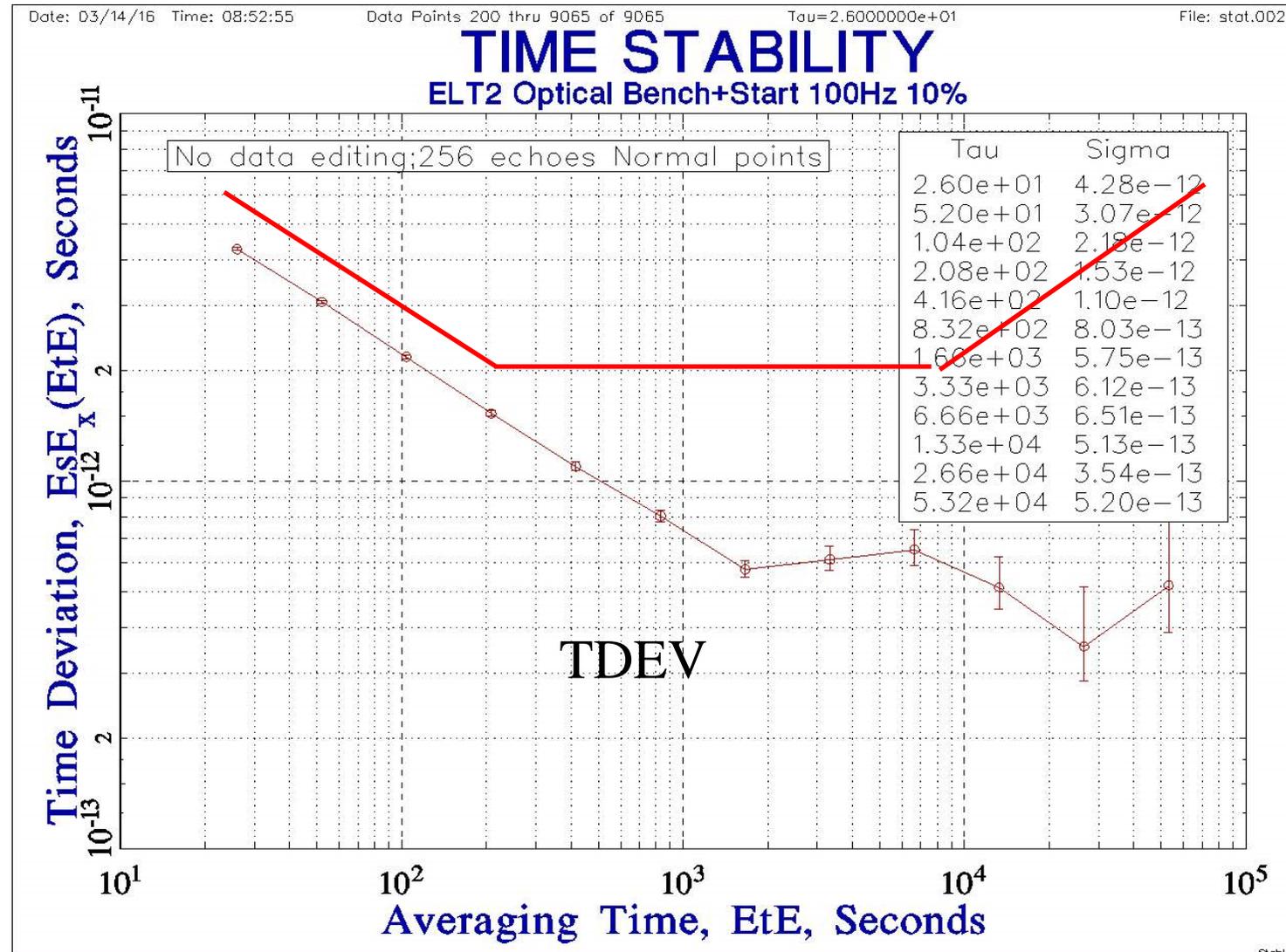
n ELT test bench at clean room facilities

