Timing and Time Transfer at SLR Stations

ILRS Networks and Engineering Standing Committee

Jan Kodet, et. al.

Technische Universität München, GO- Wettzell

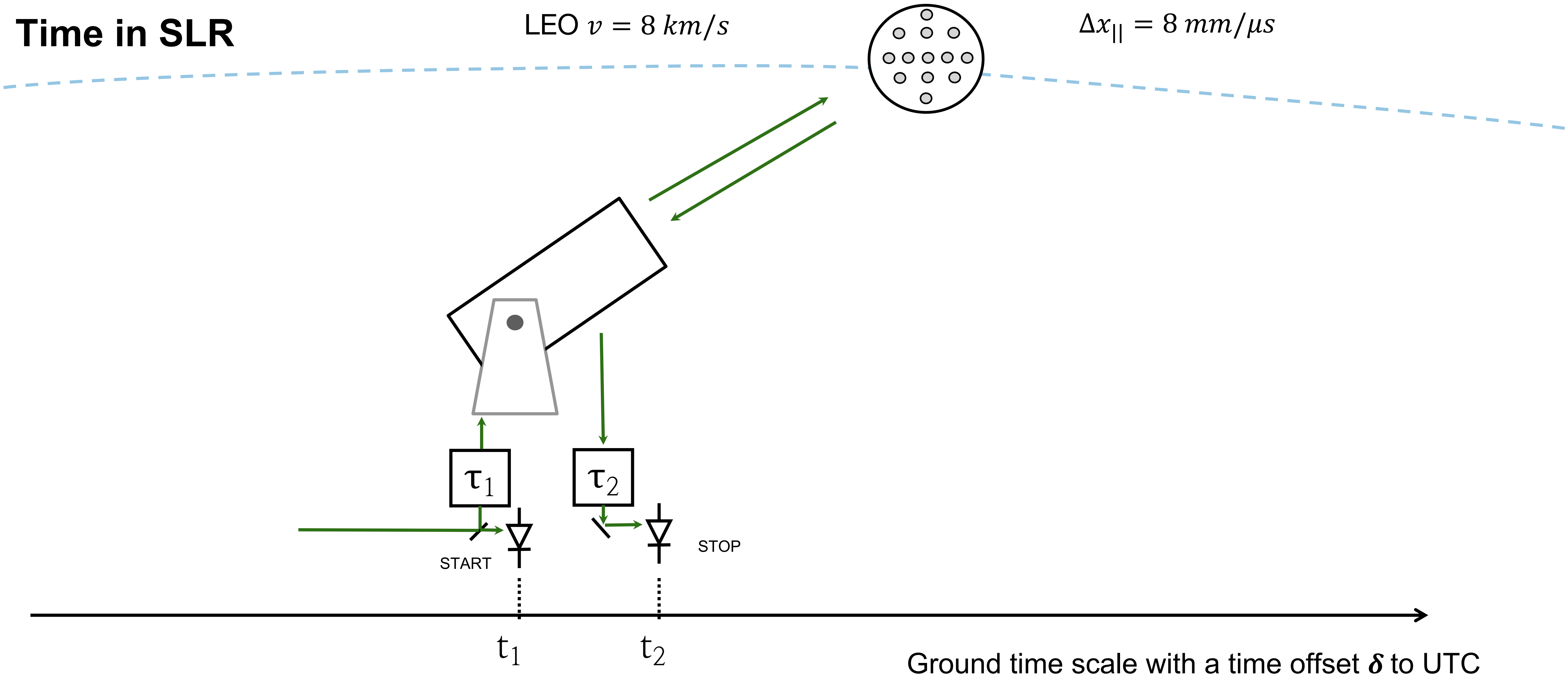
and

Bundesamt für Kartographie und Geodäsie, GO- Wettzell

TECHNISCHE UNIVERSITÄT MÜNCHEN

Federal Agency for Cartography and Geodesy

Time in SLR



$$\mathbf{R} = \frac{c}{2}[(t_2 + \tau_2 + \delta) - (t_1 + \tau_1 + \delta)] = \frac{\mathbf{c}}{\mathbf{2}}[\mathbf{t_2} - \mathbf{t_1} + \Delta\boldsymbol{\tau}_{\mathbf{calib.}}]$$

At first glance - Independent of absolute time synchronization

- The requirement to hit the satellite with a speed of 8 km/s sets the need to synchronize an orbit with local time and UTC. => **Requirement for SLR stations is 100 ns**.
- However, the time interval accuracy depends on clock accuracy. The largest round trip of **2.7 s** for the Moon range **defines clock accuracy as 10^{-13}** (rang error < 1 mm).
- The phase noise of the clock limits the resolution. For **10 MHz** with noise floor -155dBc and integration time of 2.7 s, transfers to a **2.5 ps** timing jitter.

Summary:
Time and frequency in SLR are not an issue, and SLR statin can be referenced to a GNSS disciplined clock.

