ACES – ELT laser link performance and ps accuracy optical time transfer

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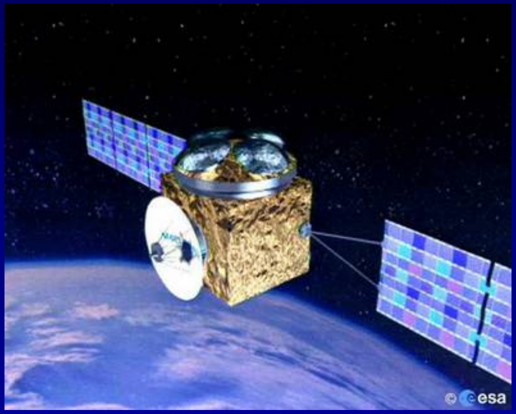
Outline

- Optical time transfer capabilities on photon counting level
- ELT detector package EM tests
- ELT timing properties
- Single photon Two Way Time Transfer
- Possible future applications
- Conclusions

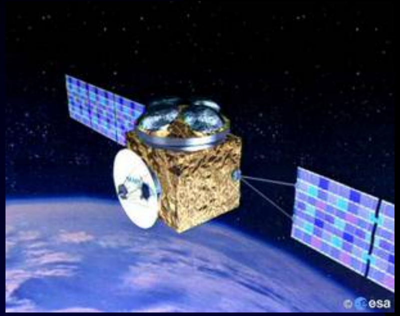


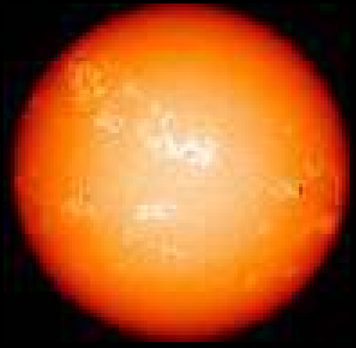
WHY Single photon in metrology ?

Not just „ .. higher sensitivity .. „

- quantum nature of light = > two states detected 0 / 1
- NO analog signal processing = > **NO systematic errors**
- Extremely weak signals = > **High dynamical range**
- Measurement by-products
  optical signal intensity
  signal shape
  measurement precision ~ $N^{-1/2}$
- **= > sub-ps precision, ps accuracy and ps stability**
- Space qualified devices existing – see next …
  T2L2 space segment,/ OCA Grasse/ GNSS network,..

Photon Counting Approach Limitations

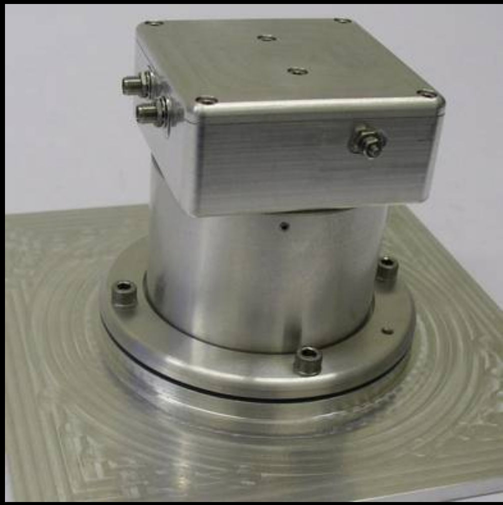




- Background photon flux, Sun, Earth albedo, etc…
- Large data volumes
- Complex data processing
- All items solvable (operational missions > 6 yrs)

