Recent achievements in ground to space laser time transfer technologies

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Outline

- GENERAL - Requirements on laser time transfer are still increasing in comparison to ACES 2008
  - temperature delay drift < 300 fs / K
  - precision TDEV < 0.3 ps @ 100s
  - long term stab. p - p < 1 ps over days
- Our recent progress in:
  - Photon detector for space temperature stability
  - Photon detector for ground temperature stability
  - Development of NPET timing system for space
- Summary and conclusion

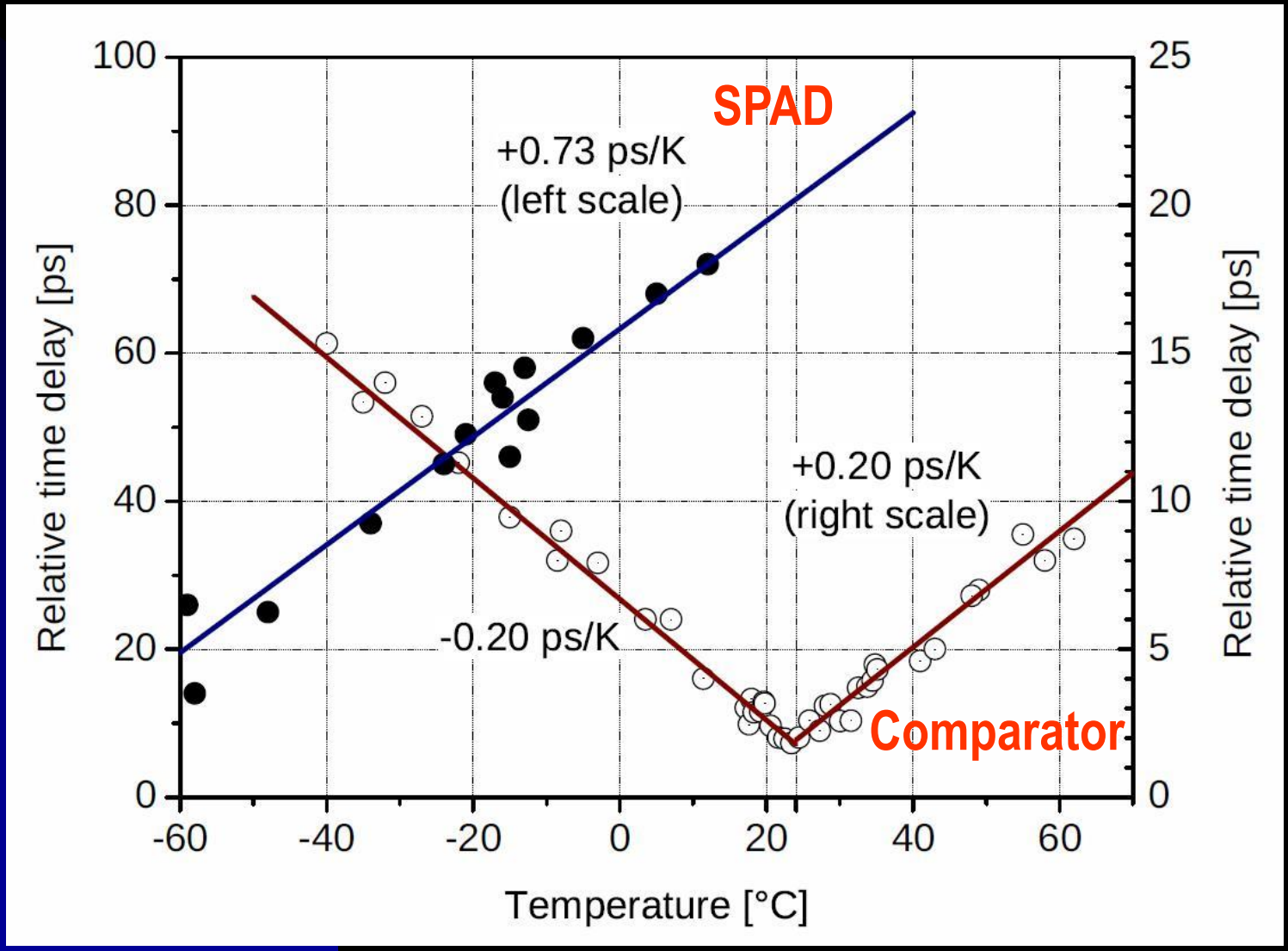
Space Detector Upgrade 1
Reduction of temperature drift