The Terrestrial Reference Frame

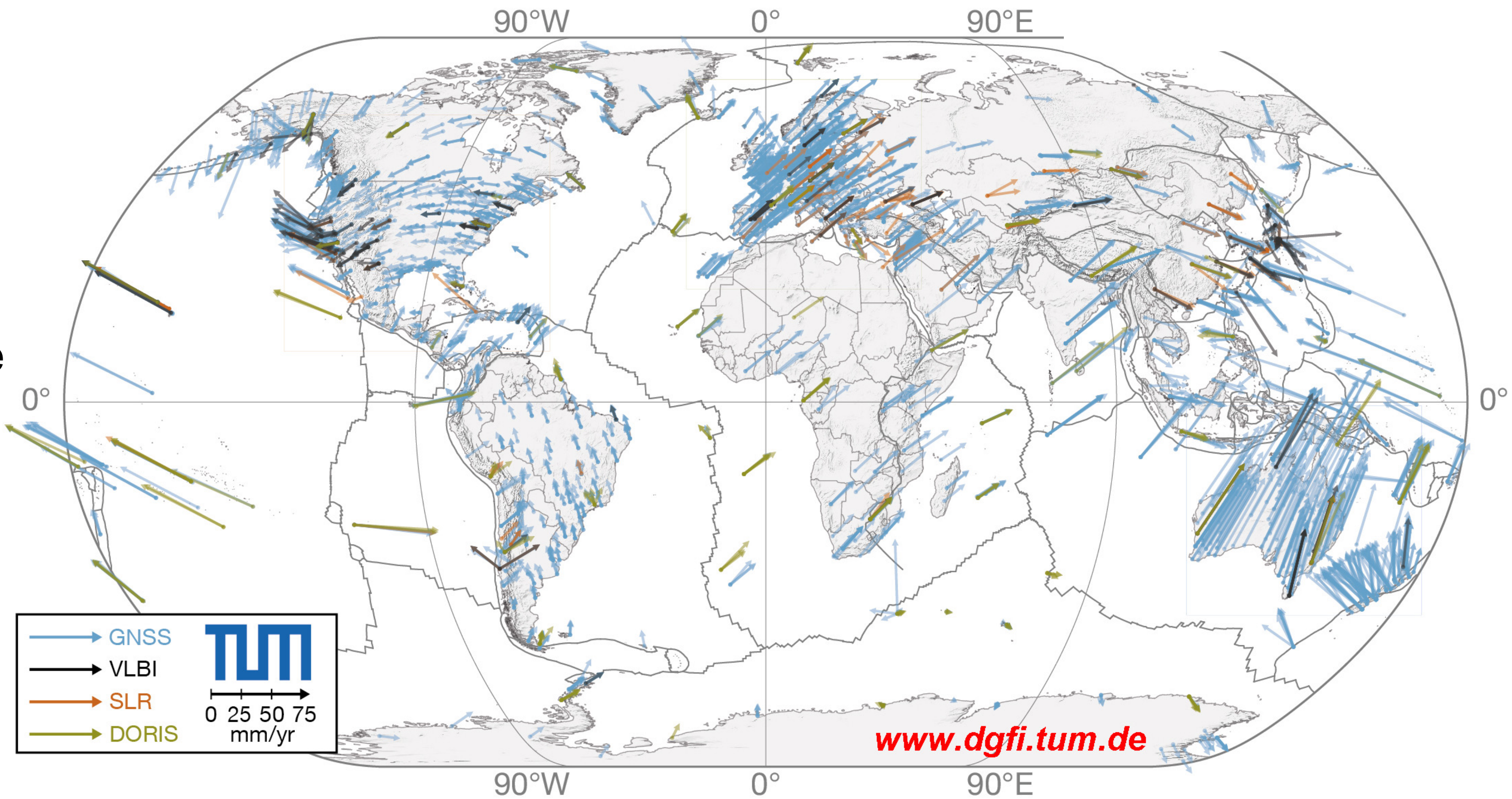
- The terrestrial reference frame (TRF) is the physical realization of a terrestrial reference system (TRS)

- Only the combination of the 4 techniques of space geodesy provides all parameters

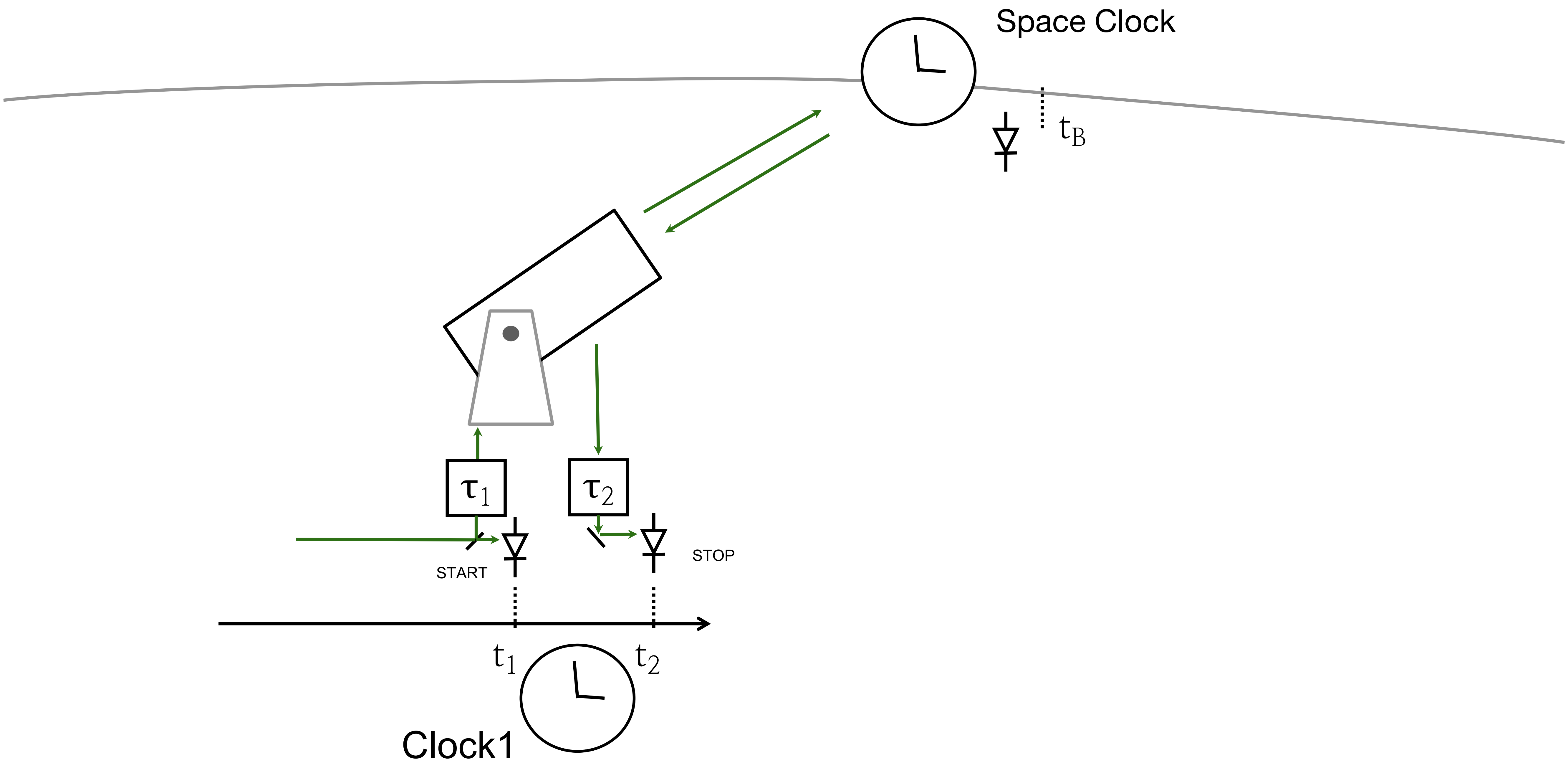
- Ties are provided by the local geodetic surveys