n Fiber laser 85 ps @ 531 nm

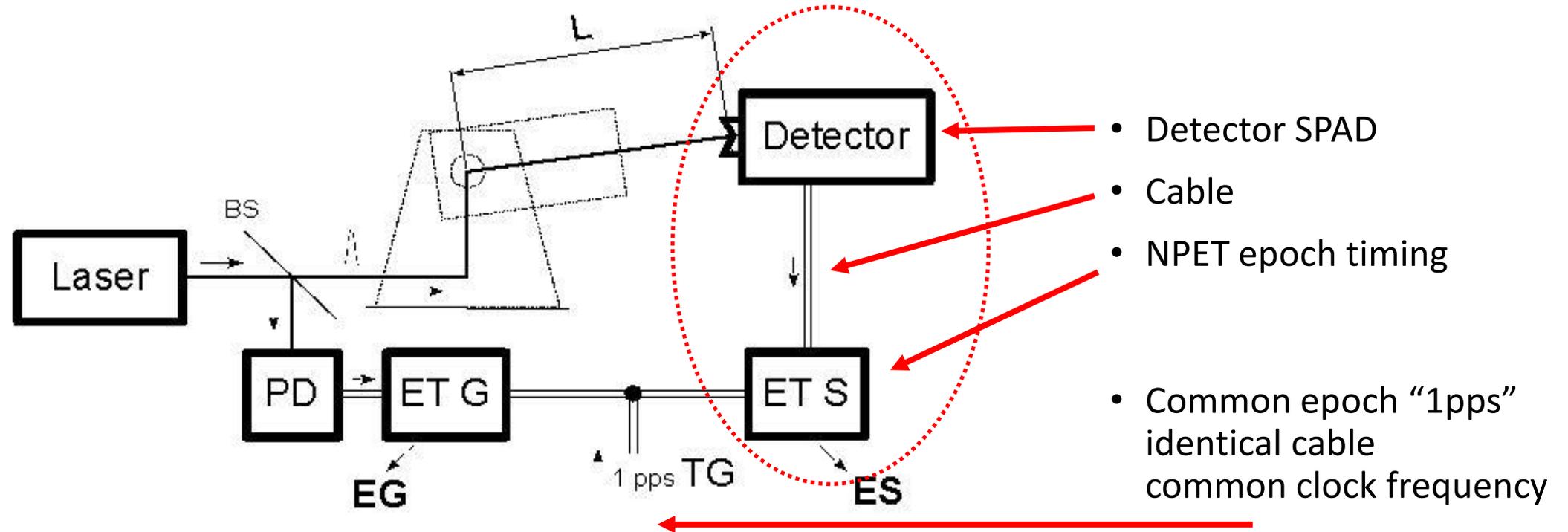
n NPET timing



ELT Detector Flying Unit – long term stability



Identification and calibration of one – way biases in SLR systems



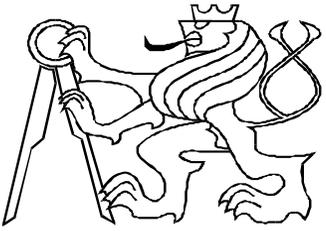
- The Calibration Device delays determined with $\leq 20\text{ps}$ accuracy
- Considering the Calibration Device delays and a real distance L the transmit delay related to “1pps” input may be determined with the same accuracy

Calibration Device ELT



- The ELT Calibration Device was developed for ACES – ELT certified transportation container, insurance coverage, ATA Carnet custom proc. for non-EU missions, etc..
- ELT Calibration missions completed in Wettzell (2014), Graz (2015,2016) and Herstmonceux (2016)
- Similar device was prepared for SSA activities of ESA
- One way delays in SLR systems were / will be calibrated at Zimmerwald (2017) and Potsdam (2019)