European Laser Timing ELT-ACES
Detector EM assembly and tests

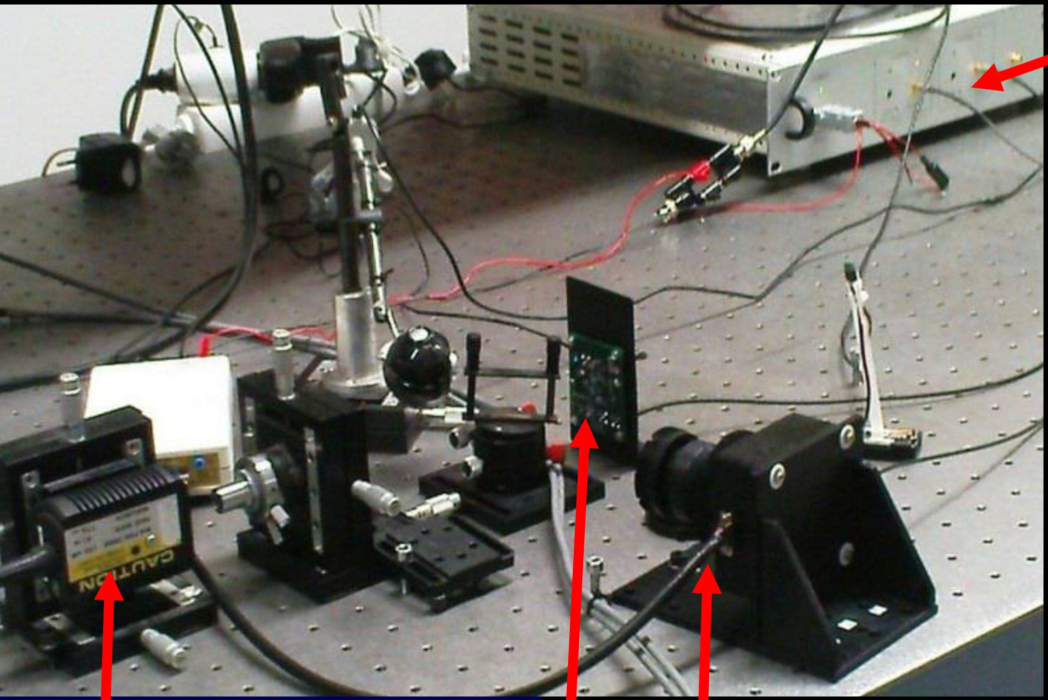
Detector EM assembly in CTU labs 2011

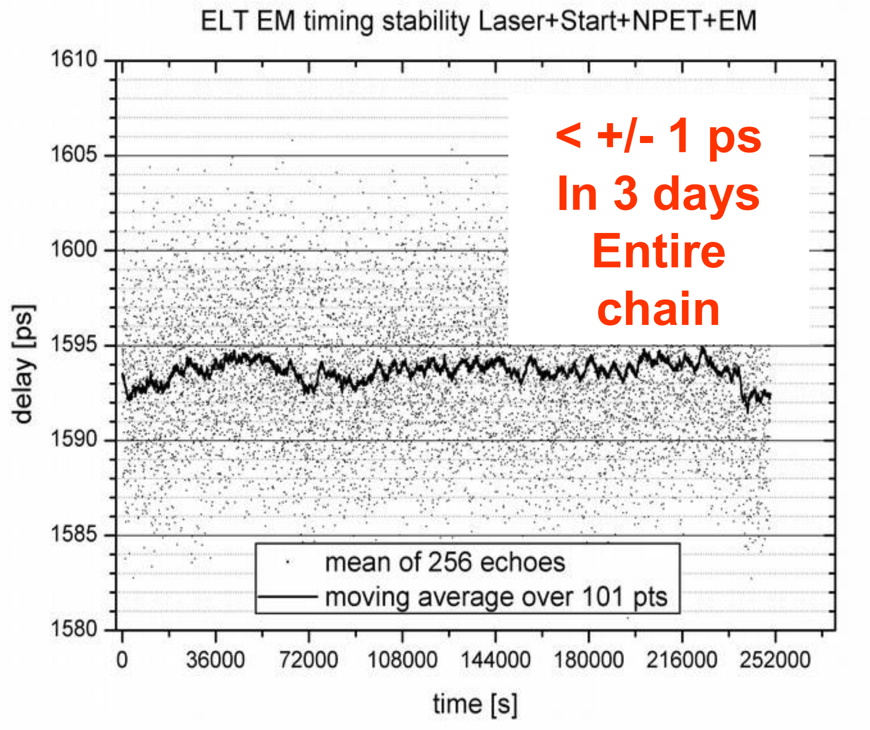


Detector package EM
500 grams
0.6 Watt

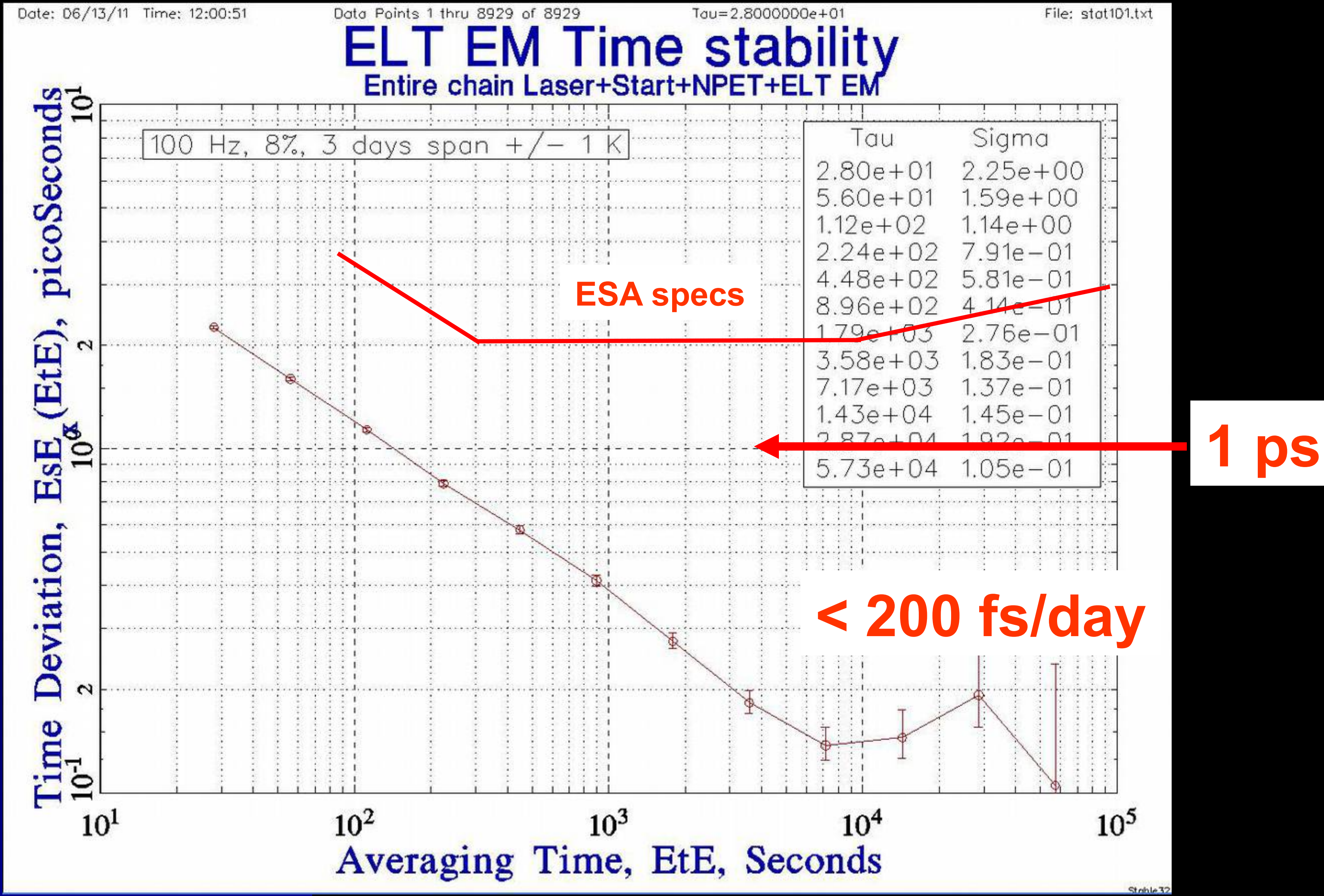
Flying unit FM nearly complete 2013

Detection delay LONG TERM STABILITY

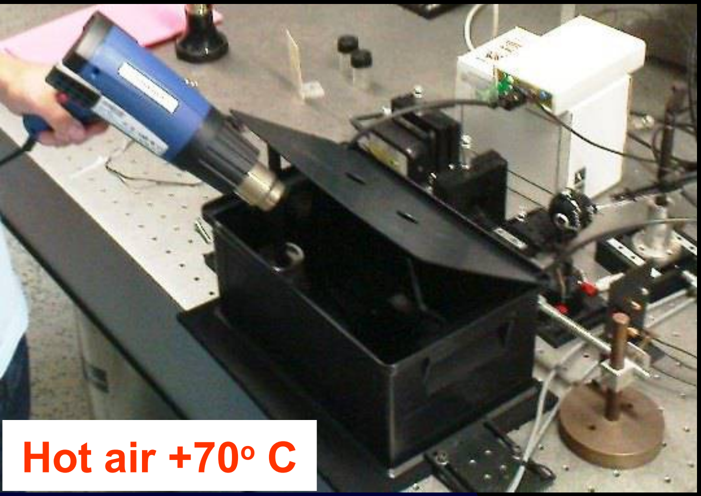




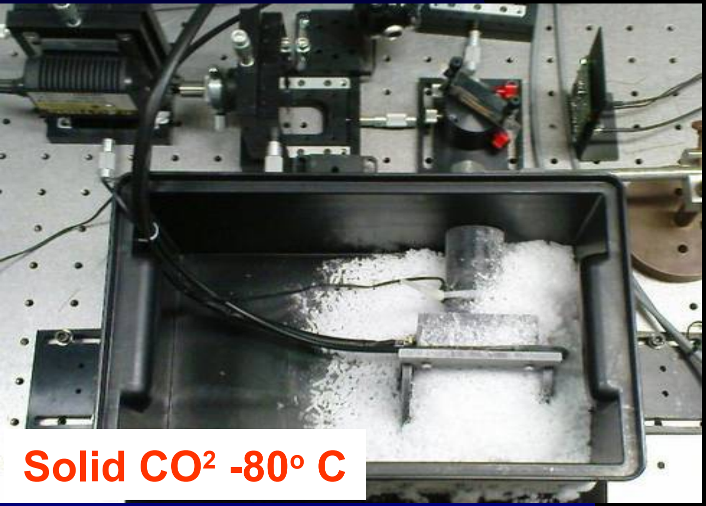