- Based on ACES-ELT concept and design
- Passive temperature delay compensation
- Fine “tuning” of two resistors values only (!)
- = > temp. drift abs. < 250 fs / K (3x)
- = > TDEV ~ < 100 fs @ hr (5x)
- Space qualification preserved from ACES

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

Space Detector Upgrade 2

Two key contributors to temperature drift



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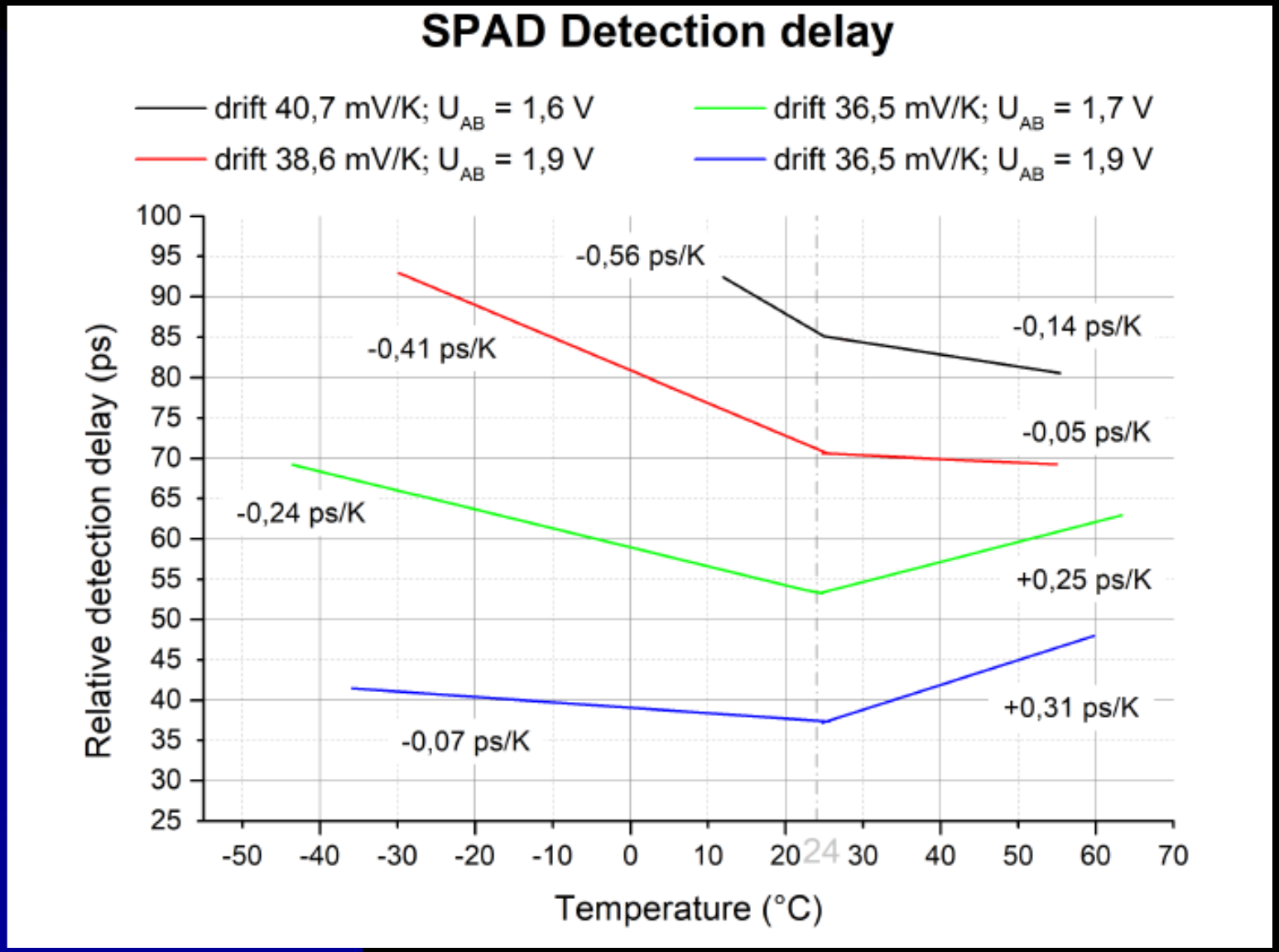
Space Detector Upgrade 3