CONCLUSION 1

ELT status and performance



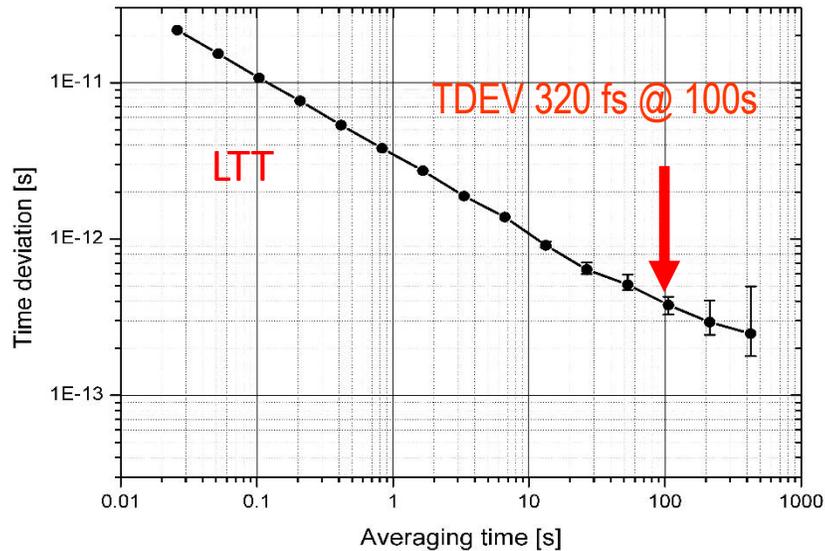
- The ELT detector: completed, tested and delivered
- The detector performance meets all requirements with a great margin
- The SLR ground segment (3 x) was tested and calibrated
- The synergy with other techniques / projects identified and utilized (one way ranging, optical transponder, space debris optical tracking,....)

European Laser Timing – future challenges

- Preparation of optical clocks on ground and in space frequency stability $\sim 10 \text{ E-17}$
- Requirements on laser time transfer chain ground & space (improvement $> 10 \times$)

precision	TDEV	$< 0.5 \text{ ps @ } 100\text{s}$
stability	p - p	$< 1 \text{ ps over days}$
- ESA mission under consideration (ACES follow on) I – SOC (Iss - Space Optical Clock)
PI: Stephan Schiller, HH University Düsseldorf, Germany
- Chinese missions under preparation: Tiangong-2 Compass Beidou, version 2020
- Others ?

