European Laser Timing

current status, expected performance and future challenges

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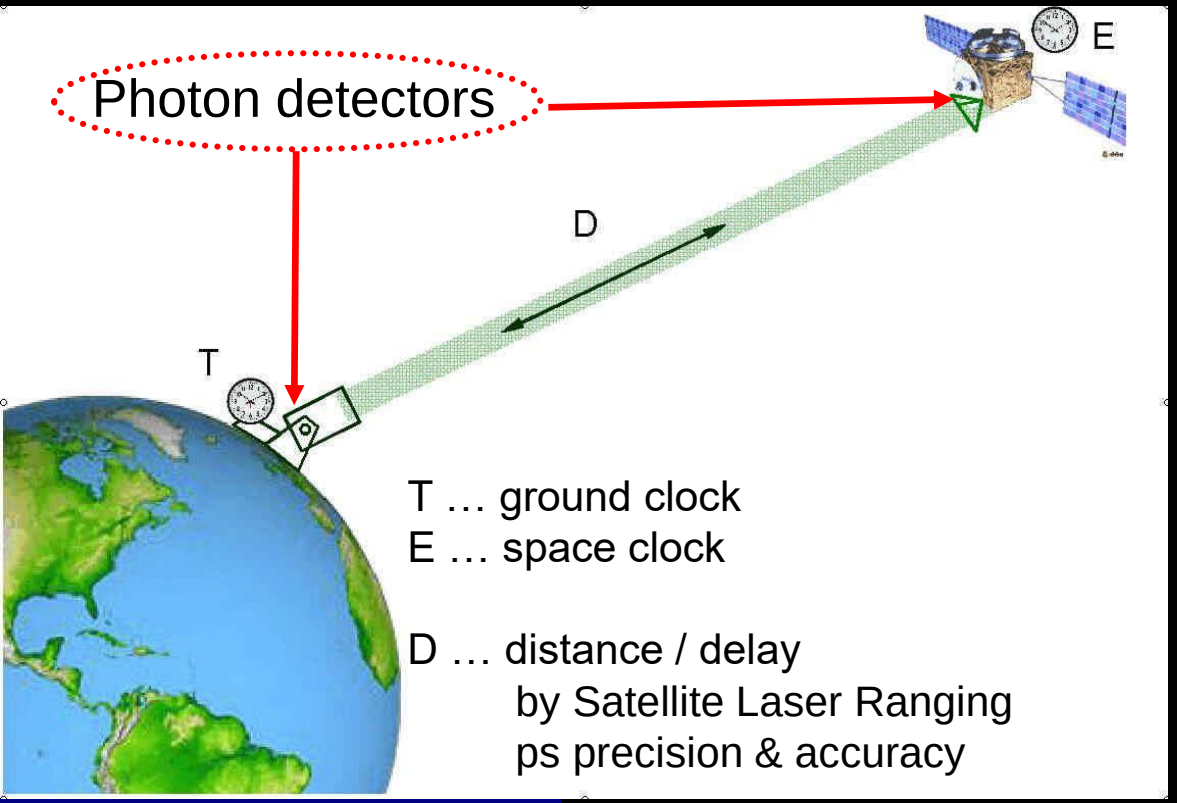
Laser Time Transfer ground – space principle