Reduction of temperature drift – fine resistors tuning



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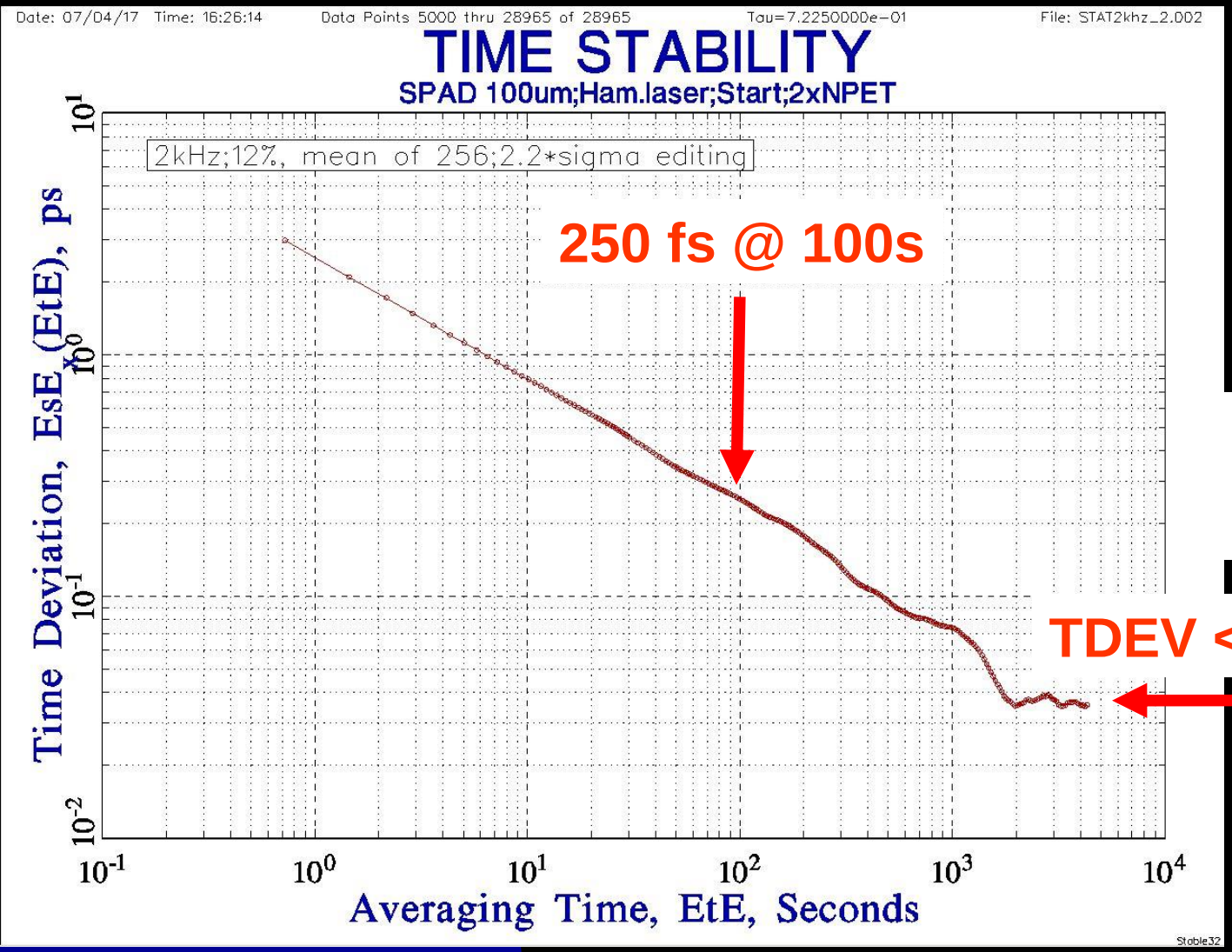
Space Detector Upgrade - performance test



Indoor Prague
+ / - 1 K

Complete LTT loop laser, Start, SPAD, 2 x NPET

TDEV < 40fs@hr

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

Ground Detector Upgrade

Reduction of temperature drift

- New SPAD detector for SLR and laser time transfer ground segment

  https://cddis.nasa.gov/2019_Technical_Workshop/docs/2019/

- Based on 100um diameter SPAD chip K14 TE1 cooled to reduce its effective dark count rate