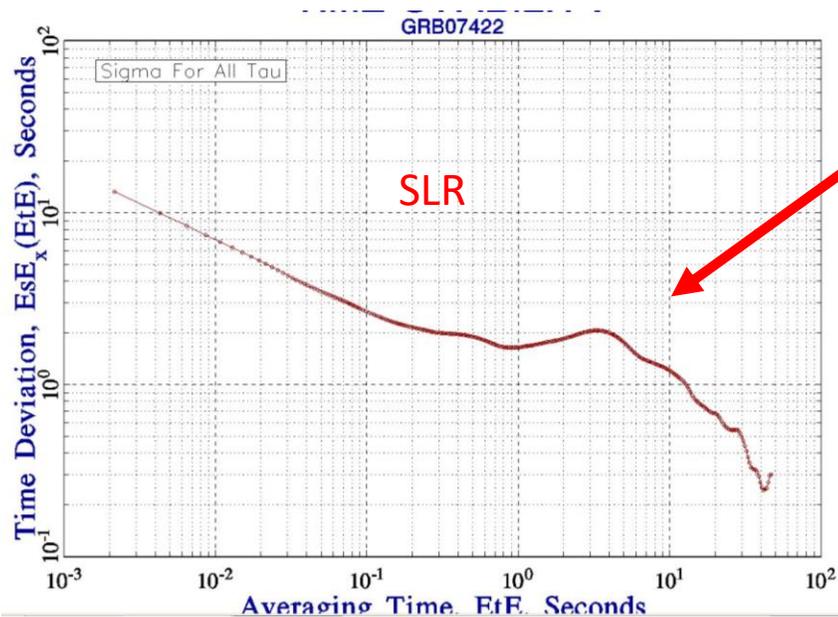
ELT time transfer field tests



- ELT detector EM + ELT Calibration timing
- 500Hz rate

=> TDEV < 250 fs @ 100s
possible for 1 kHz rep. rate SLR

Adv. in Space Res. Vol 59 (10), 2017



TDEV Grace B, Graz, 2017

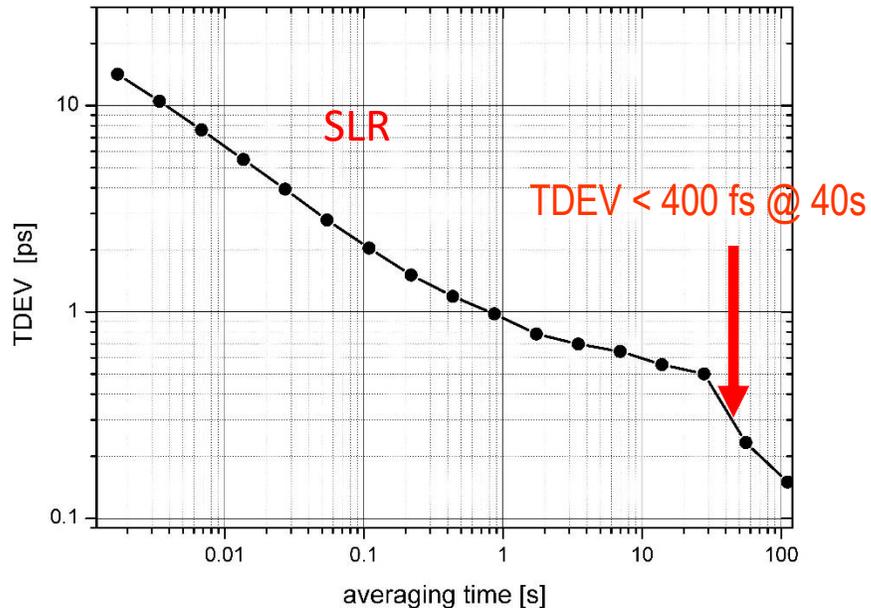
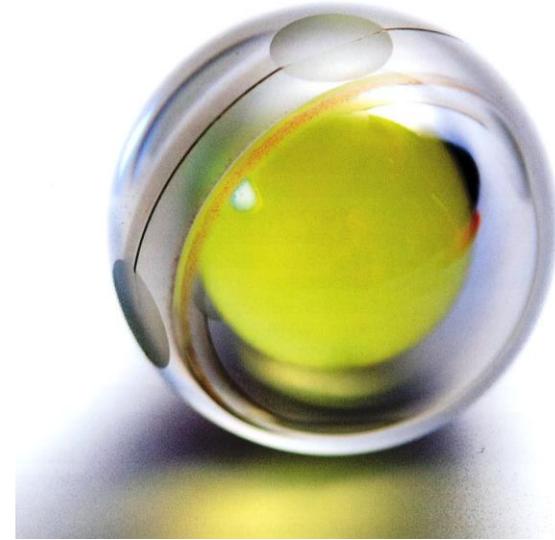
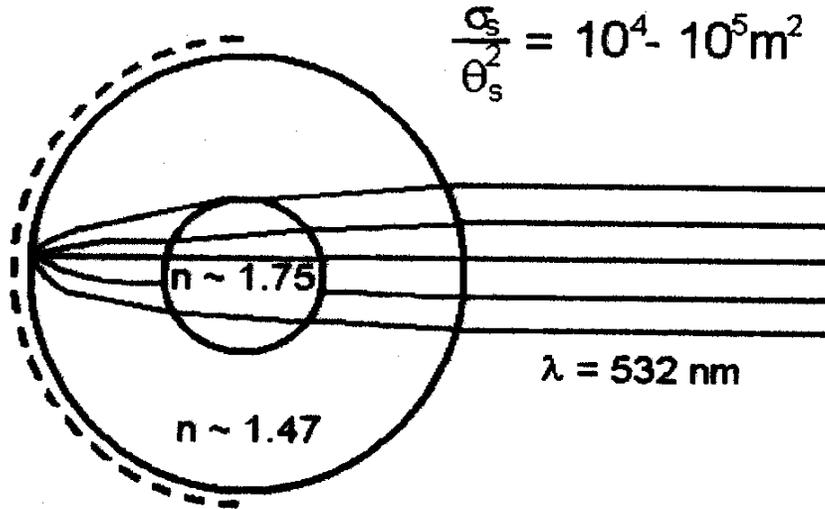
= > ELT overall TDEV < 2 ps @ 100 is achievable