Relying on available technology and SLR ground segment

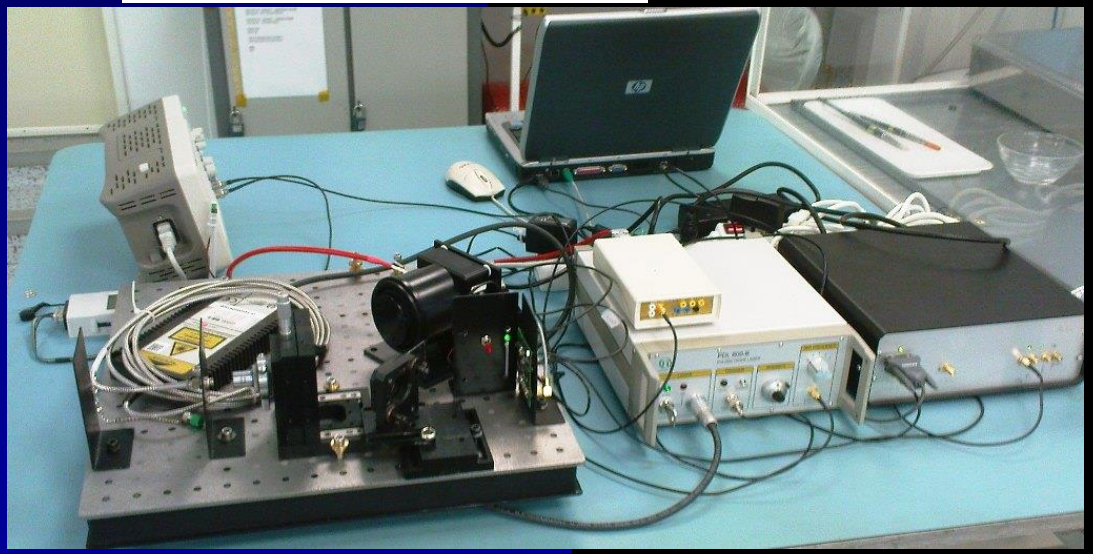
Sub-ps precision limit

Propagation delay in space fully compensated by SLR !!