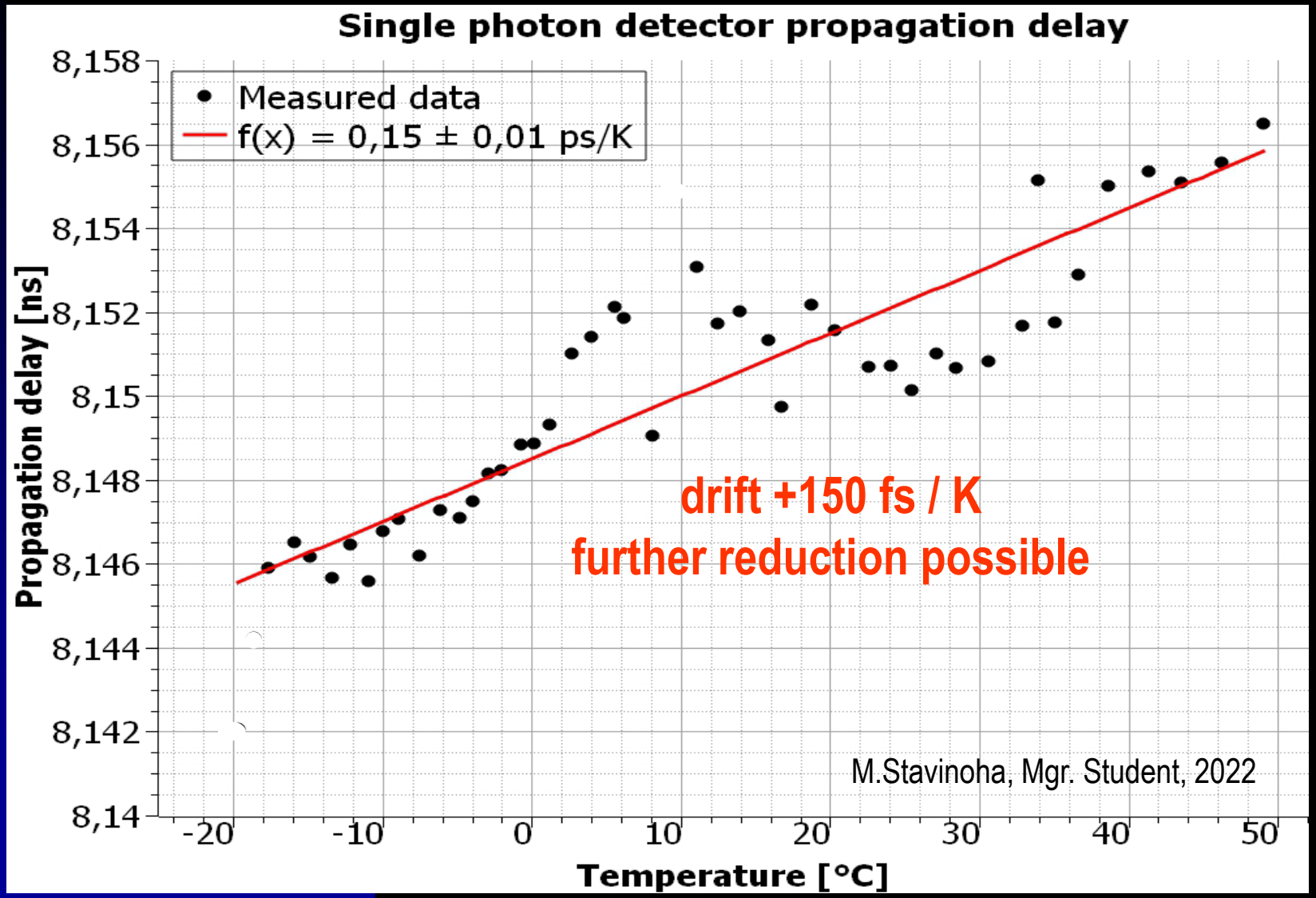
- The passive compensation of the detection delay temperature dependence

- New comparator was implemented
  => “flat” temperature delay dependence

- = > The over all temperature delay drift
  < 100 fs / K is possible

Ground Detector Upgrade 2

Reduction of temperature drift – the very first result



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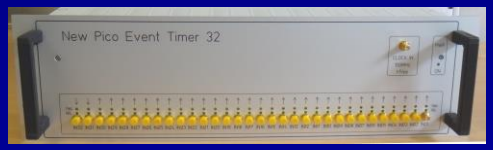
New Pico Event Timer NPET

Portable 1 ch NPET

Standard 1 ch NPET

Standard 2 ch NPET



Switch 32 inputs, 1 ch NPET

- Theory and design P. Panek, 2005
  U.S. Patent 7,057,978 B2, Jun. 2006.
- Sub-ps performance