=> limitation is the retro-reflector

Space detector & NPET timing & SLR station Graz, Austria

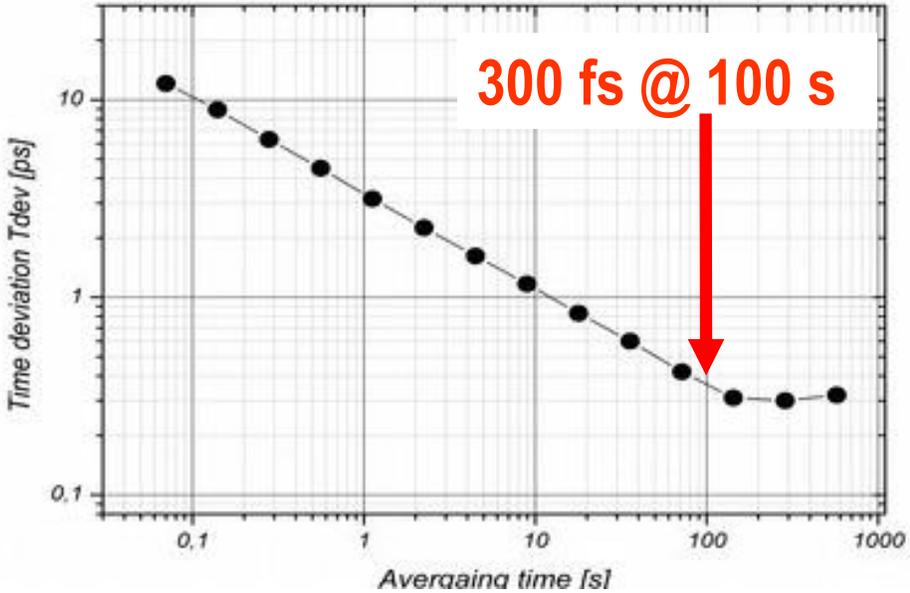
Laser retro-reflector for sub-ps precision

“Luneburg sphere”



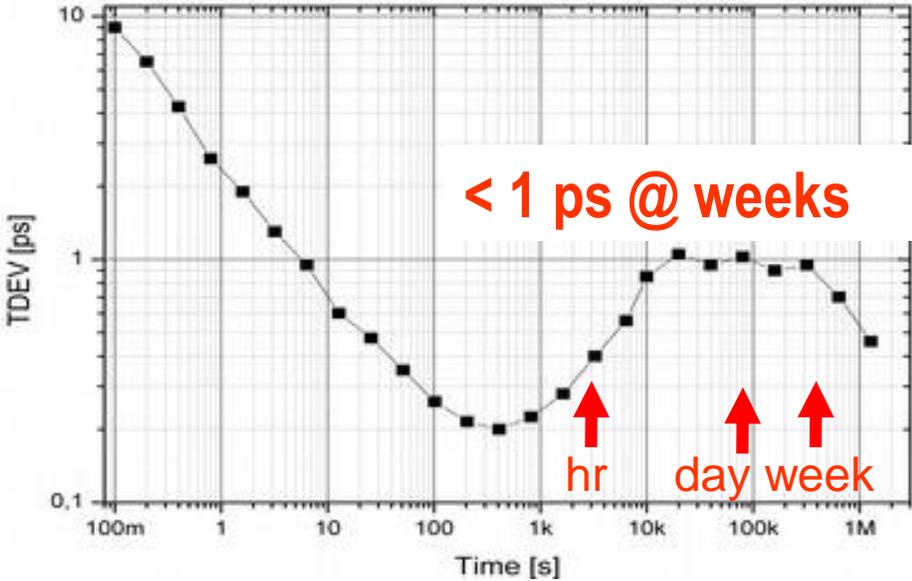
- n SLR to spherical satellite Blis, Graz
- n TDEV increase (3-30s) caused by spin (not existing on ISS)
- n => TDEV << 0.4 ps @ 100s possible

CAPABILITIES OF PHOTON COUNTING



Ground to space propagation time,
2kHz rate, ~ 30 000 km

I.Procházka et al, IEEE 2013



Ground segment stability

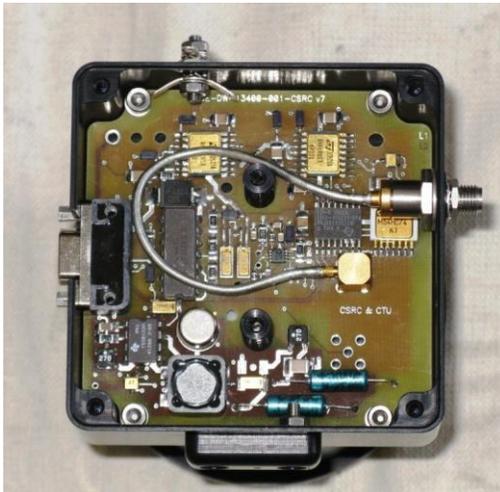
Verified via ground laser ranging
January – May 2013, Graz, Austria