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

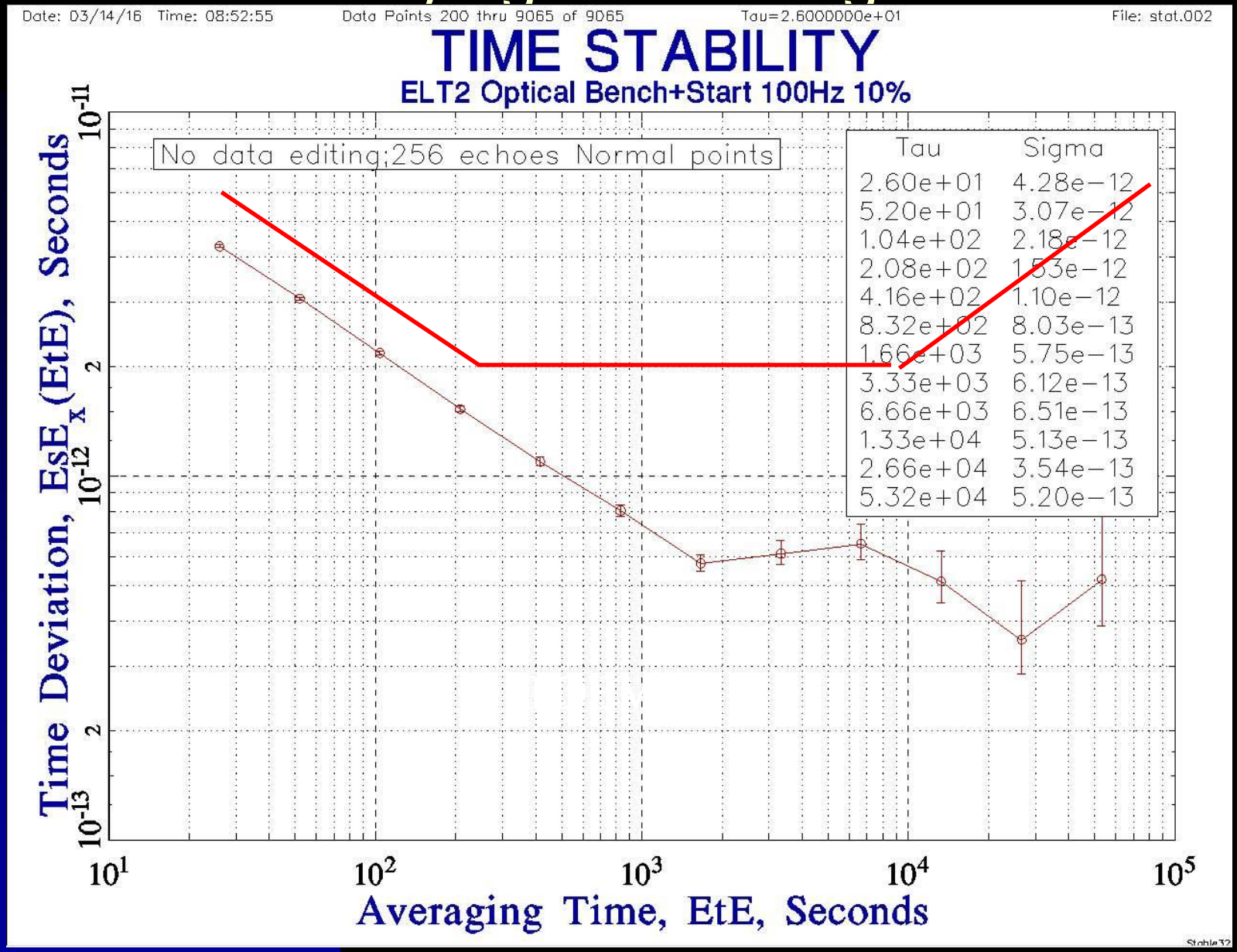
ELT Detector Flying Unit

- 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

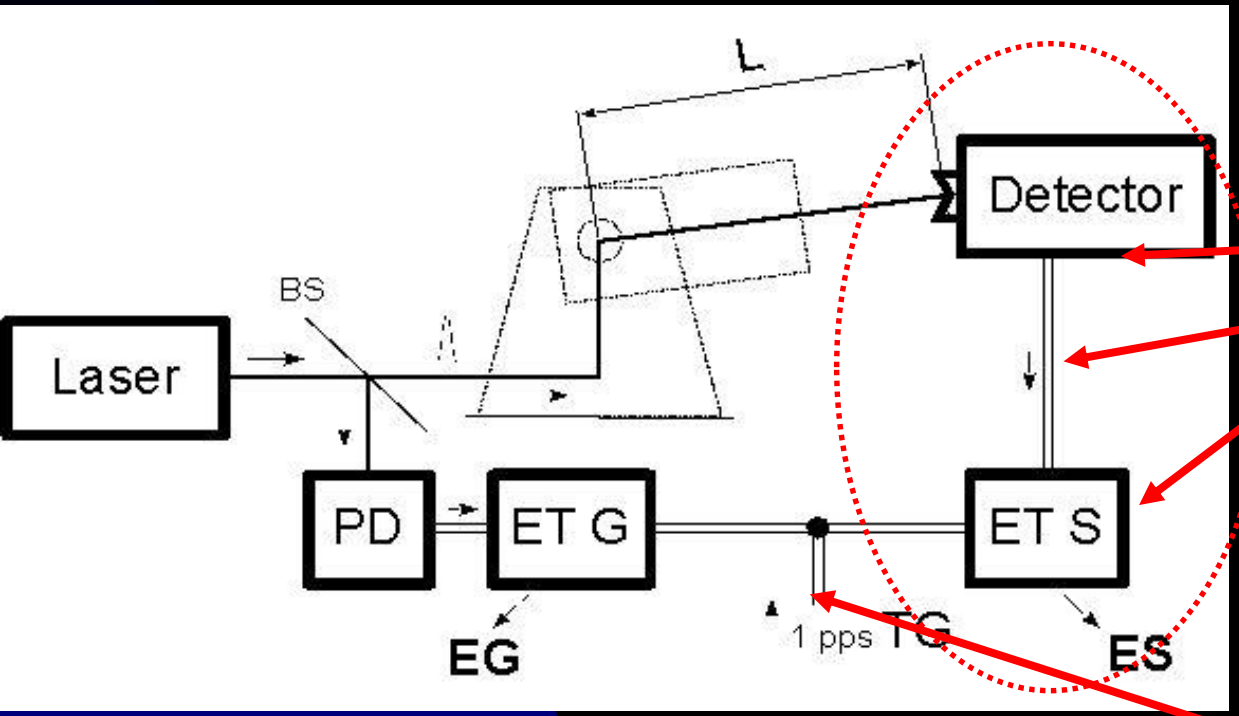


- ELT test bench at clean room facilities
- Fiber laser 85 ps @ 531 nm
- NPET timing

ELT Detector Flying Unit – long term stability



Identification and calibration of one – way biases in SLR system



Calibration Device

Detector SPAD

Cable

NPET epoch timing

Common epoch “1pps”; identical cable common clock frequency

- The Calibration Device delays determined with ~< 20ps 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

- GENERAL
  Preparation of optical clocks on ground and in space
  frequency stability ~ 10 E-17

- Requirements on laser time transfer chain ground & space (improvement > 10 x)
  precision TDEV < 0.5 ps @ 100s
  stability p - p < 1 ps over days

