# Recent achievements in photon counting laser time transfer

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*ACES Workshop*

*Fundamental and applied science with clocks and cold atoms in space*

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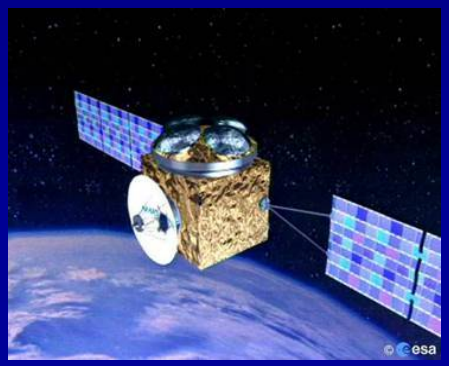
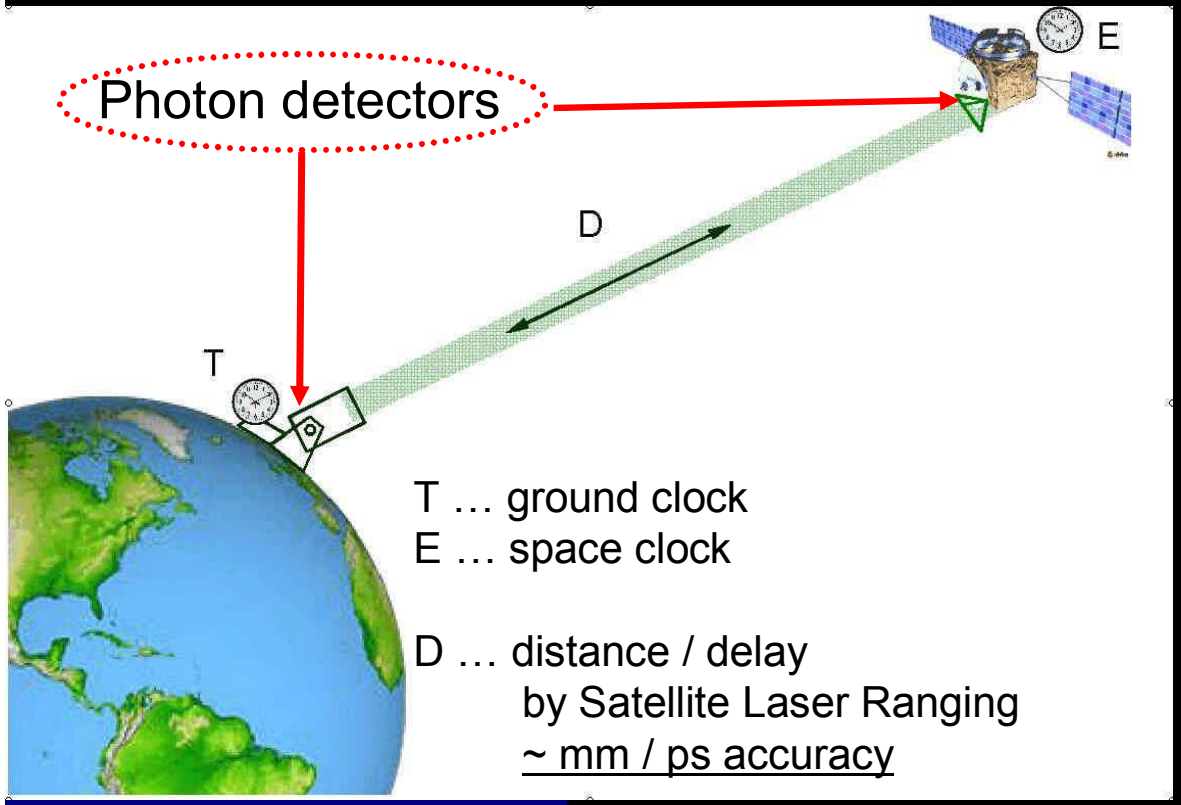
# OUTLINE

- Laser Time Transfer ground <=> space principle
- ACES – ELT hw performance
- SPAD detectors for ground & space segments
- New technology achievements
- Conclusion



# Laser Time Transfer ground – space principle




Time and frequency transfer using ps laser pulses in space

Relying on available technology and ground segment for Satellite Laser Ranging SLR

Sub-ps precision limit

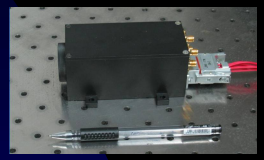
Propagation delay in space fully compensated by SLR !!

- ps optical pulses detected and time tagged both in space and on ground
- WHY Single photon approach ?
- NO analog signal processing => simple & precise
- = > **reducing the systematic errors ~ 10 ps level**

# Laser Time Transfer ground – space

## History & Concepts & Performance & Requirements

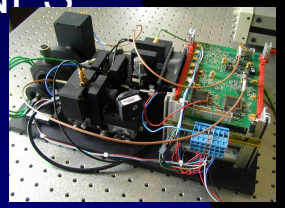
- LTT Compass (2003/2007)



single photon
- precision / accuracy

achieved
TDEV 30ps@500s / NA

- T2L2 CNES (2003/2008)



multiphoton
- precision / accuracy

achieved
TDEV 10ps@200s / ~ 100 ps !!