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

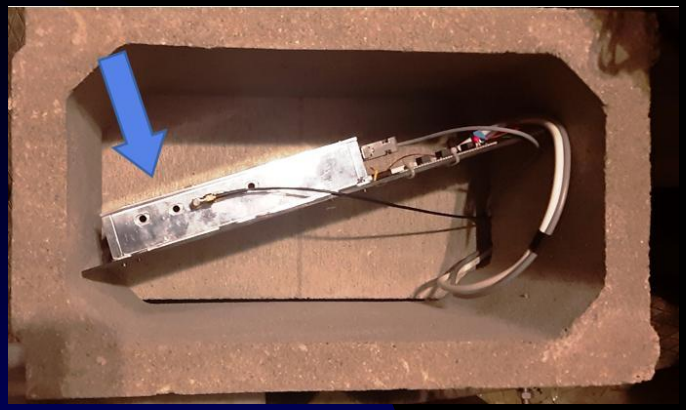
- Installed and used on numerous sites worldwide, various configurations
- It is attractive also for space application, however development of a complete “space version” would require
  > 3 years > 3 MEUR ☹
- We decided to check the radiation resistance of the existing NPET electronics.

New Pico Event Timer radiation tests 1

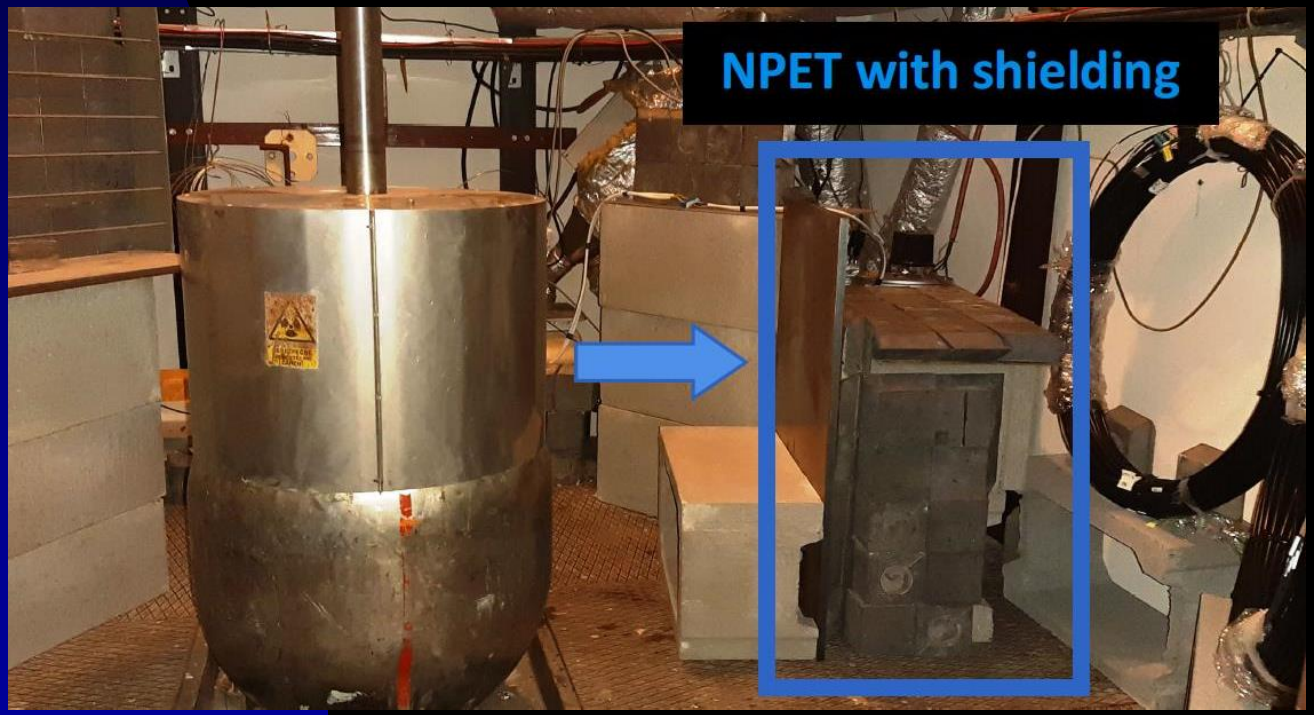
- Standard NPET board, Al housing RF shield, passive heat distribution
- no radiation shielding effect ☹
- Radiation tests ^{60}Co organized, Jan.-Feb.2022