Satellite Laser Ranging of GNSS satellite, Graz, Austria

Detector Upgrade – Space Segment



- Based on ACES-ELT concept and design mass, power req., etc...
- Passive temperature delay compensation
 - = > temp. drift $\sim < 100 \text{ fs / K}$ (10x)
 - = > prec.& stab. $\sim < 100 \text{ fs @ hr}$ (5x)
- Space qualification preserved from ACES



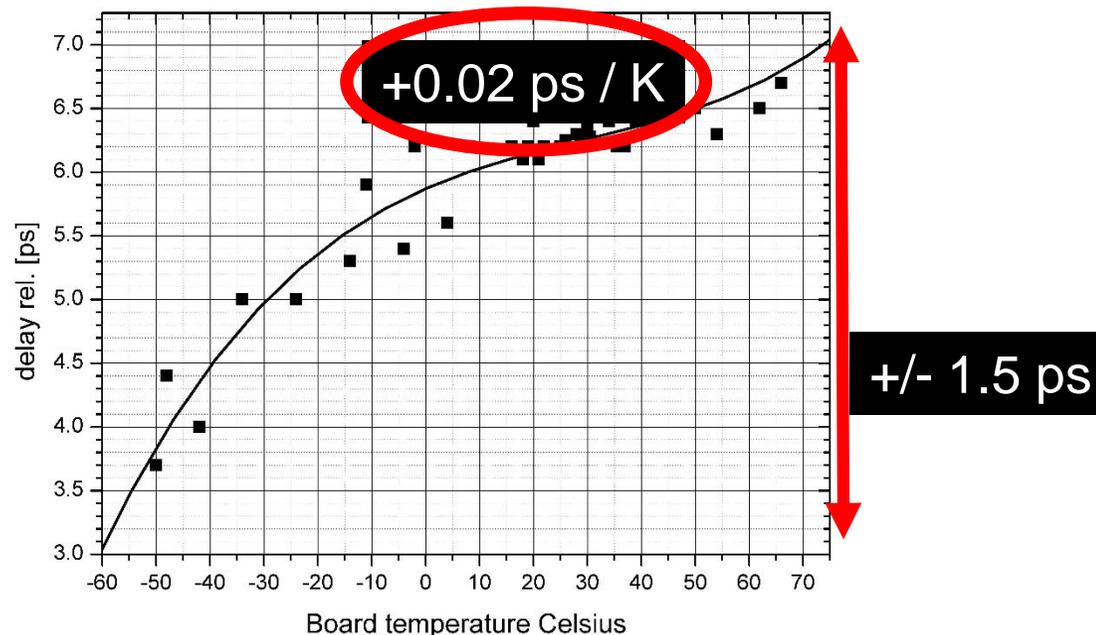
Rev. of Sci. Instruments 89, 056106 (2018)

Detector upgrade – Ground segment



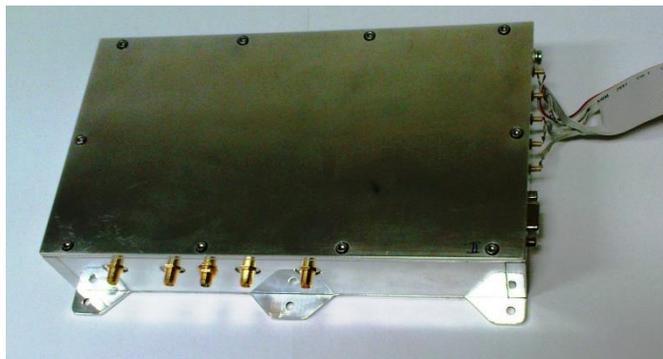
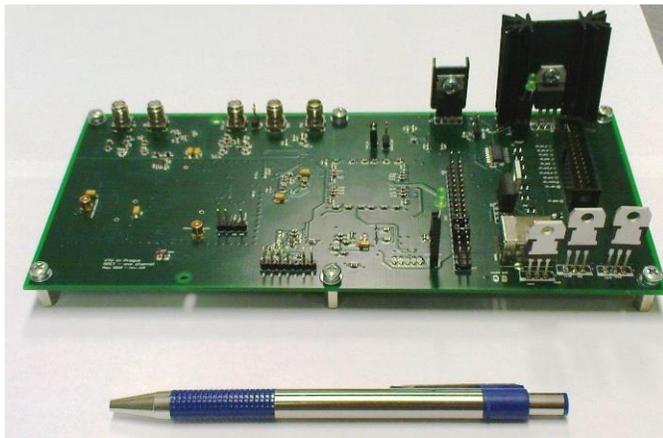
8 GHz comparator + PCB + housing + internal cabling