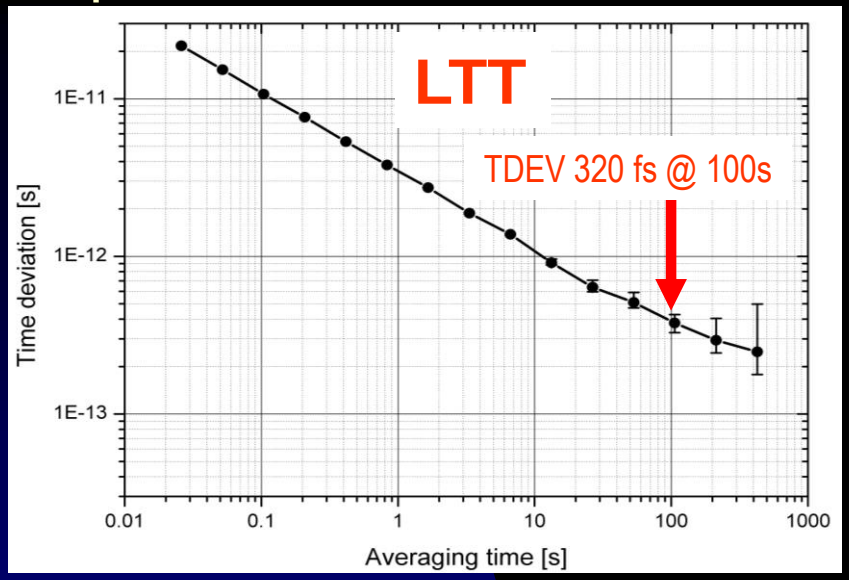
- ESA mission under consideration (ACES follow on)
  I – SOC (Iss - Space Optical Clock)
  Stephan Schiller, HH University Dusseldorf, Germany

- China missions under preparation
  Tiangong-2
  Compass Beidou, version 2020

- Others ?

ELT time transfer field tests

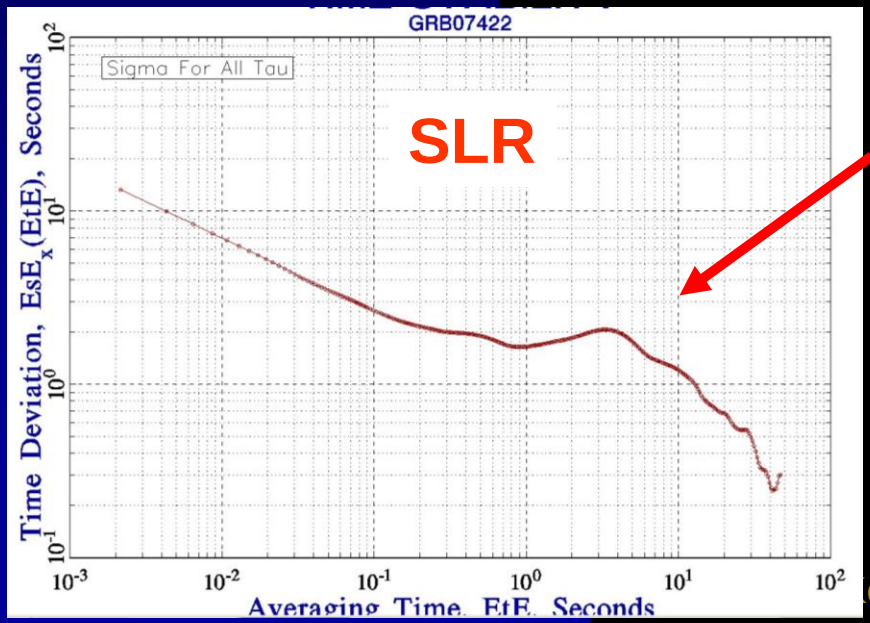
Space detector & NPET timing & SLR ground seg. Graz, Austria