UJV Rez, udergound radiation facility

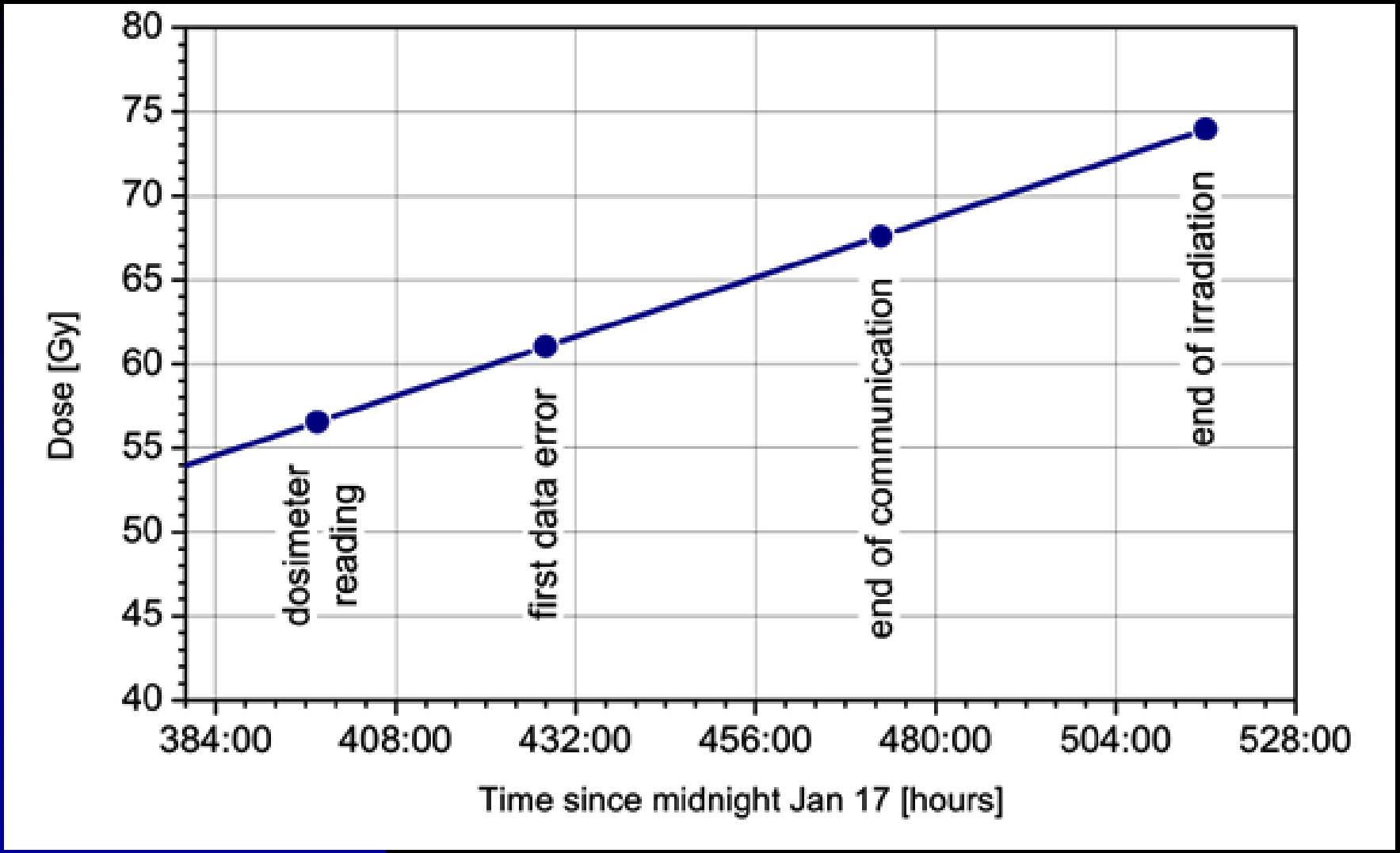
New Pico Event Timer radiation tests 2



- NPET board running in a self-test mode 1 kHz rep. rate
- The 100 MHz clock source, power supply and control PC were located outside radiation chamber