ELT Detection delay LONG TERM STABILITY



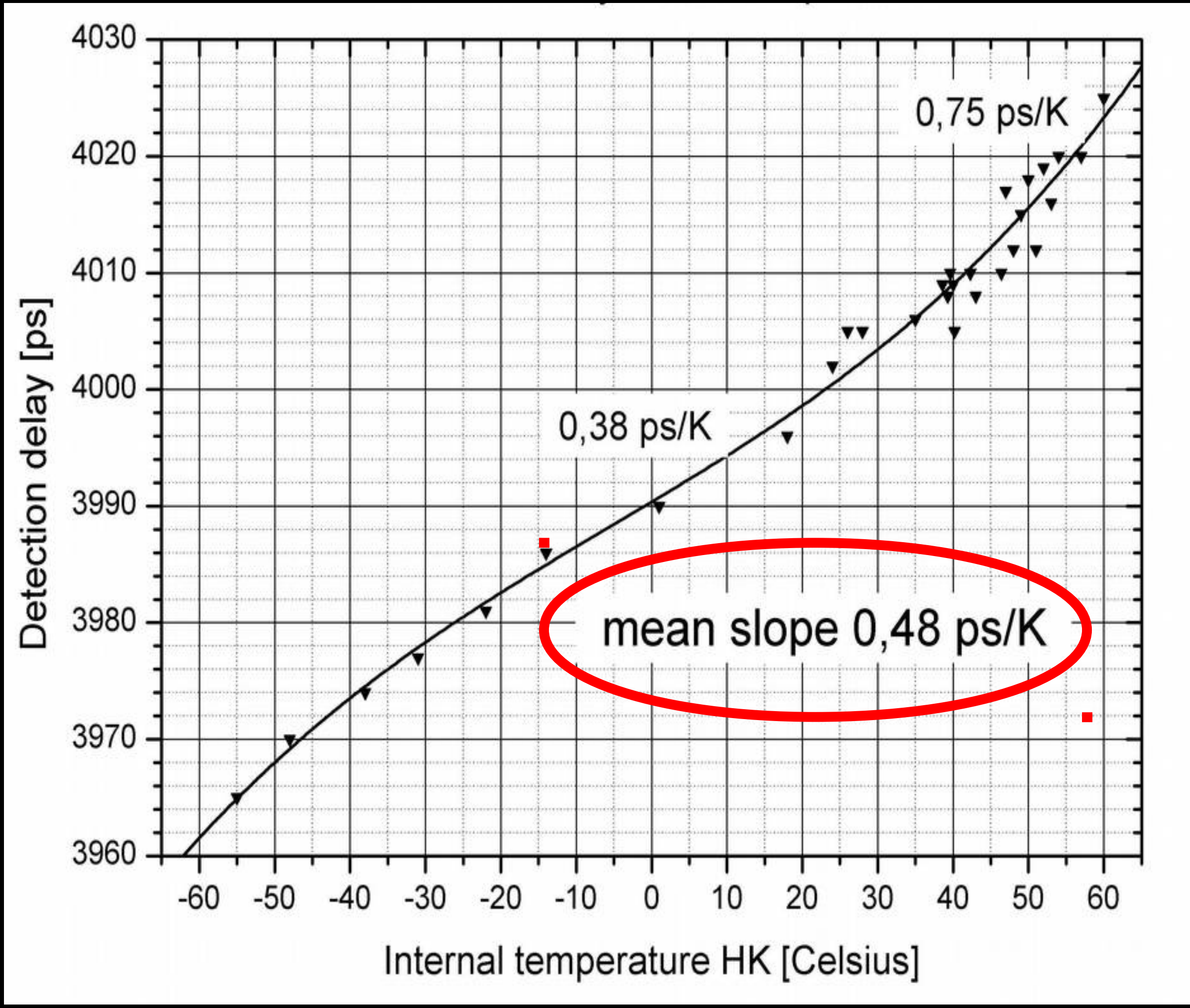
Detection delay temperature dependence



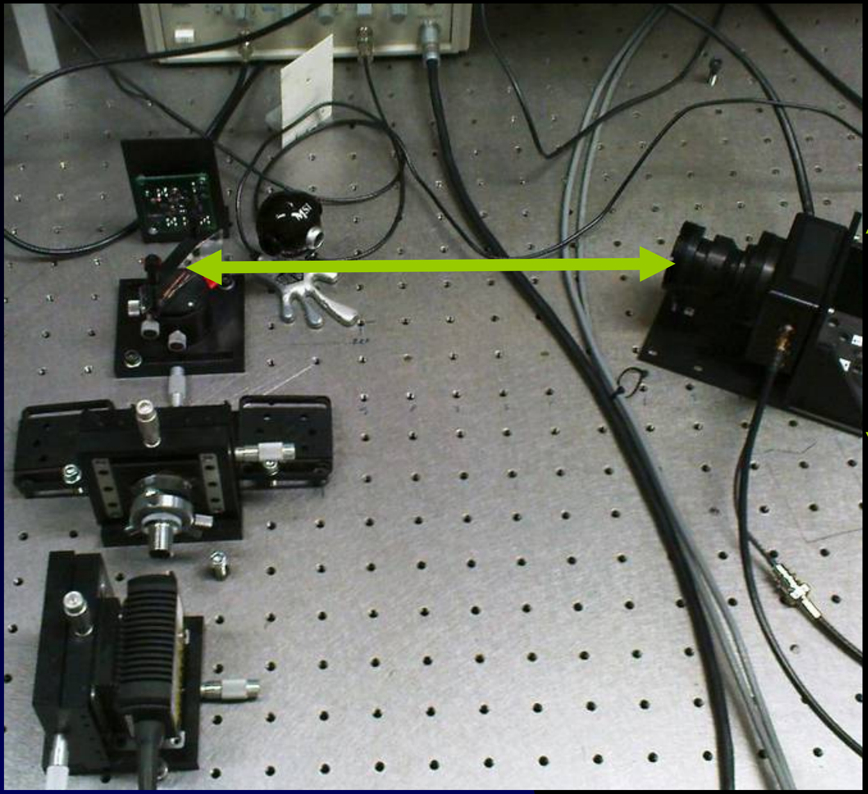
Hot air +70° C



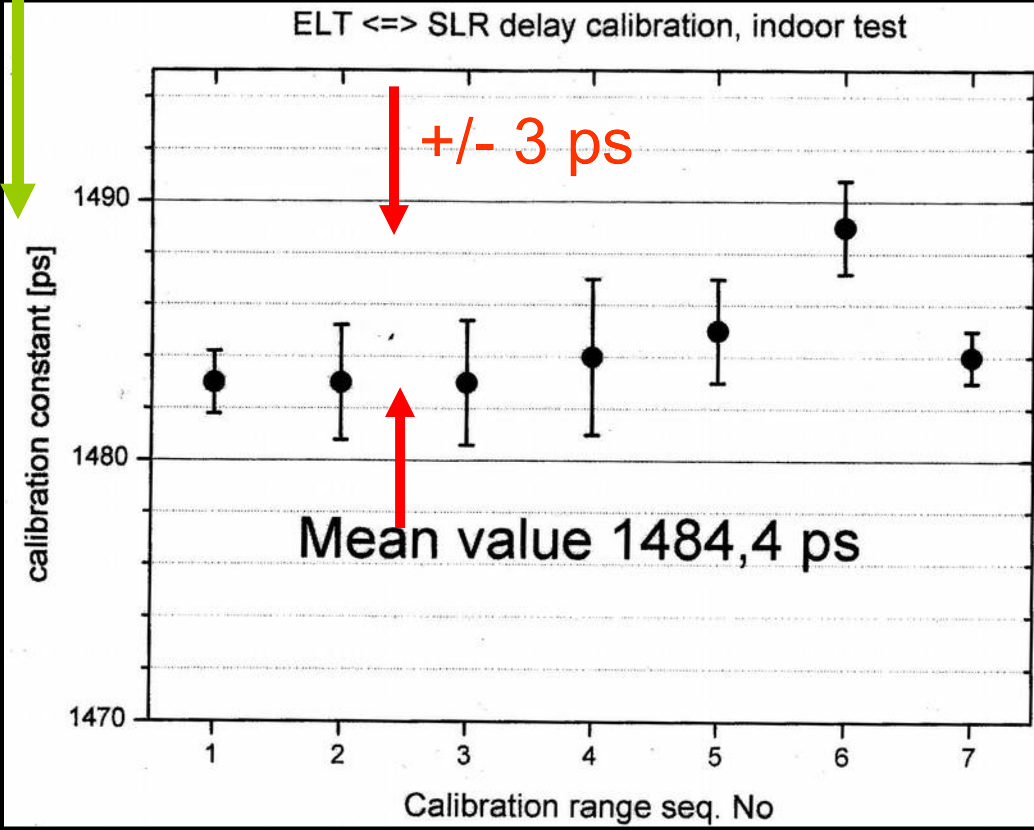
Solid CO² -80° C



Ground + Space segments delay calibration – demo



- Range 50 …. 250 mm in 6 steps
- Angles +/- 5 to +/-60 degrees
- One day averages



GROUND
"SLR"

SPACE
EM