ELT detector EM + ELT Calibration timing 500Hz rate

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

Adv. in Space Res. *Vol 59,No.10, 2017*



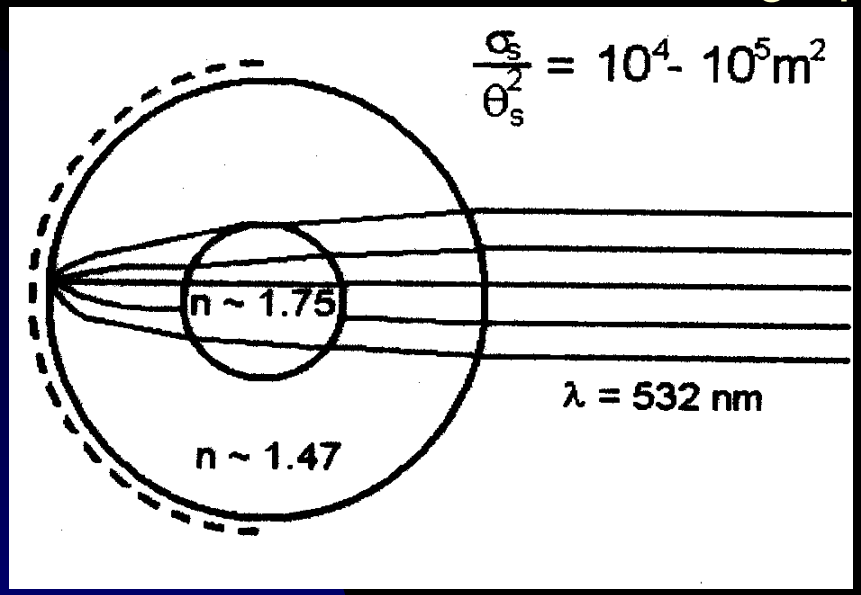
TDEV Grace B, Graz, 2017

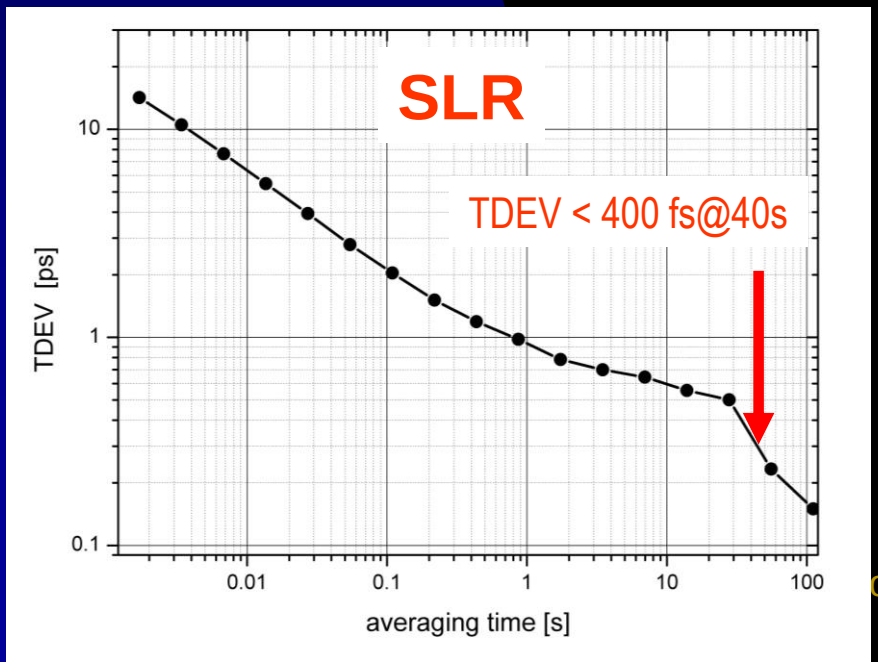
= > ELT overall TDEV < 2 ps @ 100 s is achievable

=> **limitation is a retro-reflector**

Laser retro-reflector for sub-ps precision

"Luneburg sphere"

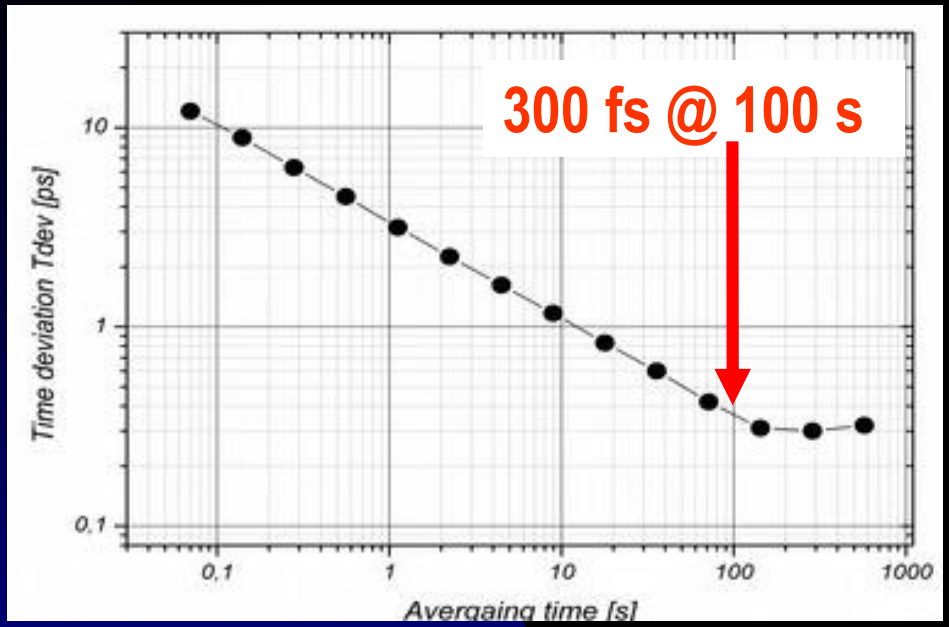




- SLR to spherical satellite Blis, Graz
- TDEV increase (3-30s) caused by spin (not existing on ISS)
- = > TDEV << 0.4 ps@100s possible