- ELT ACES (2010/2018)

single photon
- precision / accuracy

required
TDEV 5 ps@100s / ~ 20 ps

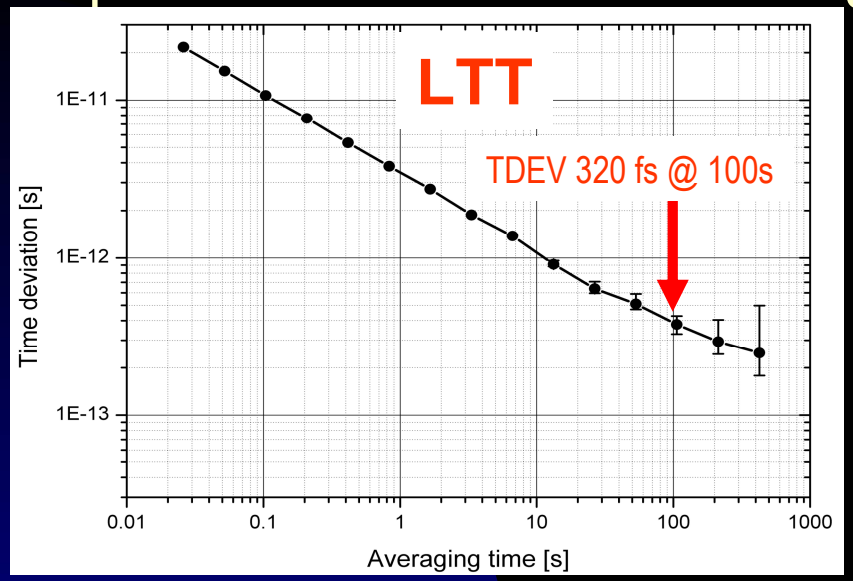
- ELT+ ISOC (2017/ ????)

single photon
- precision / accuracy

required
TDEV 0.5 ps@100s/ ~ 20ps

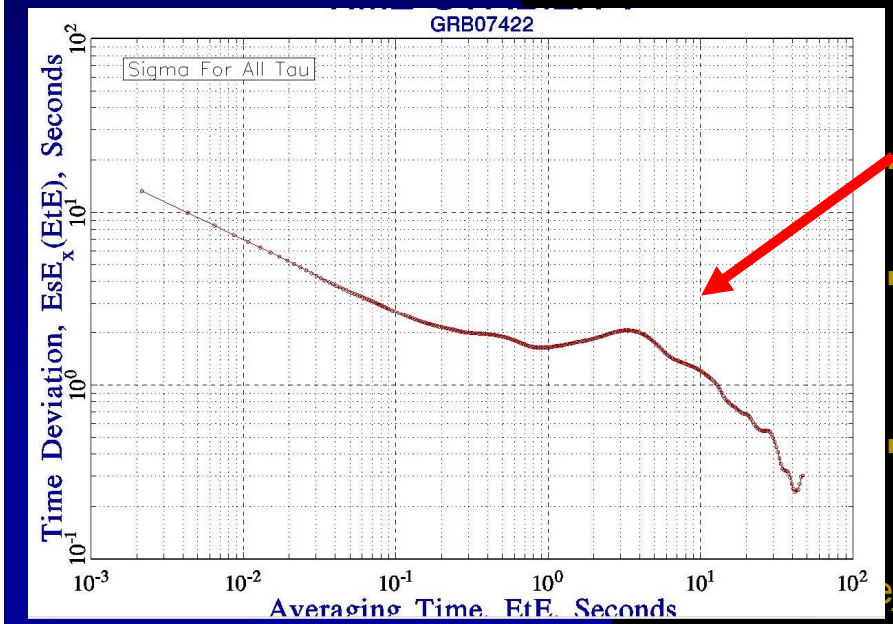
# ELT time transfer field tests

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




- ELT detector EM + ELT Calibration timing unit
- 500Hz data acquisition only
  TDEV < 250 fs @ 100s possible for 1 kHz rate