- Systematic errors are limiting the achieved accuracy to about a factor of 5 above the desired GGOS value of 1 mm (position) and 0.1 mm/year (velocity)

ITRF solution *DTRF2020*



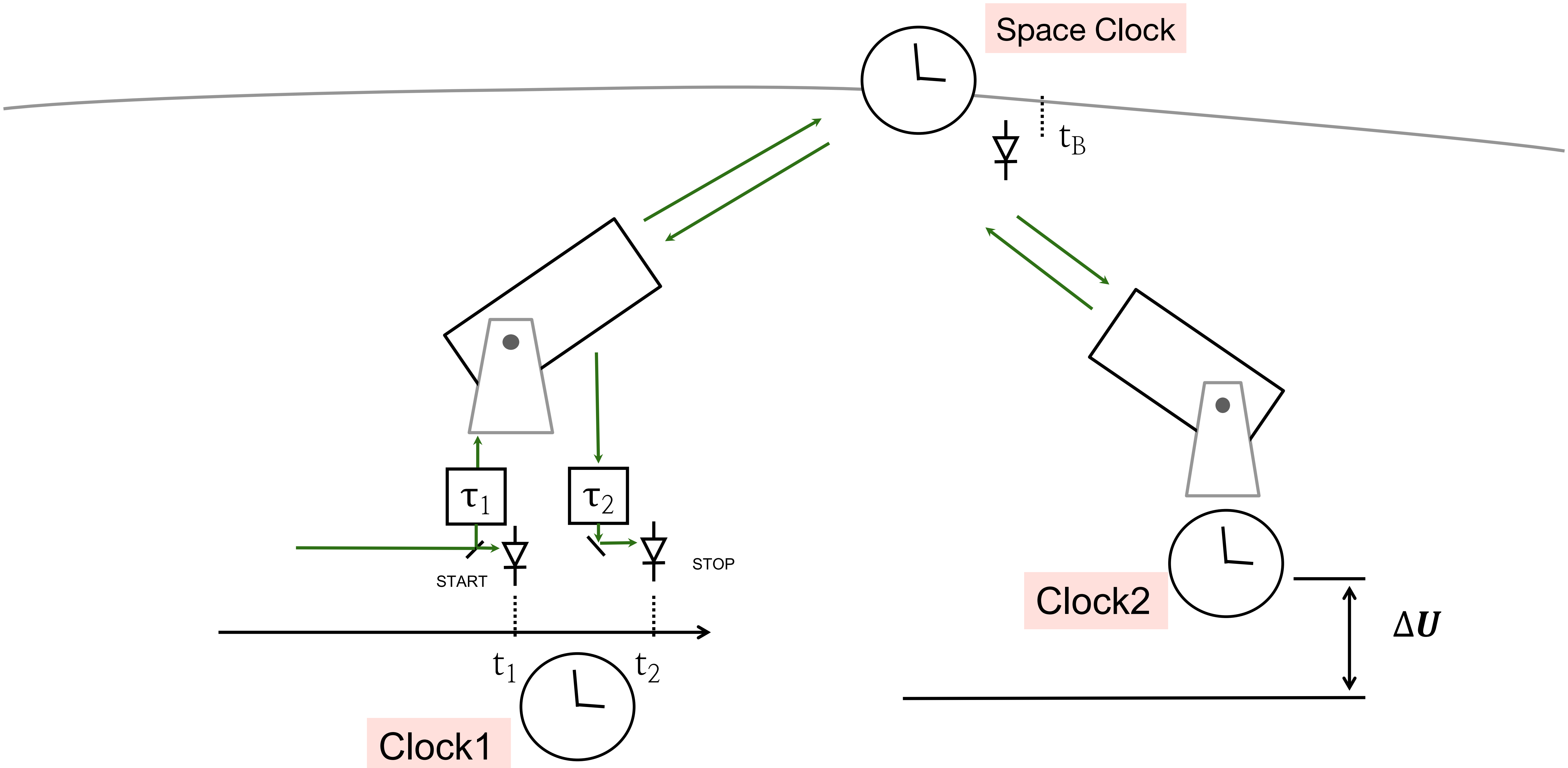
Where in SLR we need time?



Difference between two clocks

$$\Delta \boldsymbol{t} = \boldsymbol{t_1} + \boldsymbol{\delta} + \underbrace{\frac{1}{2}(t_2 - t_1 + \Delta\boldsymbol{\tau}_{\mathbf{calib.}})}_{\text{Range}} - \boldsymbol{t_B}$$

Where in SLR we need time?