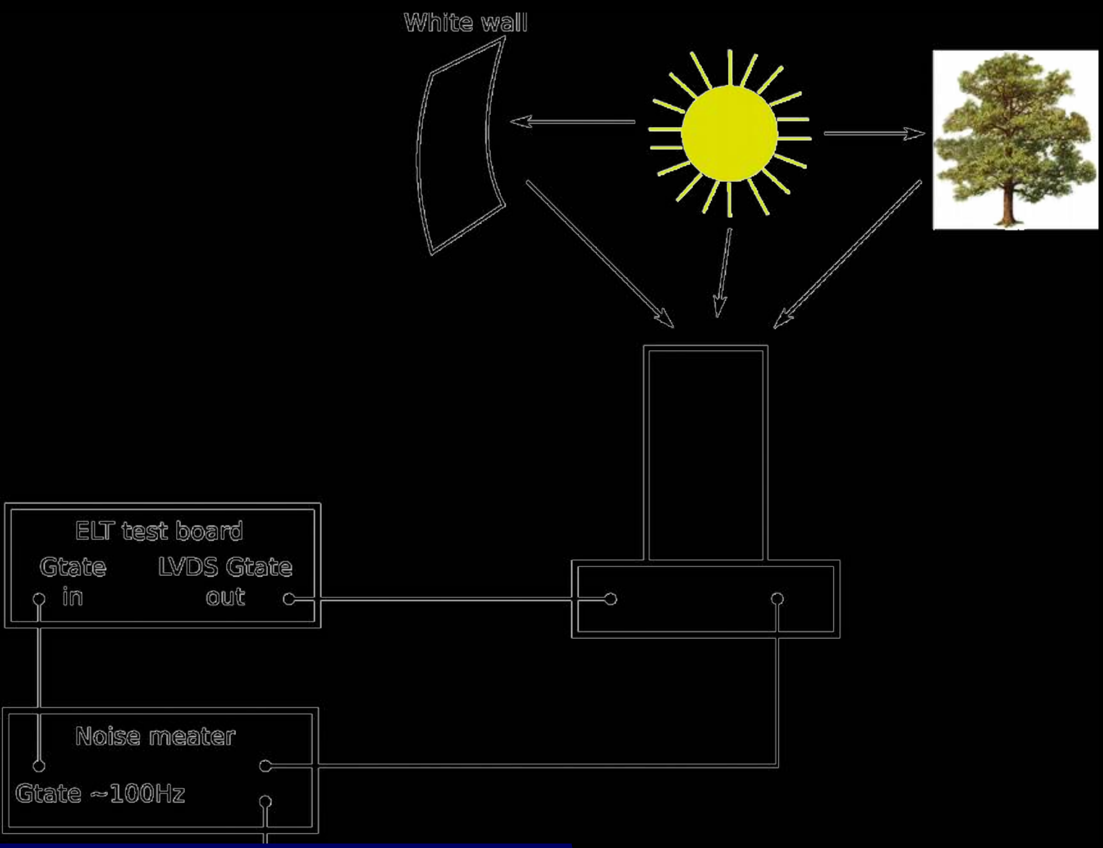
NPET #1 timing

NPET # 2 timing

Common 10MHz, 1pps

=> ~ 3 ps Accuracy estimate

Detector ELT Background Illumination tests



Dark count rate	0.4 Mc/s
Pointing to	
Sun 45 deg.	< 6 Mc/s
white paper, +/- 60º	< 3 Mc/s
trees	< 1 Mc/s

CONCLUSIONs

- acceptable for the daylight operation, range gate 300 ns (90m) before
- operational (photon counting) under direct Sun exposure (!!)