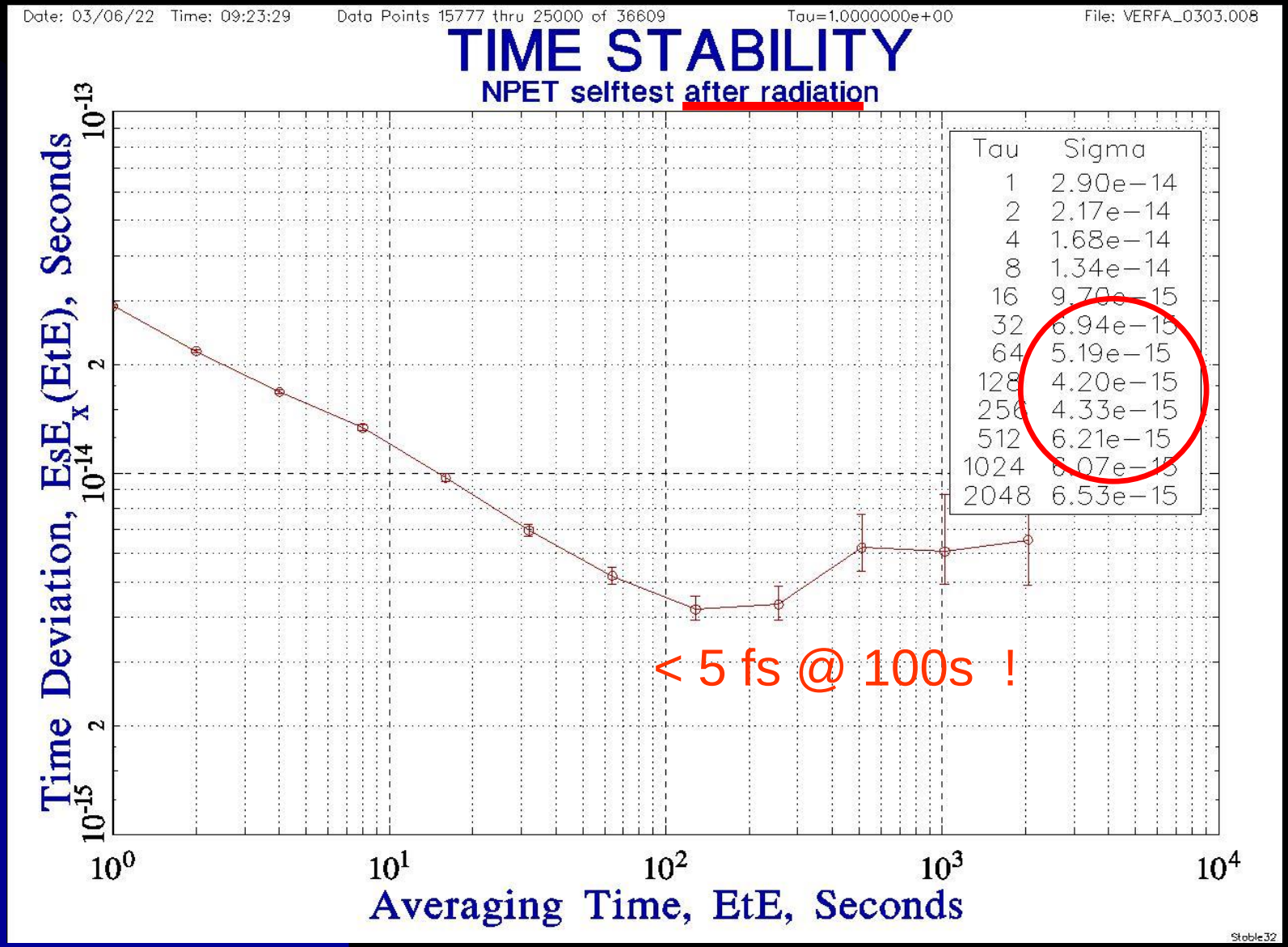
New Pico Event Timer radiation tests 3



New Pico Event Timer
radiation tests results

- NPET board operated in a self-test mode indicated first communication problems after 60 Gy dose, day #18
- After the dose of 67 Gy (day #20) the data communication stopped
- The radiation test was terminated with a total dose of 75 Gy (day #22).
- The NPET device was taken to the lab for detailed examination.
- The only radiation damaged component was the RS232 communication interface. This was the only one circuit manufactured by CMOS technology.
- The device communication was switched to low levels TTL and the entire device was operational again.

New Pico Event Timer radiation tests 5



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New Pico Event Timer – space version

The NPET timing board “survived” ok the radiation dose of 75 Gy.

It corresponds to operation on LEO for several years.

- For routine space operation the board will be slightly modified:
  - trigger input circuit will be added
  - mechanical design will be modified for space
  - The additional radiation tests are planned
  - Significantly higher radiation tolerance is expected.