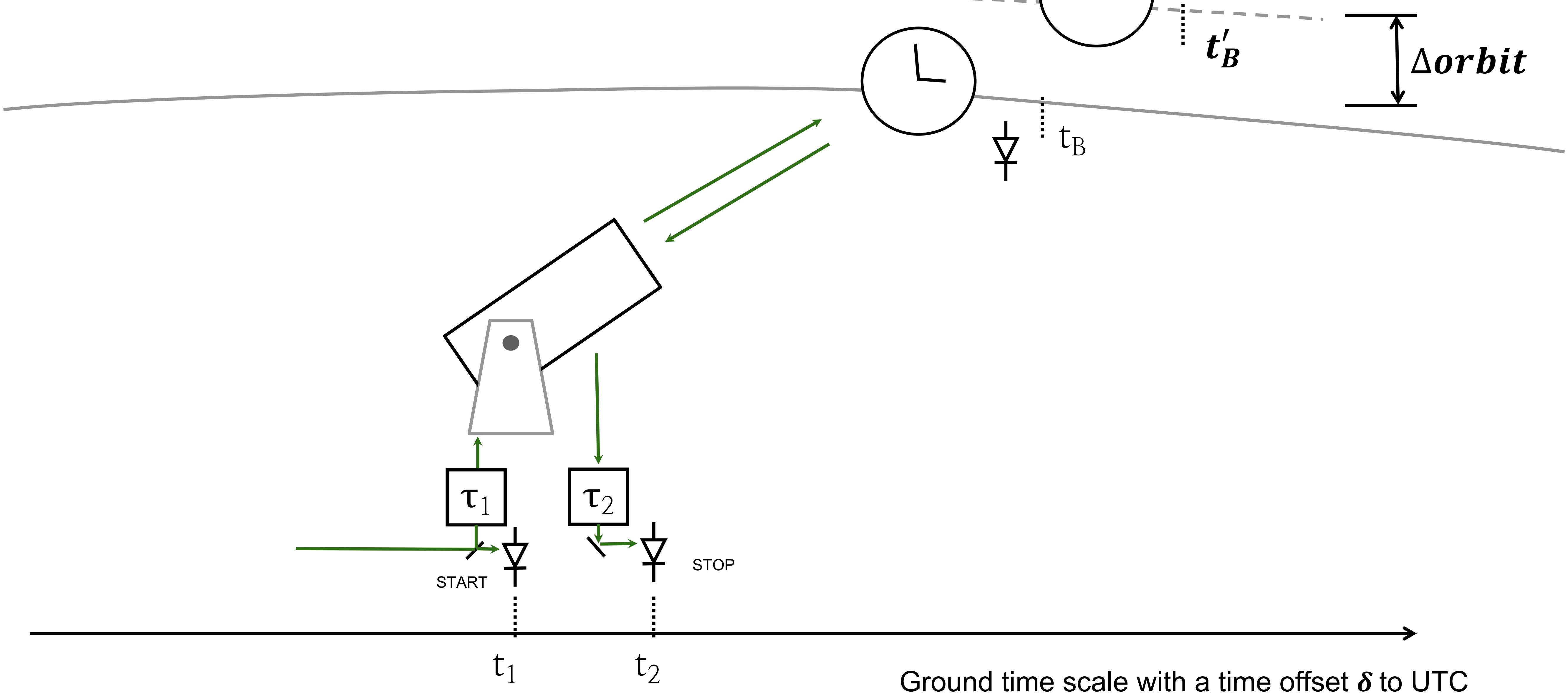


Difference between two clocks

$$\Delta \boldsymbol{t} = \boldsymbol{t_1} + \boldsymbol{\delta} + \underbrace{\frac{1}{2}(t_2 - t_1 + \Delta\boldsymbol{\tau}_{\mathbf{calib.}})}_{\text{Range}} - \boldsymbol{t_B}$$

- Physical heights determination based on clocks
- Introducing new, **not geometrical** tie -> linking clock and geometry

Where in SLR we need time?



Difference between two clocks

$$\Delta t = t_1 + \delta + \underbrace{\frac{1}{2}(t_2 - t_1 + \Delta\tau_{calib.})}_{\text{Range}} - t_B$$

- System variable bias; ~1 ps
- Absolut calibratable; ~tens of ps
- Correlated with orbit determination, etc.

E. Samain et al., “Time transfer by laser link: a complete analysis of the uncertainty budget,” doi: 10.1088/0026-1394/52/2/423.

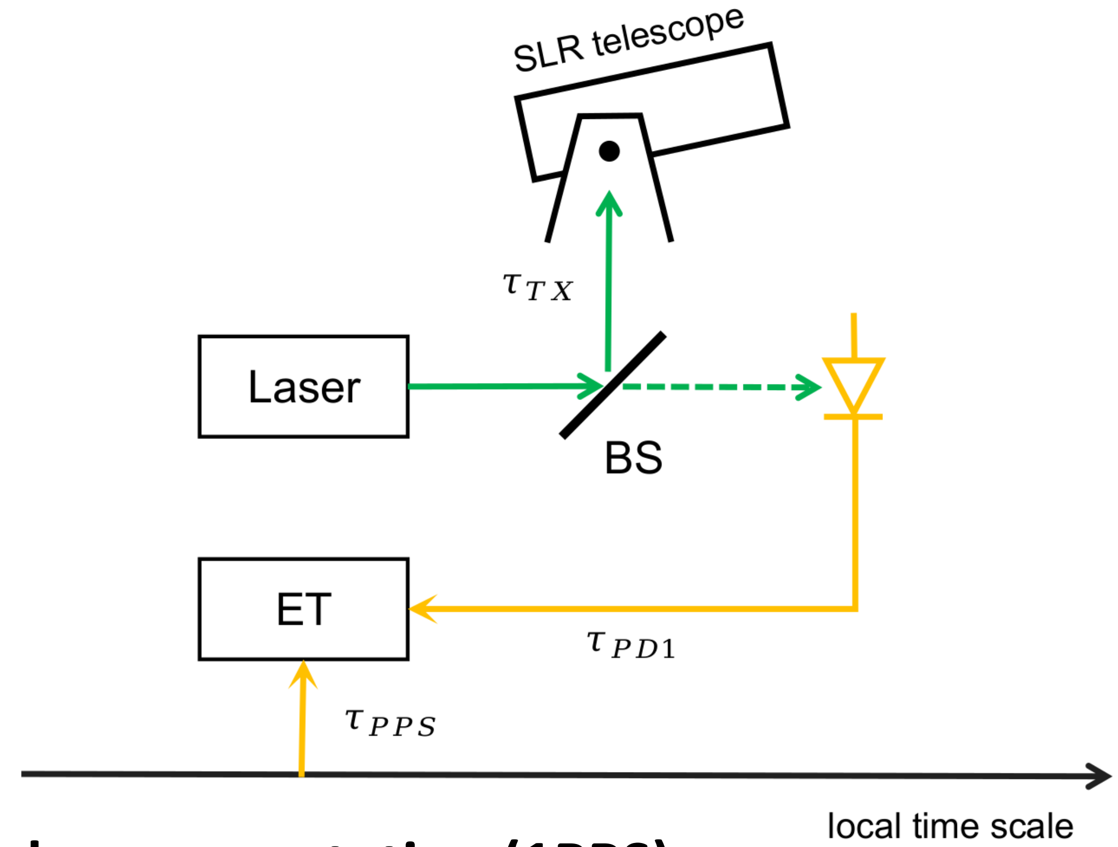
I. Prochazka, et. al. doi: http://dx.doi.org/10.1016/j.asr.2017.02.027.