CONCLUSION # 1 – ELT detector package

- EM device tested,
  radiation resistant, space qualified, safe for ISS
- FM is being completed

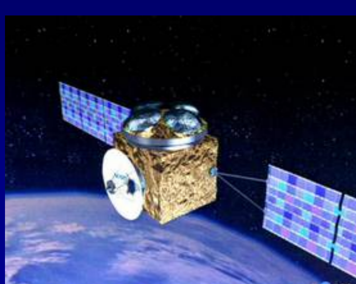
- Detector parameters

jitter	<	20	ps rms
delay drift	+	480	fs / K
delay **stability Tdev**	**~**	**200**	**fs / day**

- System delay calibration schemes designed
  and tested for both ground and space segments
  overall ~ **10 ps accuracy** expected

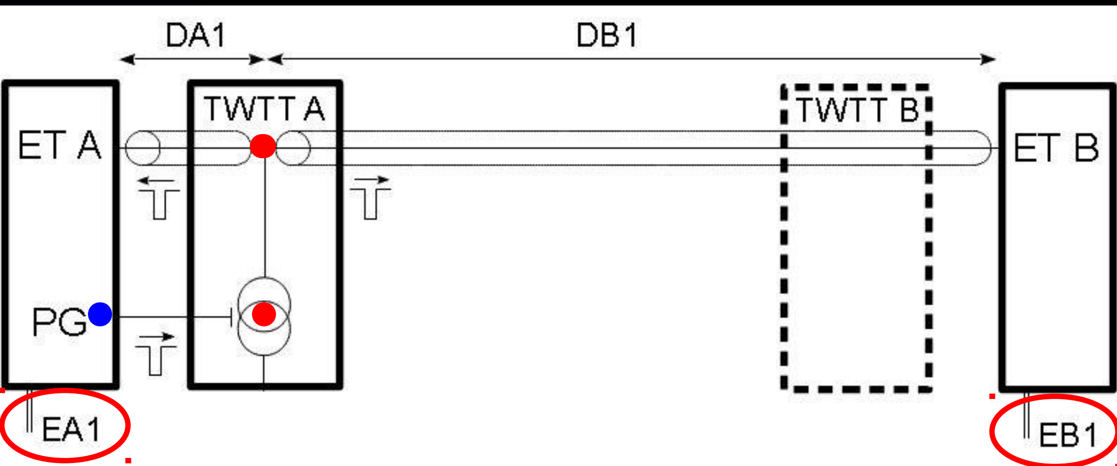
- Operational under Solar background flux

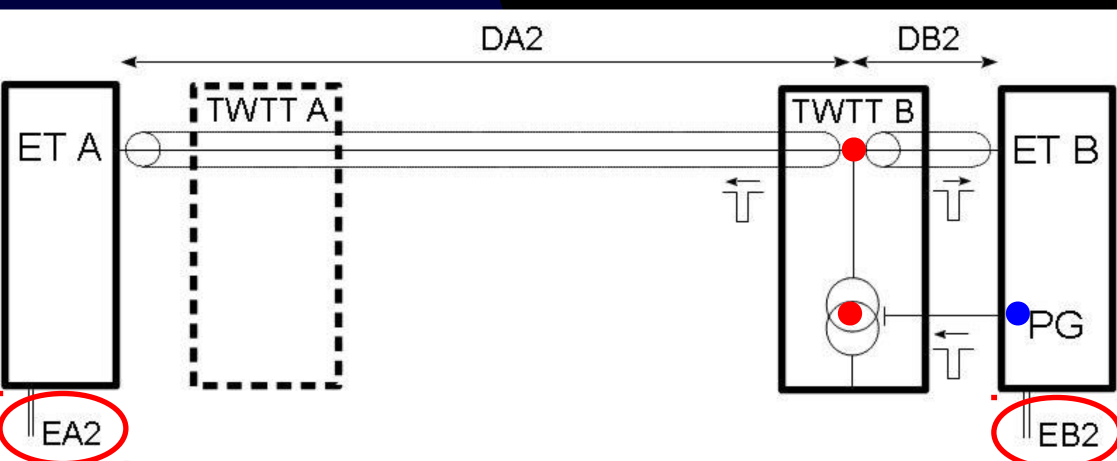
Earth vegetation	< 1 MHz
ideal white surface	< 3 MHz
direct Sun exp.	< 6 MHz (operational!)



Two Way Time Transfer - Operating Principle

J. Levine, Metrologia, Vol,45, 2008





- Resulting
  time scale difference **DS**
  propagation delay **DC**

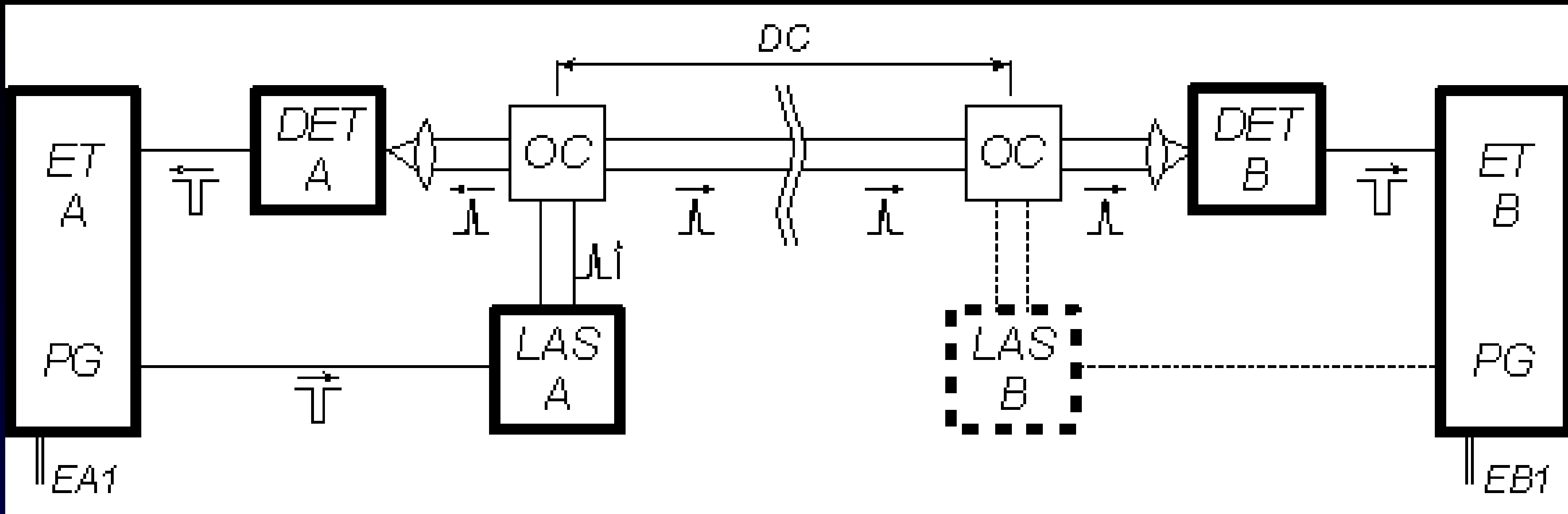
- Electrical coax. cable
  Optical free space