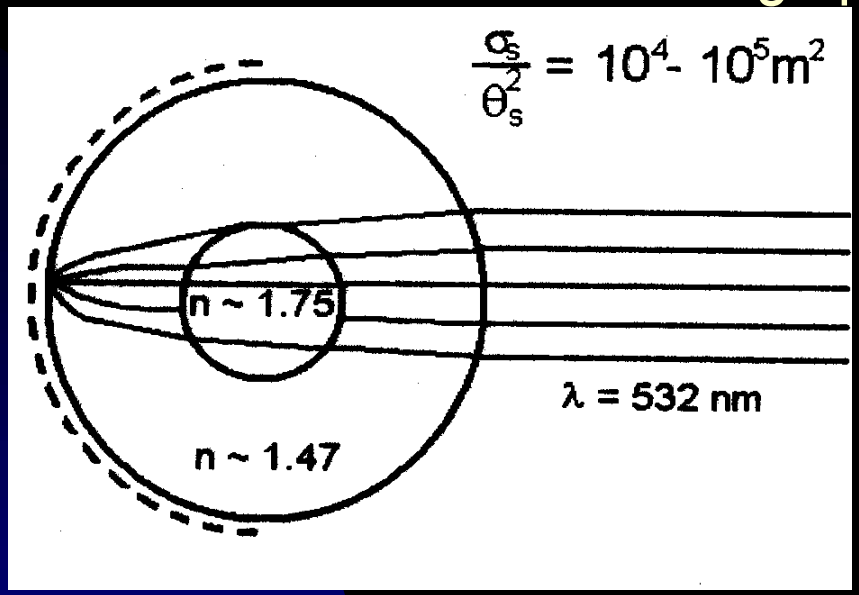
*Prochazka I,* ***Adv. in Space Res****. Vol 59,No.10, 2017*

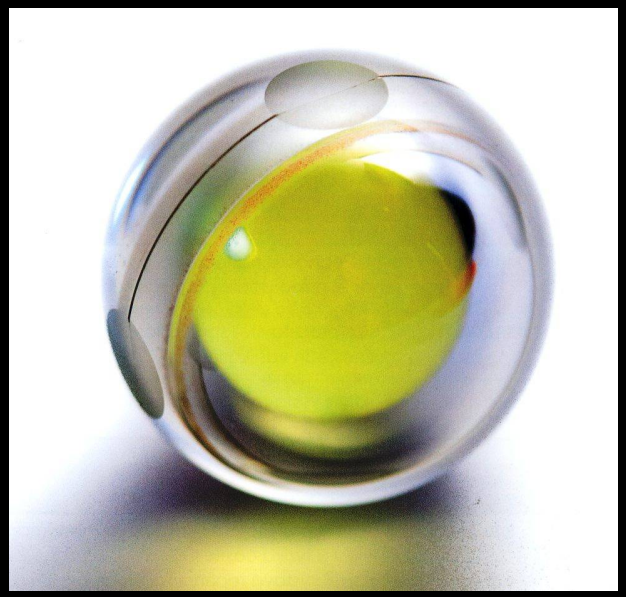


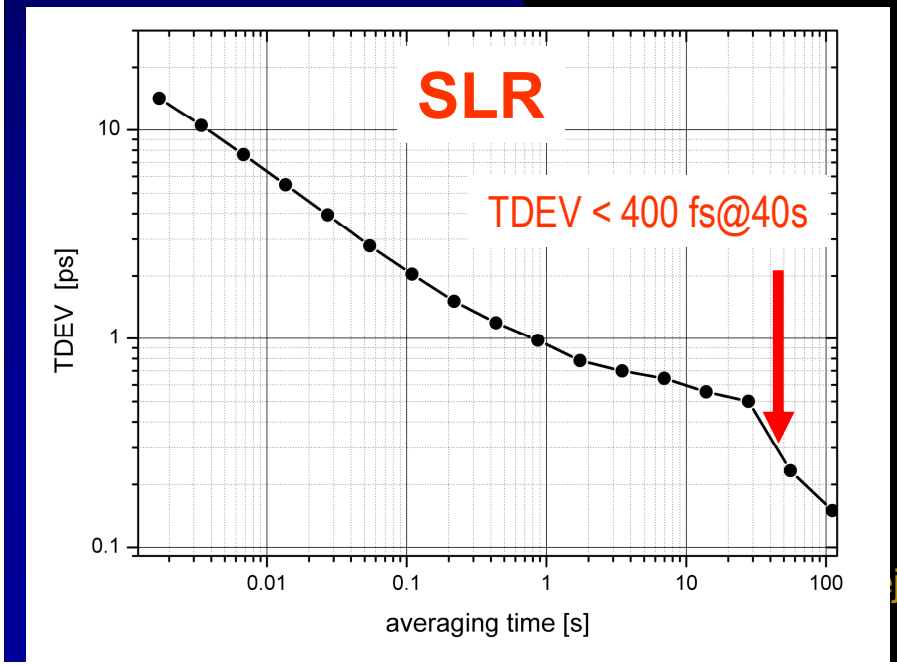

- TDEV Grace B, Graz, 2017
- = > ELT overall TDEV < 1 ps @ 100 s is achievable
- => main limitation is a retro-reflector and its contribution