Where in SLR we need time?

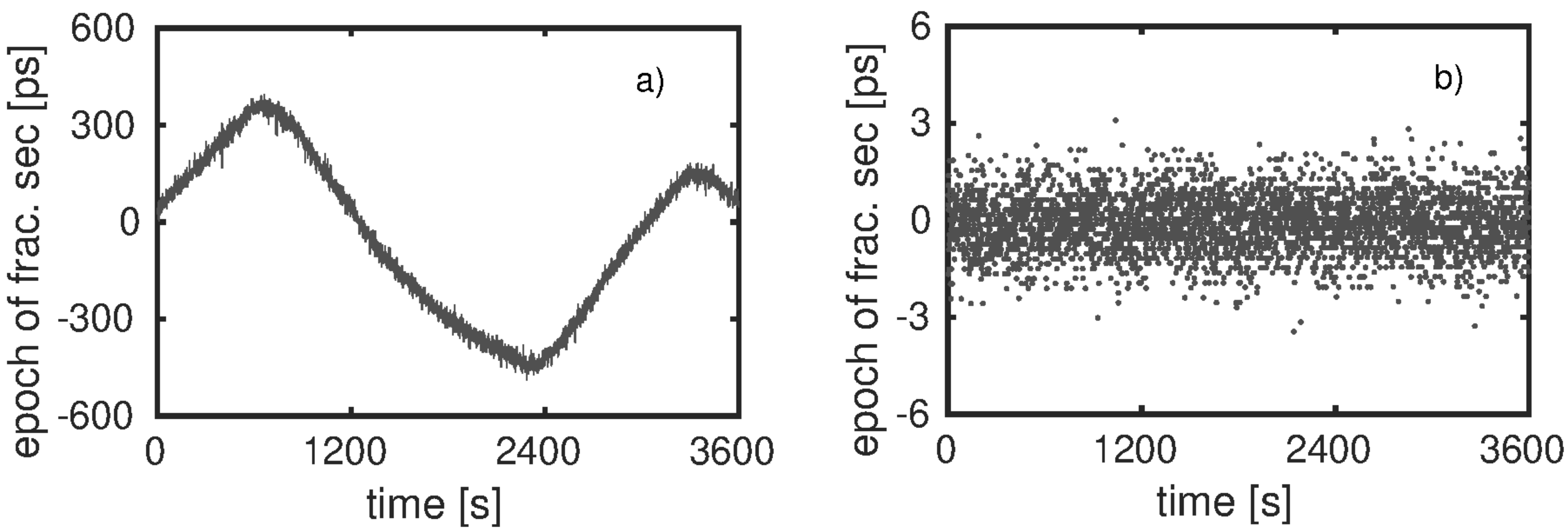
Time synchronization to a local clock

Difference between two clocks

$$\Delta \boldsymbol{t} = \boldsymbol{t_1} + \boldsymbol{\delta} + \underbrace{\frac{1}{2}(t_2 - t_1 + \Delta\boldsymbol{\tau}_{\mathbf{calib.}})}_{\text{Range}} - \boldsymbol{t_B}$$