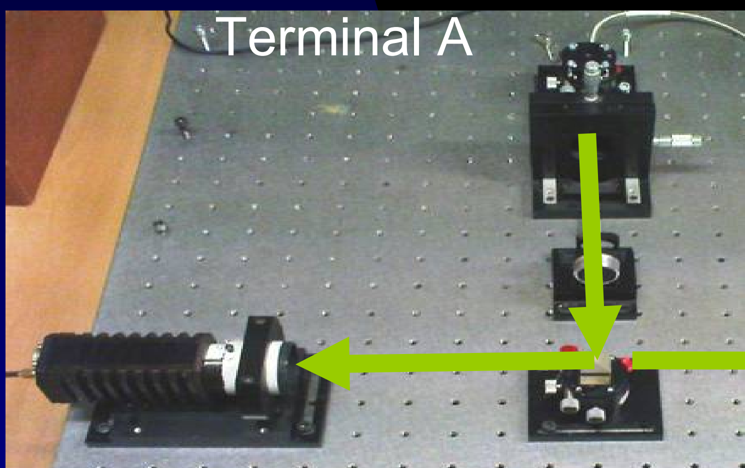
- Prerequisite for ps accuracy
  <u>**Symetry**</u>

  Metrologia, Vol. 2013 *, Nr. 50,1*

- Photon counting approach
  = > ultimate accuracy

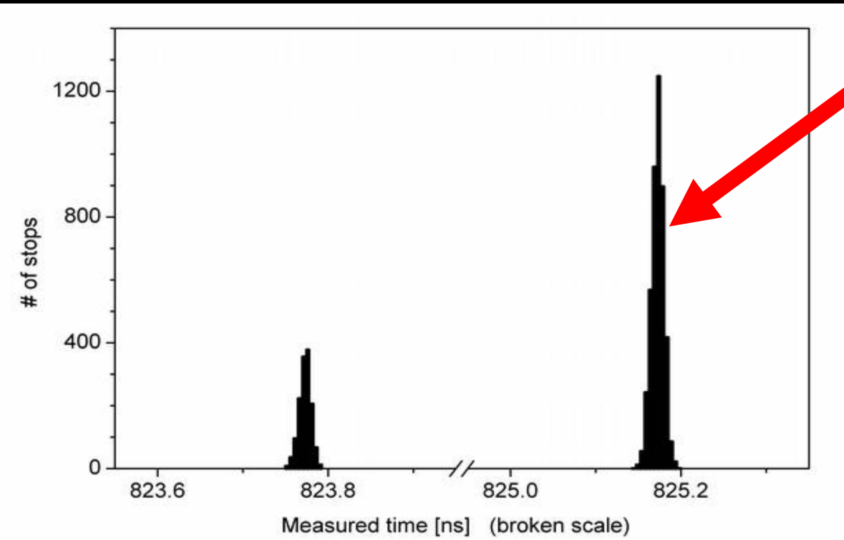
SINGLE PHOTON OPTICAL TWO-WAY TIME TRANSFER EXPERIMENT



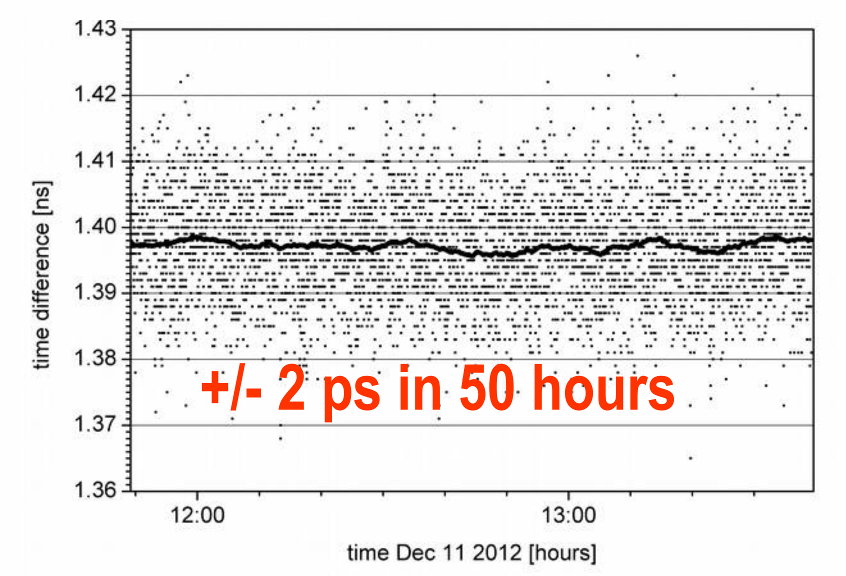


Terminal B

SINGLE PHOTON OPTICAL TWO-WAY TIME TRANSFER
RESULTS



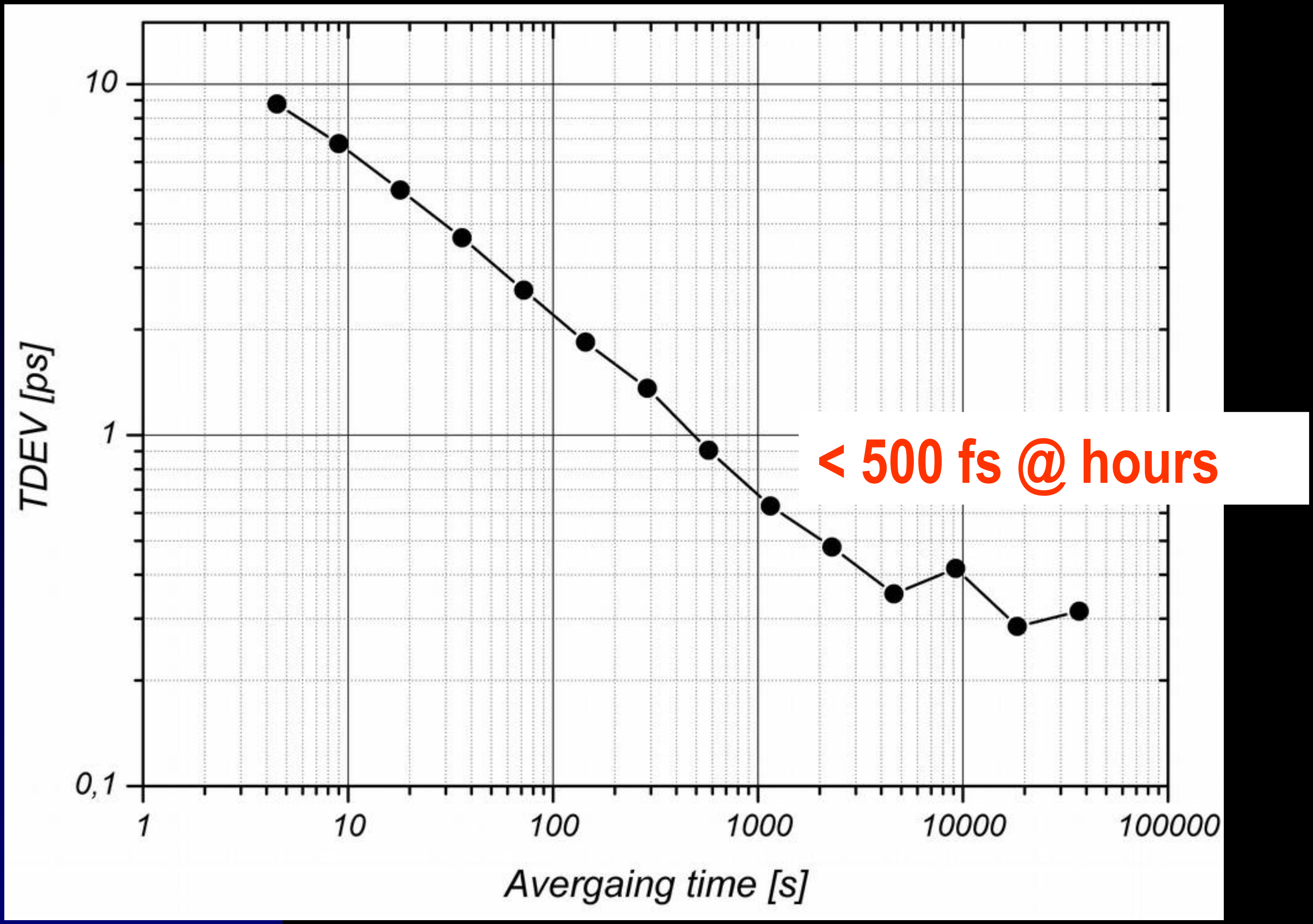
- Histogram of epochs EAx
- Timing resolution < 50 ps rms
- Useful data rate 20-50 readings / s