# Laser retro-reflector for sub-ps precision

## "Luneburg sphere"

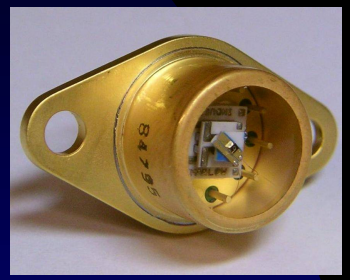




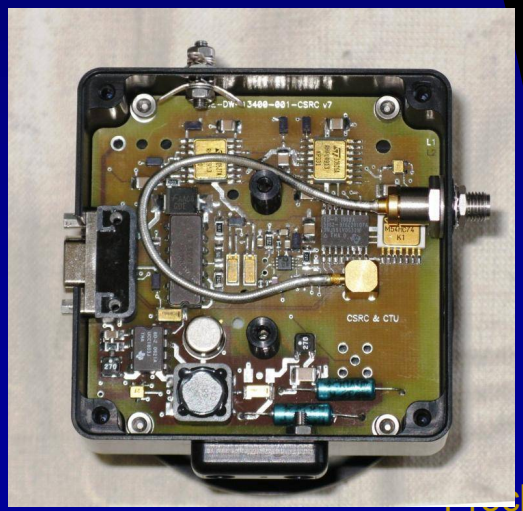

- SLR to spherical satellite Blis, Graz
- TDEV increase (3-30s) caused by spin (not existing on ISS)
- = > TDEV << 0.4 ps@100s possible

# Detector Upgrade – SLR ground segment



- Based on 25 years of experience, 5 continents SLR
- UPGRADES
- **<u>SPAD sensor tuning</u>**
  => jitter ~ 10 ps RMS ( 2x)
- **<u>Control Electronics design</u>**
  - temperature drift reduction
    = > drift ~ < 100 fs /K ( 3 x)
  - output pulses fall times < 50 ps ( 20x)
    = > prec.& stab. ~ < 100 fs @ hr ( 3 x)