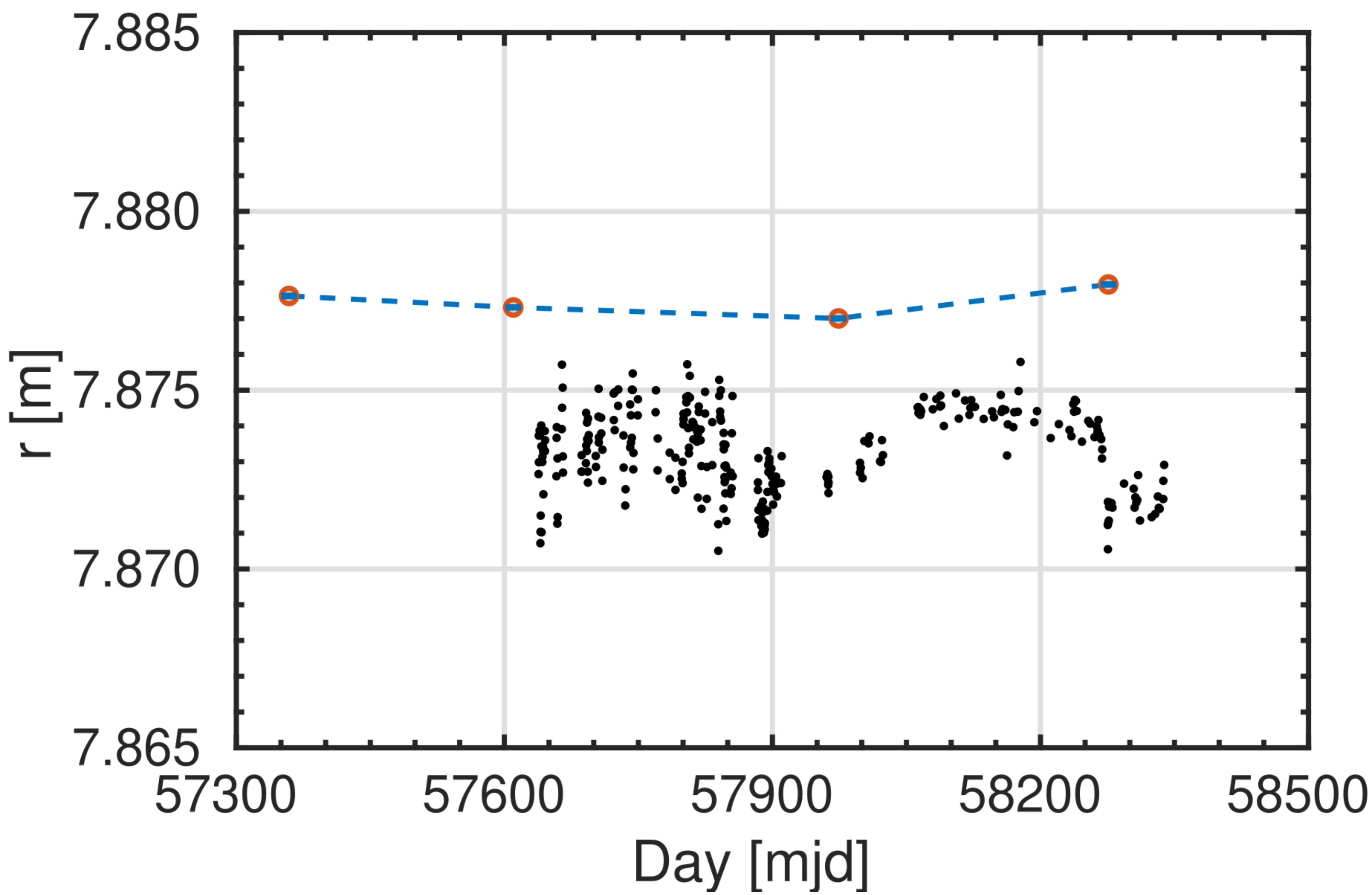
Comparison of SLR time scale representation (1PPS),



a) Poorly generated time scale, which is influenced by air conditioning in a laboratory.
b) Correctly generated time scale influenced mostly by electronic additive noise.

Where in SLR we need time?