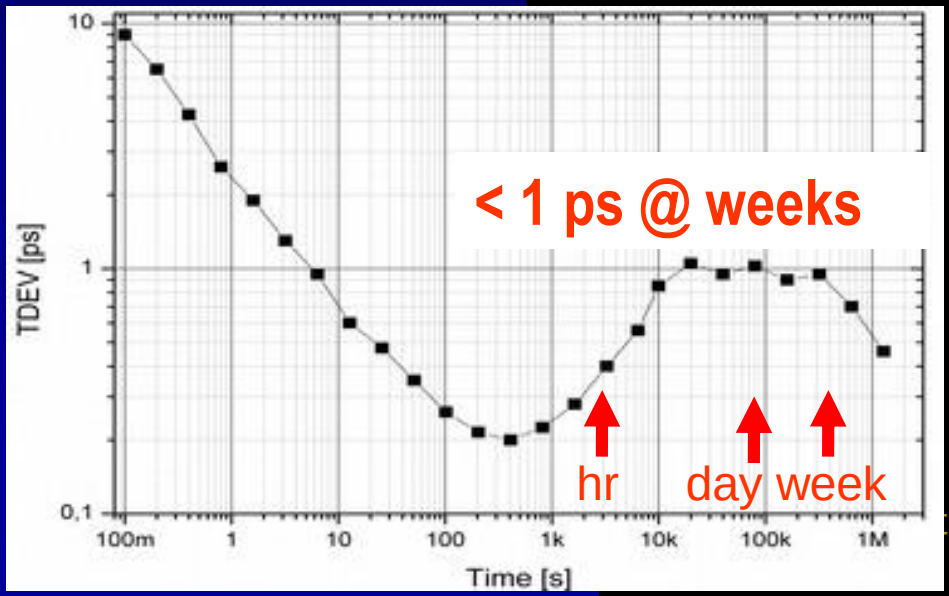
CAPABILITIES OF PHOTON COUNTING

Satellite Laser Ranging of GNSS satellite, Graz, Austria



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

I.Procházka et al, ***IEEE*** *2013*

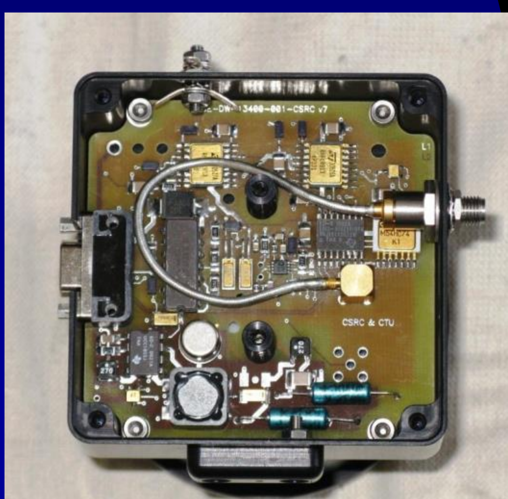


Ground segment stability

Verified via ground laser ranging

January – May 2013, Graz, Austria

Detector Upgrade – Space Segment



- Based on ACES-ELT concept and design mass, power req., etc…
- Passive temperature delay compensation

  = > temp. drift ~ < 100 fs / K (10x)