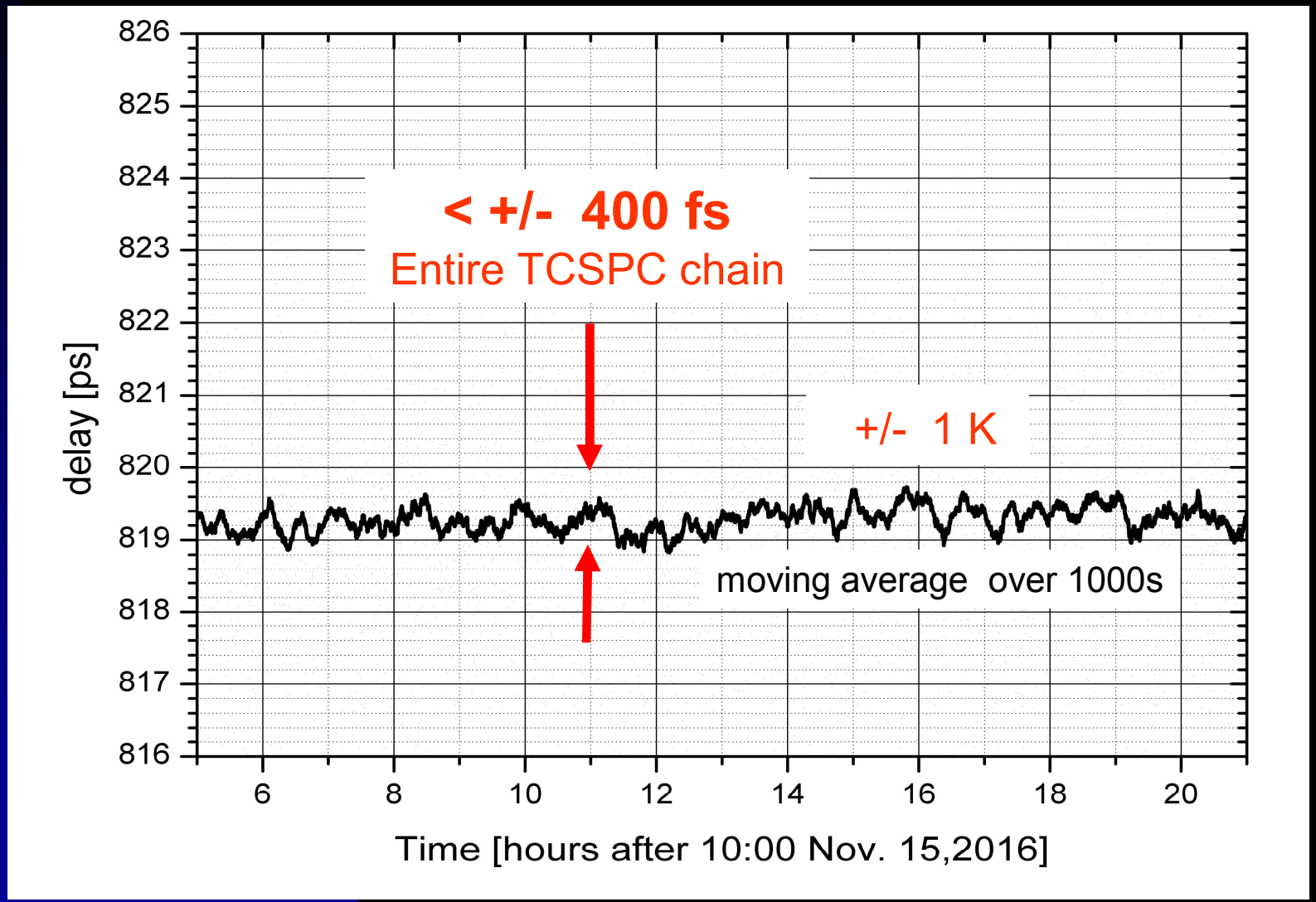
# Detector Upgrade – Space Segment ELT



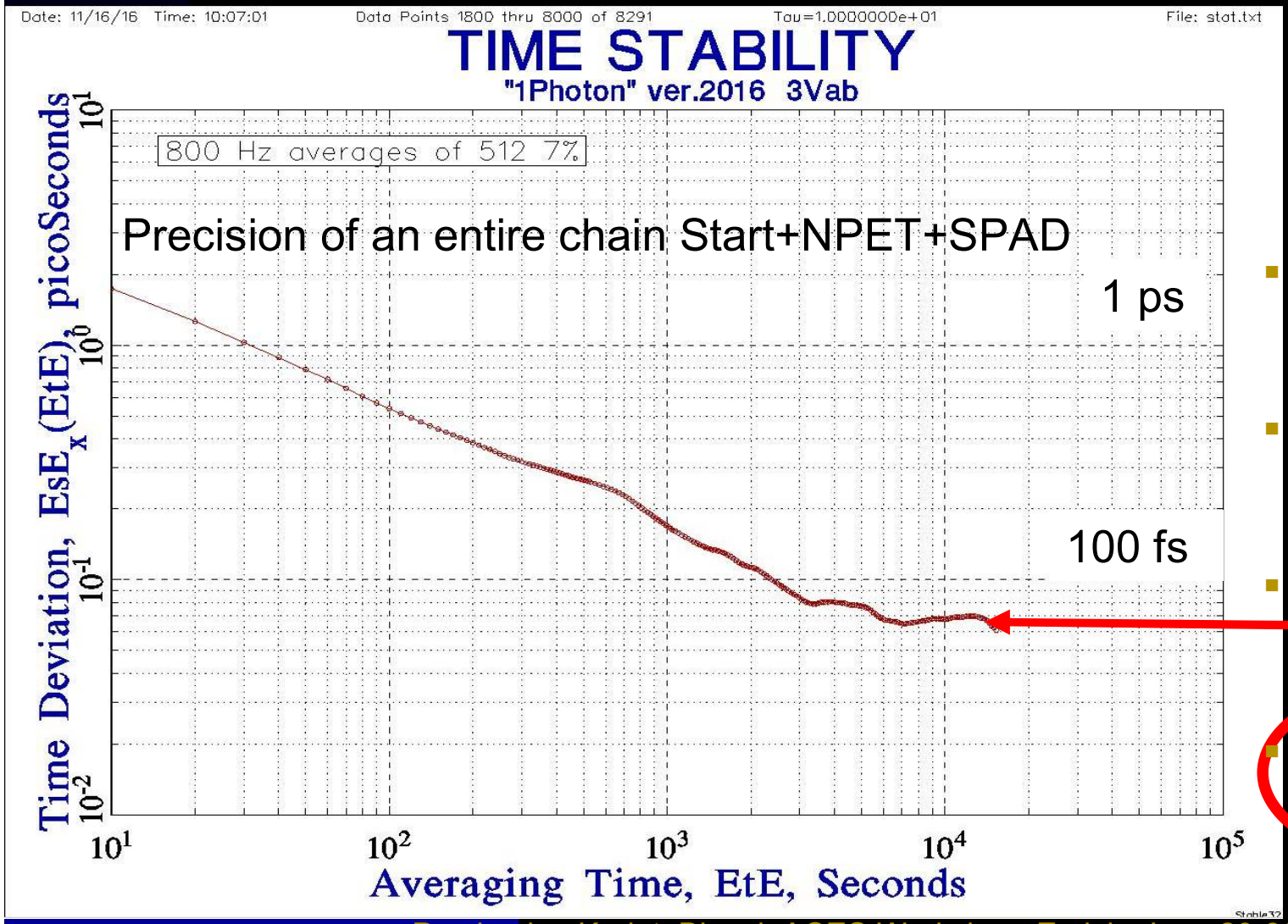
- Based on ACES-ELT concept and design
  mass, power req., etc…
- UPGRADES
- Optics modifications ????
  Increase of field of view 60 to 70 deg.
  = > increase of tracking time ( 1.5x)
- Electronics
  Passive temperature delay compensation done
  = > drift ~ < 100 fs /K (10x)
  = > prec.& stab. ~ < 100 fs@hr ( 5x)
- Other TBD ????