Calibration

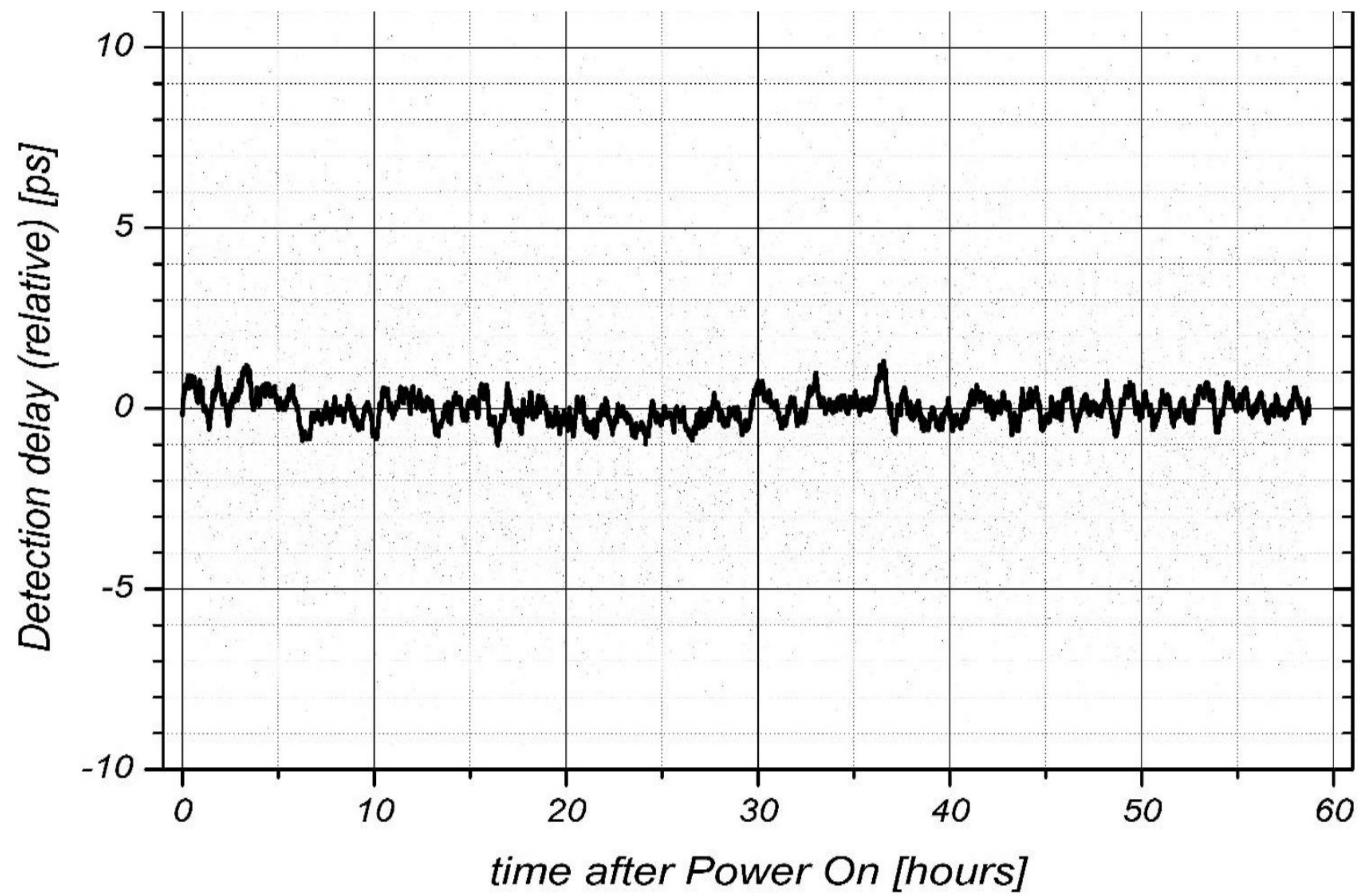


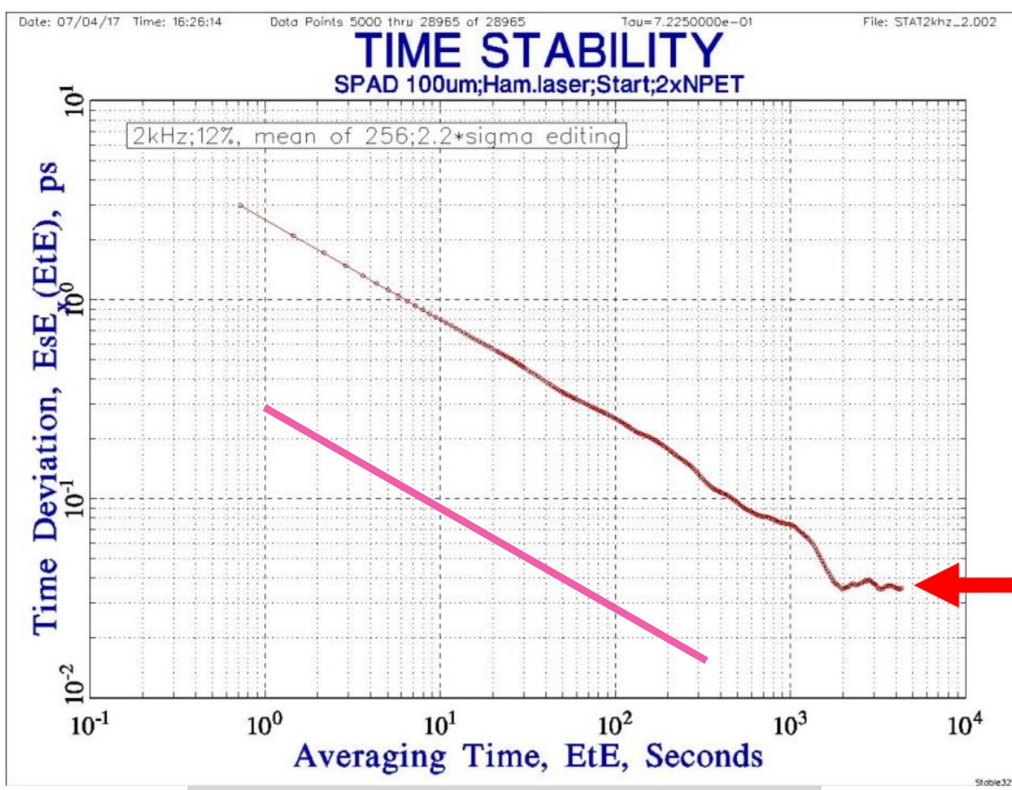
Difference between two clocks

$$\Delta \boldsymbol{t} = \boldsymbol{t_1} + \boldsymbol{\delta} + \underbrace{\frac{1}{2}(t_2 - t_1 + \Delta\boldsymbol{\tau}_{\mathbf{calib.}})}_{\text{Range}} - \boldsymbol{t_B}$$

LTT chain delay long term stability & precision

Indoor Prague
+ / - 1 K





Theoretical limit of state of the art SLR technology

TDEV < 40 fs @ hr

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

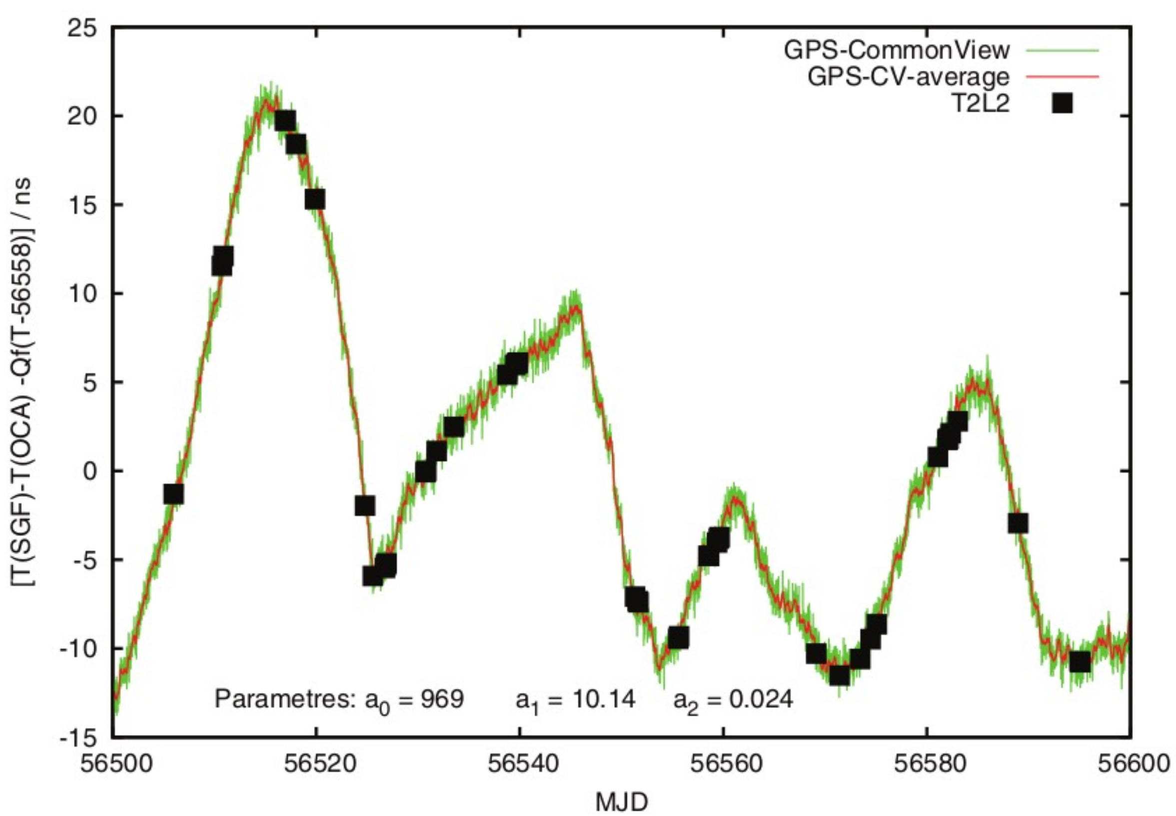
Time transfer review - ground - space - ground