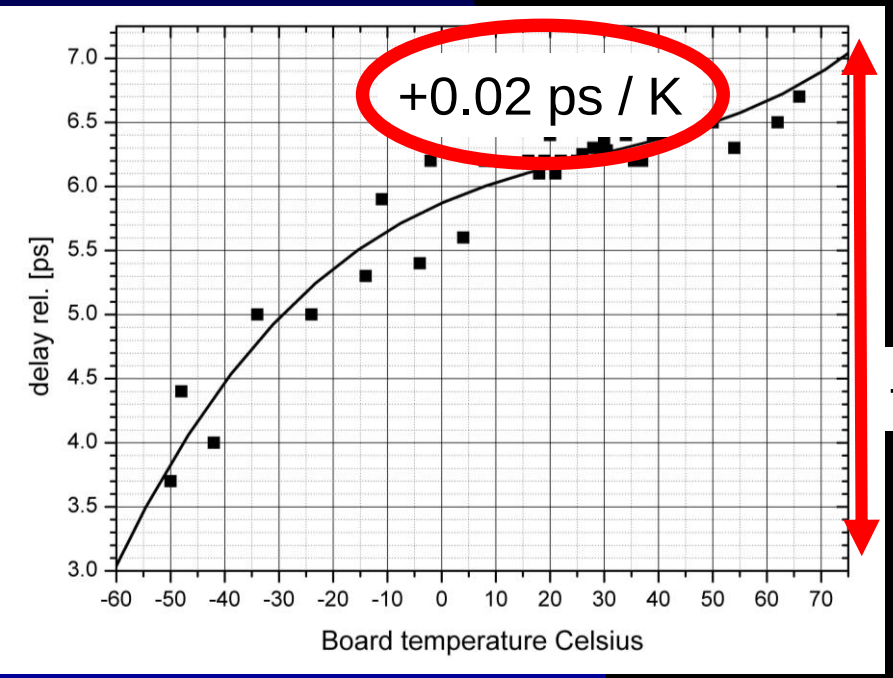
  = > prec.& stab. ~ < 100 fs @ hr (5x)
- Space qualificiation preserved from ACES

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

Detector upgrade – Ground segment

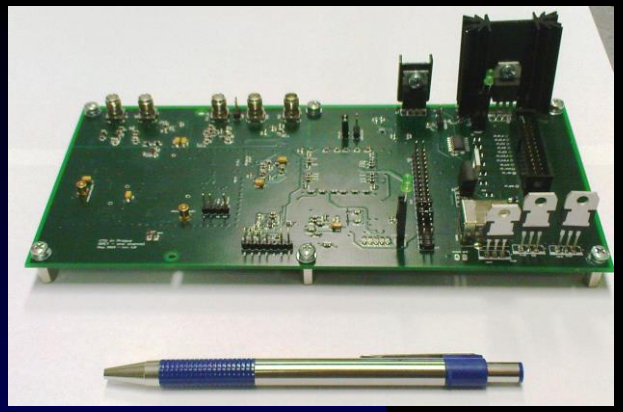
8 GHz comparator + PCB + housing + internal cabling

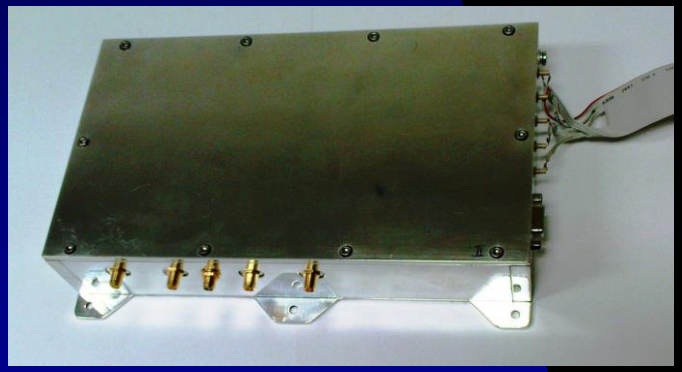
- **SLR overall jitter ~ 10 ps /1,5 mm (!)**
- **Temp. drift < 20 fs / K (!!) (0…45ºC)**
- World fastest &most stable detector
- Operational tests Wettzell since 2017
- Under preparation for APOLLO, US