- Common reference T / F for both scales
- Long term stability test of **DS**
- +/- 2 ps over two days, +/- 1K

SINGLE PHOTON OPTICAL TWO-WAY TIME TRANSFER

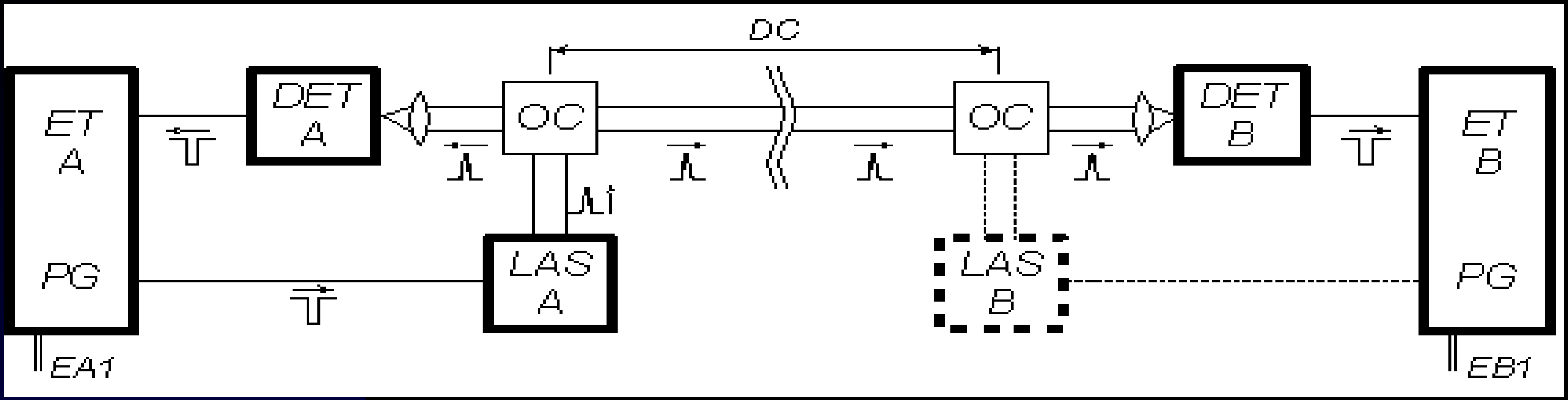
TIME SCALES DIFFERENCE



- Common reference T / F for both scales, +/- 1K
- Recorded at a useful data rate of 20..50 readings /s
- Improvements > 30x are expected for rates up to 1k read./s

Photon counting two-way time transfer

ACCURACY CHECK

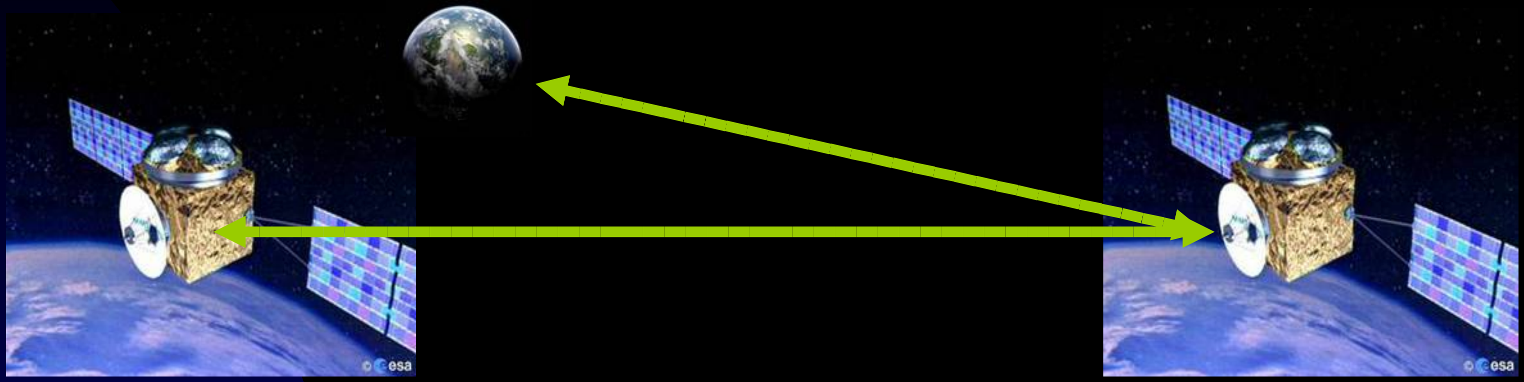


- the accuracy of time scales difference ***DS*** is higher than accuracy of optical path delay **DC**
- The evaluated DC was equal to optical path length within 1 mm / 3 ps (p-p)
- **= > <u>TWTT ACCURACY better than 3 ps</u>**