- SLR overall jitter ~ 10 ps / 1,5 mm (!)
- Temp. drift < 20 fs / K (!!)
- World fastest & most stable detector
- Operational tests Wettzell since 2017
- Under preparation for APOLLO, US



Rev. of Sci. Instruments 88, (2017)

Event Timer upgrade - space segment (LTT application)



- n Theory and design P. Panek, 2005
- n Operating in frequency domain, SAW filter
- n Sub-ps performance
 - Precision < 500 fs rms
 - non-linearity < 500 fs
 - temp. drift < 200 fs/K
 - stability < 4 fs@300s
- n Used in ELT ground segment now
- n **Space version is prepared**

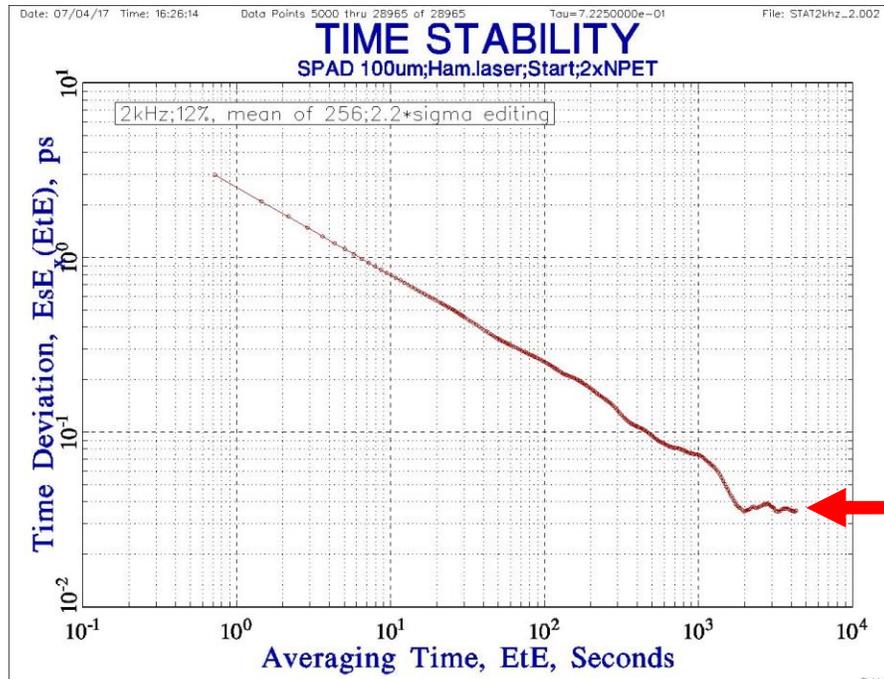
Rev. of Sci. Instruments, Vol. 78, No1, 2007

U.S. Patent 7,057,978 B2, Jun. 2006.