Detection delay LONG TERM STABILITY

# both Ground & Space Segment detectors

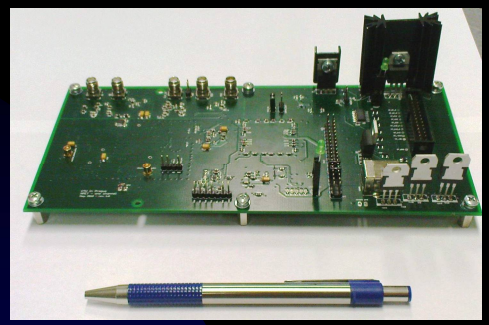


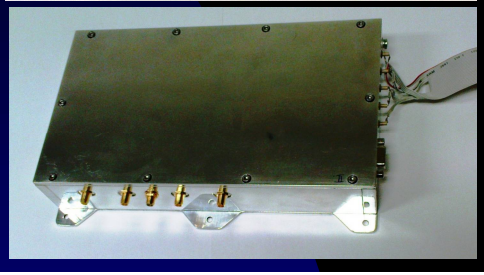
# New generation of SPAD detectors for SLR and LTT with fs stability
# both Ground & Space Versions




- START detector
  TDEV =< 50 fs
- NPET Timing
  TDEV ~< 30 fs
- TOTAL
  TDEV ~ 70 fs
- => Detector
  TDEV ~< 40 fs

# New Pico Event Timer NPET



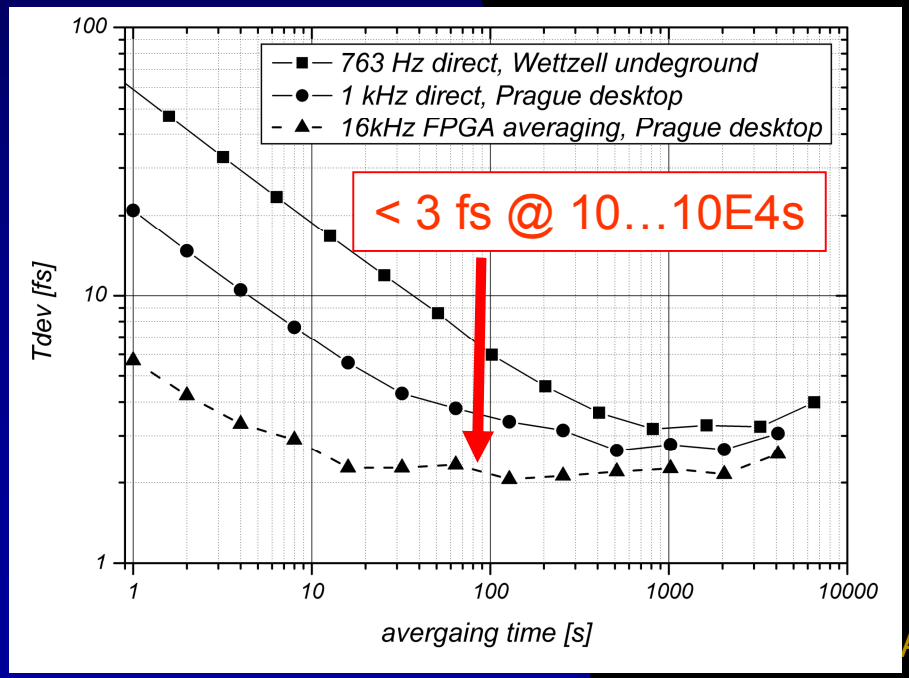


- Theory and design P.Panek, 2005
- Operating in frequency domain, SAW filter
- Sub-ps performance

| | |
|---|---|
| Precision | < 500 fs rms |
| non-linearity | < 500 fs |
| temp. drift | < 200 fs/K |
| stability | < 4 fs@100s |

Used in ELT ground segment

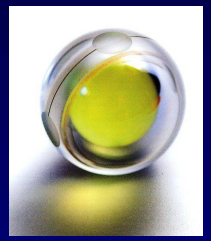
Space version under consideration




*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*

# CONCLUSION

1. ELT we have demonstrated space detector and ground segment SLR in Graz, Austria experiment
=> precision achieved fits requirements with sufficient margin



2. I-SOC series of upgrades of detectors and reflector
The overall LTT performance fits I–SOC requirements
The reflector has space heritage and is available (Russia)

3. The NPET timing system is providing sub-ps timing and fs stability, its space qualified version is under consideration