***Rev.of Sci. Instruments 88**, (2017)*

Event Timer upgrade - space segment
for LTT applications





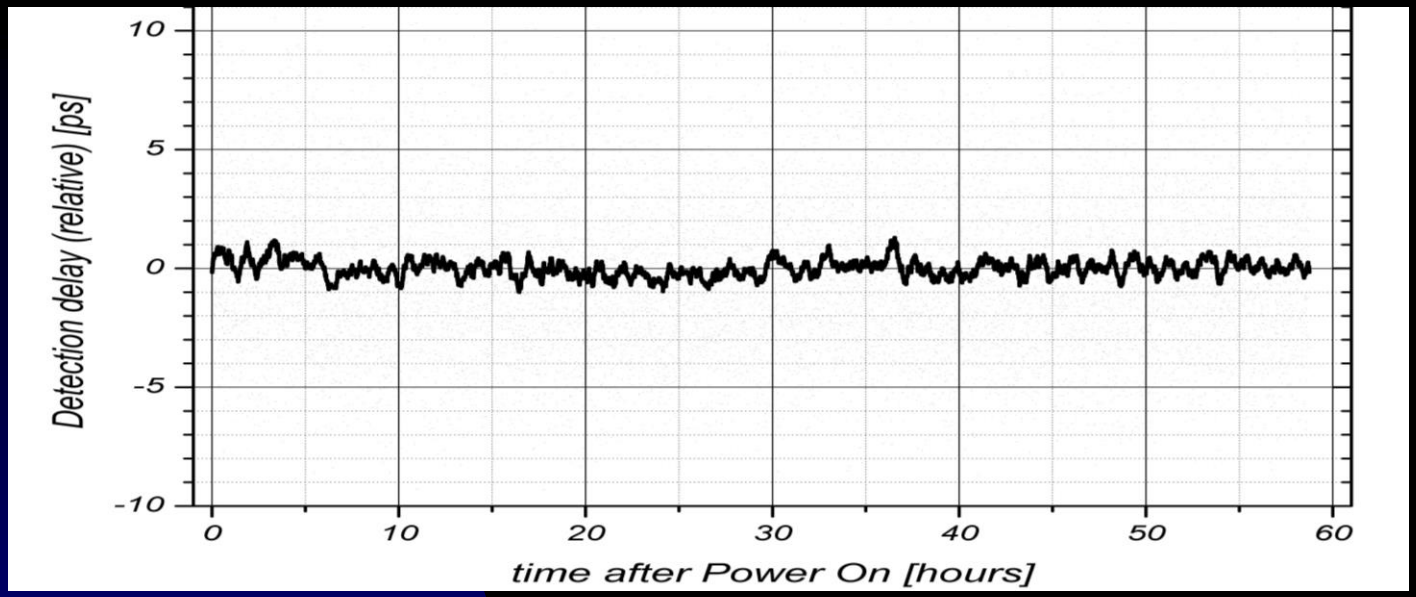
- Theory and design P.Panek, 2005
- Operating in frequency domain, SAW filter
- Sub-ps performance

Precision	< 500 fs rms
non-linearity	< 500 fs
temp. drift	< 200 fs/K
stability	< 4 fs@300s

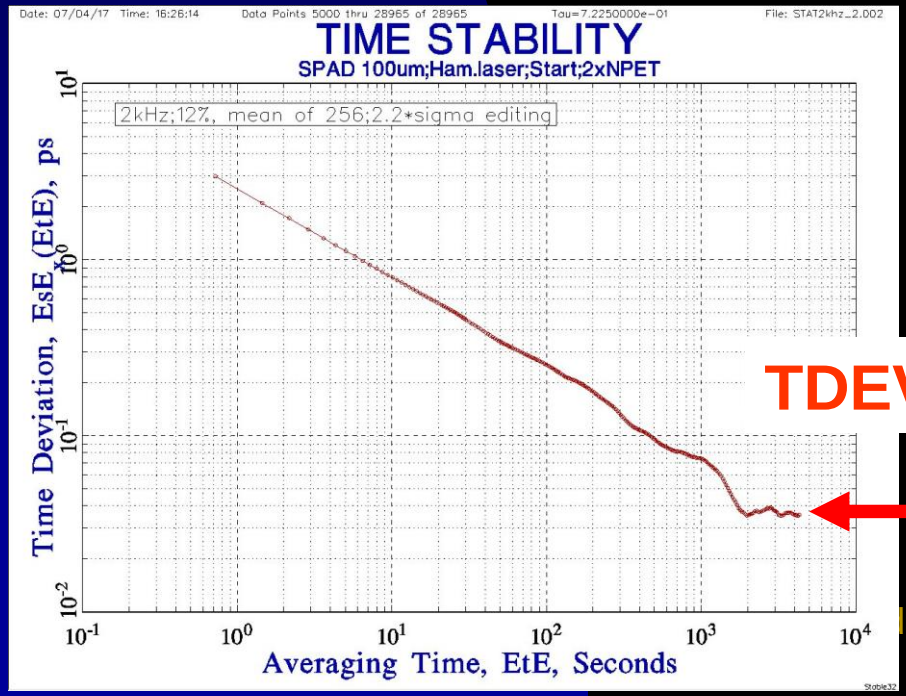
- Used in ELT ground segment now
- **Space version is prepared**

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 < 40fs@hr

***Review of Sci. Instruments 89**, 056106 (2018)*

let, ACES Workshop, Munich, October 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 ~ 1 x 10E-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 (?)