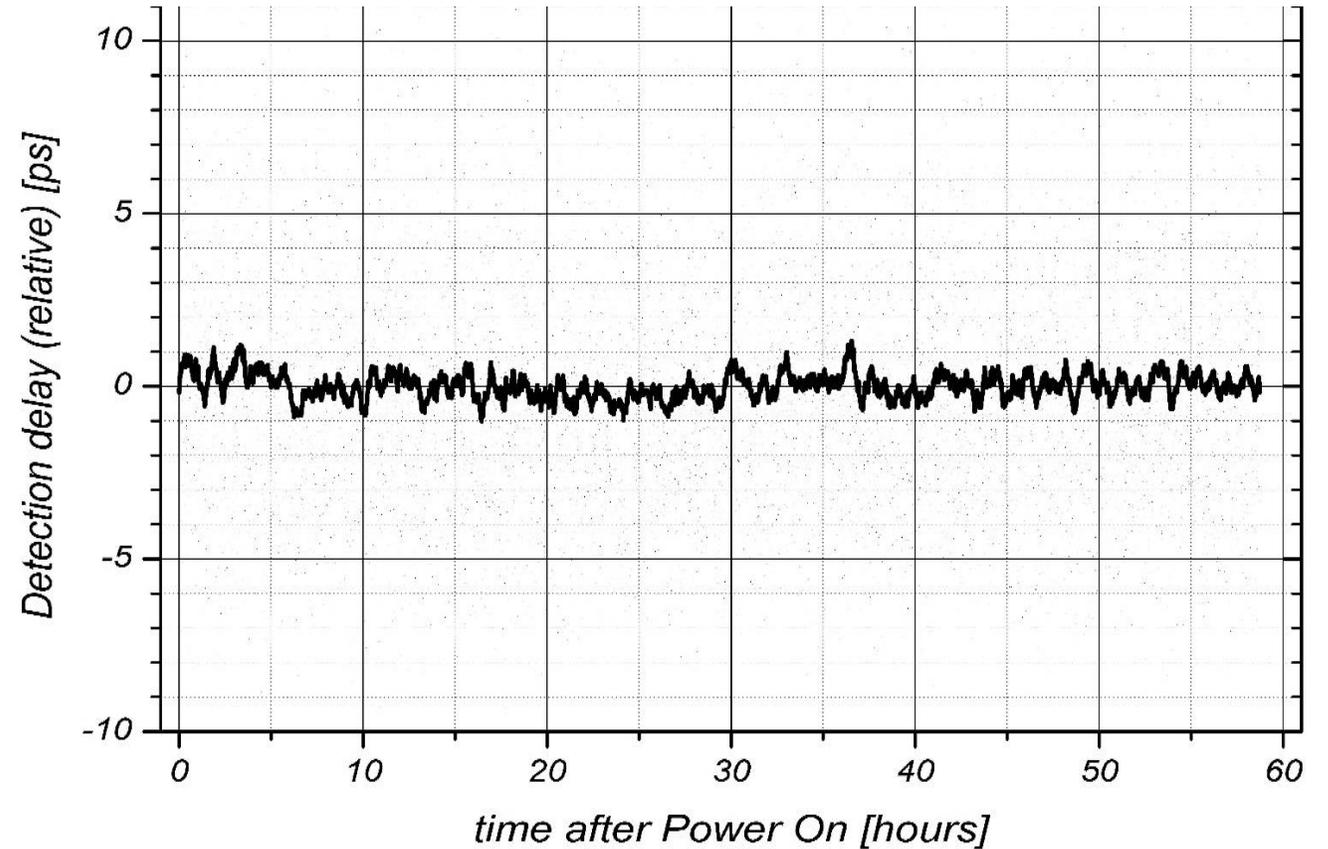
IEEE Trans. Instr. Meas., Vol. 57, No.11, 2008

LTT chain delay long term stability & precision

Indoor Prague
+ / - 1 K



TDEV < 40 fs @ hr



Review of Sci. Instruments 89, 056106 (2018)

CONCLUSIONS



- ELT - Space detector was completed, tested and delivered
It meets all requirements with a great margin
- SLR ground segment (3 x) was tested and calibrated
- The new HW for ground & space segments with improved performance was designed, constructed and tested
- It should provide frequency transfer uncertainty $\sim 1 \times 10^{-18}$ after several days of integration time !!
- Spherical retro-reflector (Luneburg sphere) provides sub-ps SLR, has space heritage, is available (Russia)
- The NPET timing system is providing sub-ps timing and fs stability, its space qualified version is under preparation
- Future
 - ESA I-SOC (2023 ?)
 - China Tiangong-2; Compass Beidou (2020)
 - Europe Galileo (?); other (?)