Photon counting two-way time transfer

POSSIBLE APPLICATION # 1

Time scales comparison in (deep) space
Analogy to asynchronous laser transponder

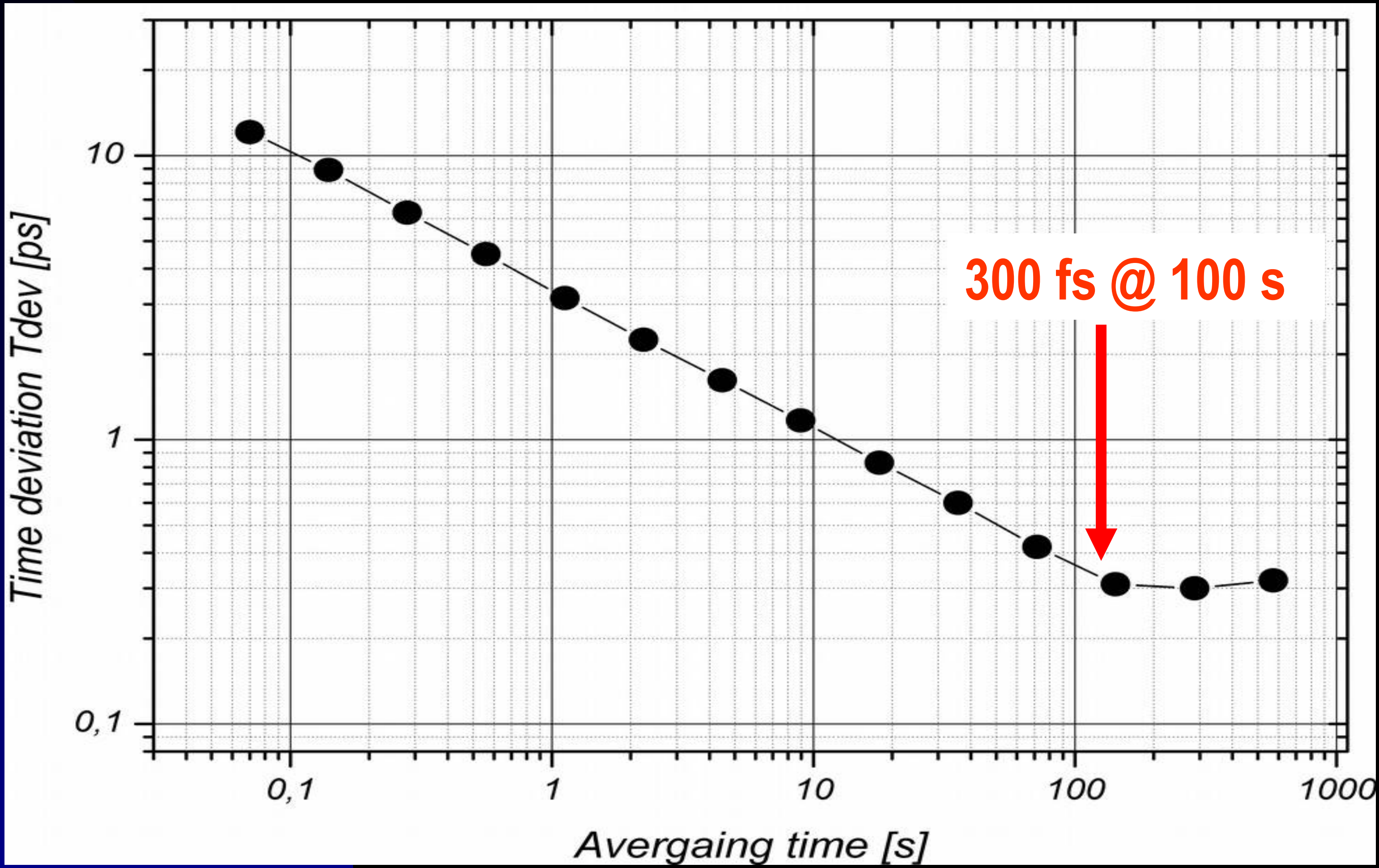


- Small, compact and reliable lasers for space
- Space qualified photon counting receivers
- Optical apertures 20… 100 mm only (in space)
- Laser altimeter hw may be used
- Ground – space **<u>distances up to Jupiter / 9 AU</u>**
- Propagation delays ionosphere + TEC independent (!)

CAPABILITIES OF PHOTON COUNTING

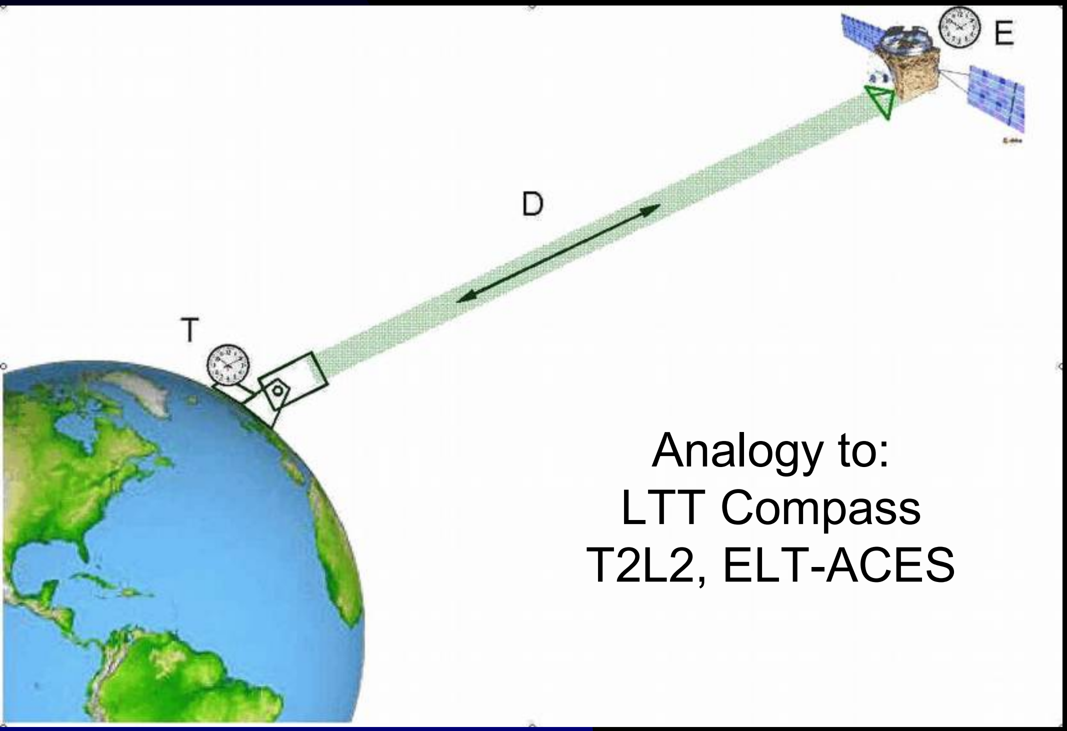
Demonstrated on Satellite Laser Ranging of GNSS satellite, Graz, Austria

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



Photon counting laser time transfer
POSSIBLE APPLICATION # 2

Ground to space time scales comparison



Achievements demonstrated 2013:

SLR up to 35 ooo km =>
TDEV ~ 3 * 1.E-13 @ 100 s

Indoor tests of 1 photon TWTT
Stability < 5 * 1.E-13 @ day

Ground to space time scales comparison
Frequency ~ 6 * 1.E-18 @ day

There is a space for further improvement ~ 2….3 times 

CONCLUSION # 2

Optical Time Transfer based on photon counting


- Photon counting approach
  provides sub-ps precision, stability
  and ps accuracy

- <u>Optical time transfer</u> (indoor tests)
  300 fs precision
  500 fs / day stability
  < 3 ps accuracy

- <u>Ground to space</u> optical time transfer
  300 fs precision (demo via GNSS satellites)
  500 fs / day stability
  < 10 ps accuracy (ground experiment)

- All the components & procedures are available 2013