4. Thanks for your attention

# Laser retro-reflector for sub-ps precision

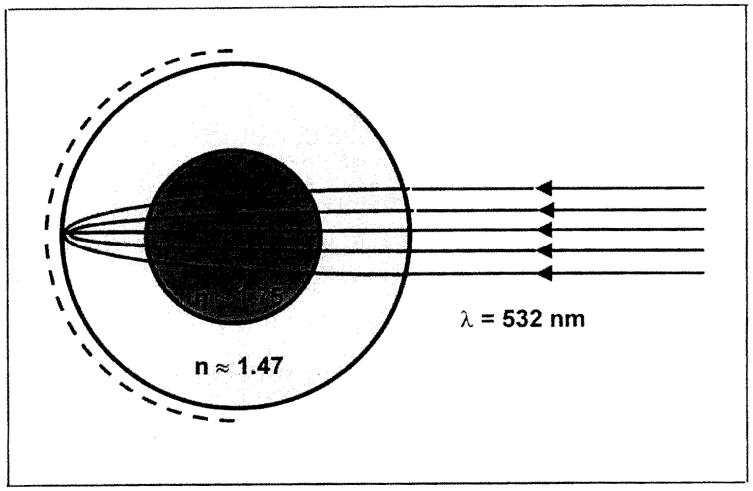



***Figure 1. Spherical retroreflector optical layout***

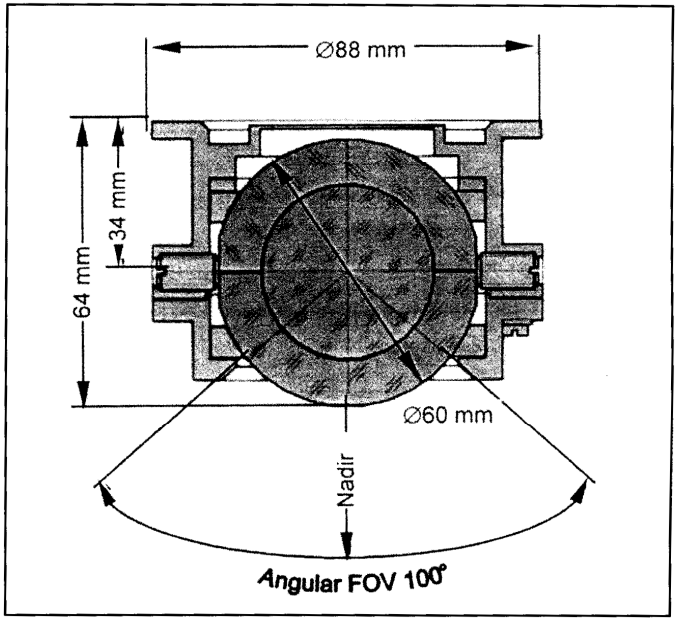
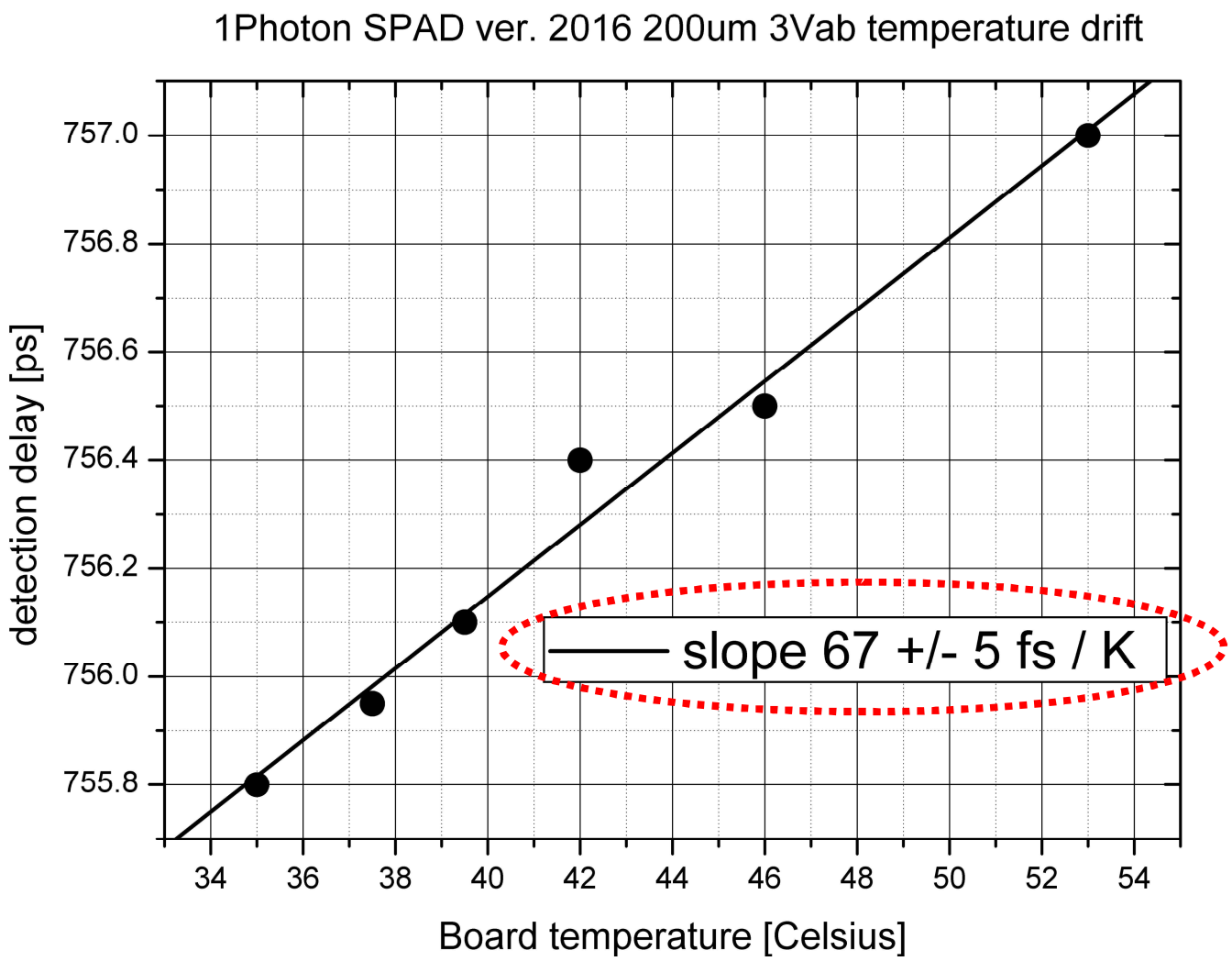
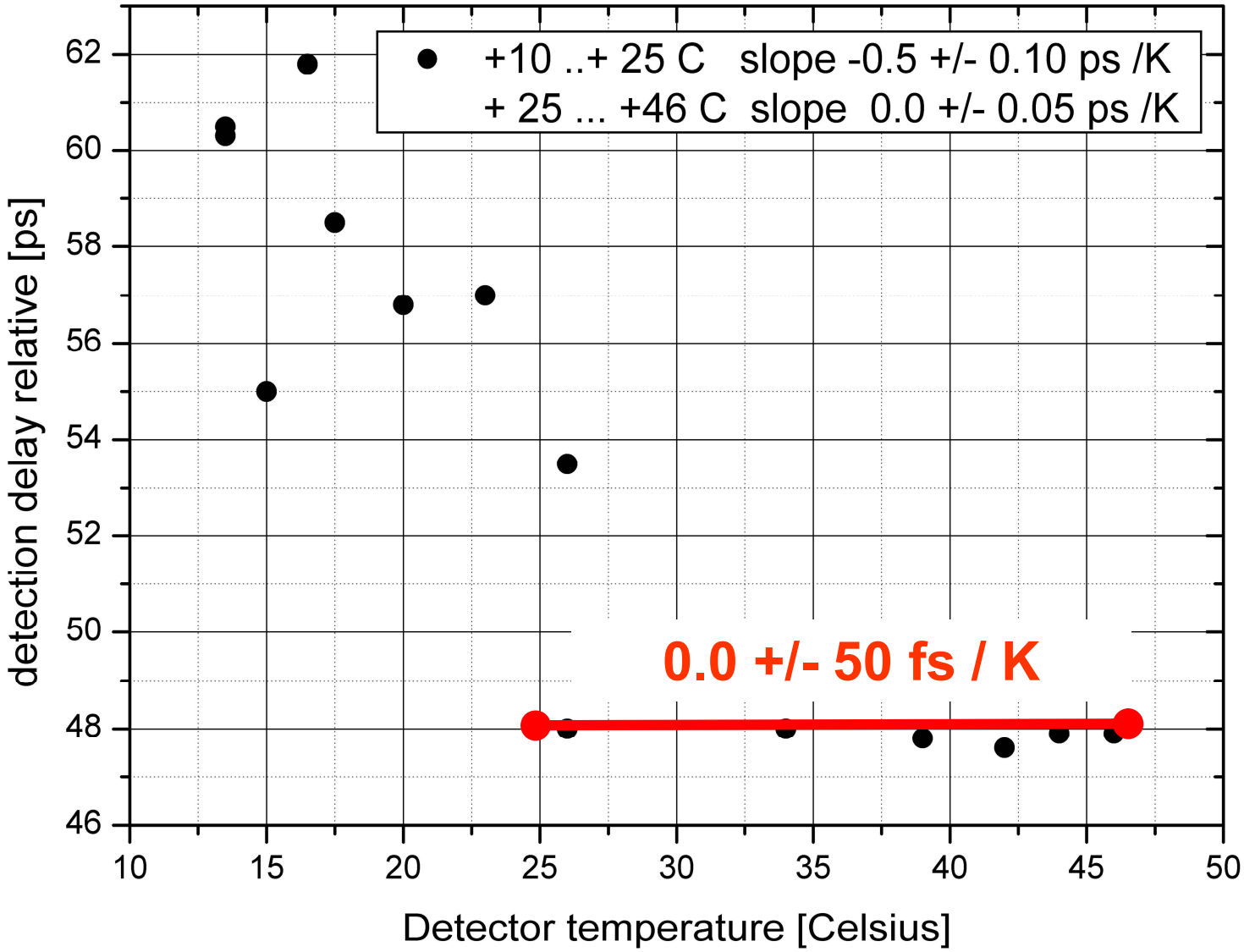



***Figure 2. Spherical retroreflector in holder***

- Spherical retroreflector - satellite Blis
- Free flying sphere
- Ultimate precision target for SLR
- TDEV limited by satellite spin and axis orientation

- Spherical retro-reflector attached to a Meteor-3 satellite
- FoV 100 deg.
- No spin , No TDEV limit

# Detector Upgrade – SLR ground segment



# Detector Upgrade – ELT+ space segment