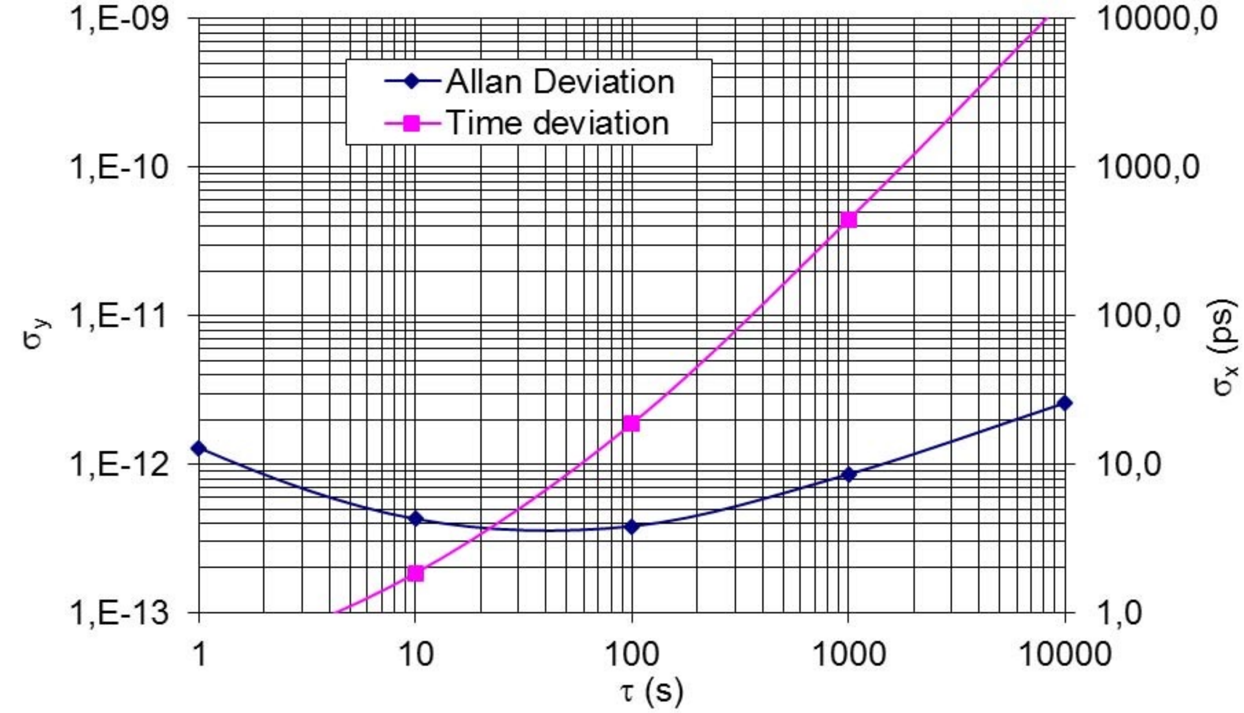
T2L2

Table 1. T2L2 calibration values (in ps) of the SLR system on each geodetic site involved during the campaign.

	Calibration C_{Cal} (ps)	Uncertainty (ps)	Date
OCA	236 601.46	33.9	
SGF	195 837.46	34.9	2013-10-22
OP	203 343.54	33.5	2013-09-17
(FTLRS)			
	203 366.46	34.2	2013-10-24
GOW	10 575.2	50.0	2013-02-26

Time difference Grasse - Herstmonceux GPS vs T2L2 within 100 ps





E. Samain et al., "Time Transfer by Laser Link (T2L2) in Noncommon View Between Europe and China," IEEE Trans. Ultrason., Ferroelect., Freq. Contr., vol. 65, no. 6, pp. 927–933, Jun. 2018, doi: 10.1109/TUFFC.2018.2804221.

P. Exertier et al., "Sub-ns time transfer consistency: a direct comparison between GPS CV and T2L2," Metrologia, vol. 53, no. 6, p. 1395, 2016.

Research Unit FOR 5456/1:

Clock Metrology: A Novel Approach to TIME in Geodesy

22 participates, 12 PhD positions

Time interval comparison GOW – PTB
$\rightarrow$ difference of time intervals T_1 , T_2 measured locally by equal clocks $\rightarrow \Delta U$

Expected uncertainties (one comparison, T = 2 days):
ELT: $\sqrt{2}\times 3$ ps (common-view via ACES)
ELSTAB: ~ 1 ps
Strontium clock @ PTB: < 1 ps
<u>Strontium clock @ GOW: 2 ps</u>
Total: ~ 5 ps

Goal (1st phase of FOR, 4 yrs.):
(A) repeated determination of ΔU with uncertainty 0.3 m
(averaging $\rightarrow$ 0.2 m (limited by SOC2 clock);
$\rightarrow$ time dependence detectable);
modeling of systematics