Review of Scientific Instruments 93, 094501 (2022)

Summary

Recent achievements in ground to space laser time transfer technologies

- New method of passive compensation of detection delay was developed and tested.
- => ELT – ACES version of space detector may be significantly improved by reducing its temperature dependence of delay.
- => The temperature stability of the detector for SLR ground segment was improved
- Both these improvements resulted in reduction of overall system TDEV typically 4x

- The NPET main board electronics was radiation tested. It is capable to operate on LEO orbits for several years.
- The modified single board version for space applications is under development

Conclusion

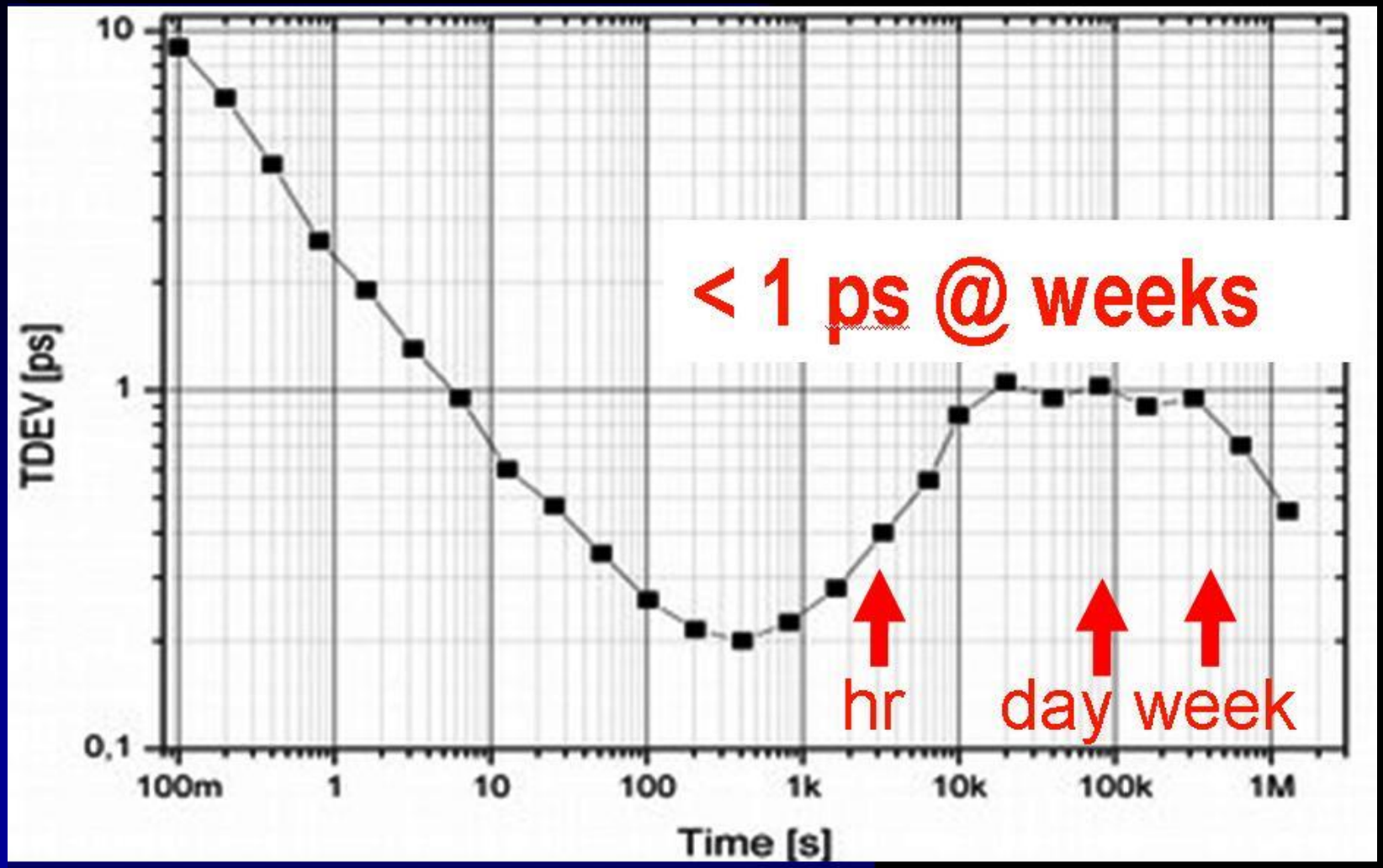
- The presented achievements should enable to achieve laser time transfer ground – space

- frequency transfer uncertainty ~ 1 x 10E-18 @ 10 days

- time transfer
  - precision ~ < 300 fs @ single LEO pass
  - stability ~ < 1 ps @ days … month
  - accuracy ~ < 30 ps

- Thank you for your attention

LTT ground segment stability, Graz SLR 2013



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