

Delay compensated Optical Time and Frequency Distribution for Space Geodesy

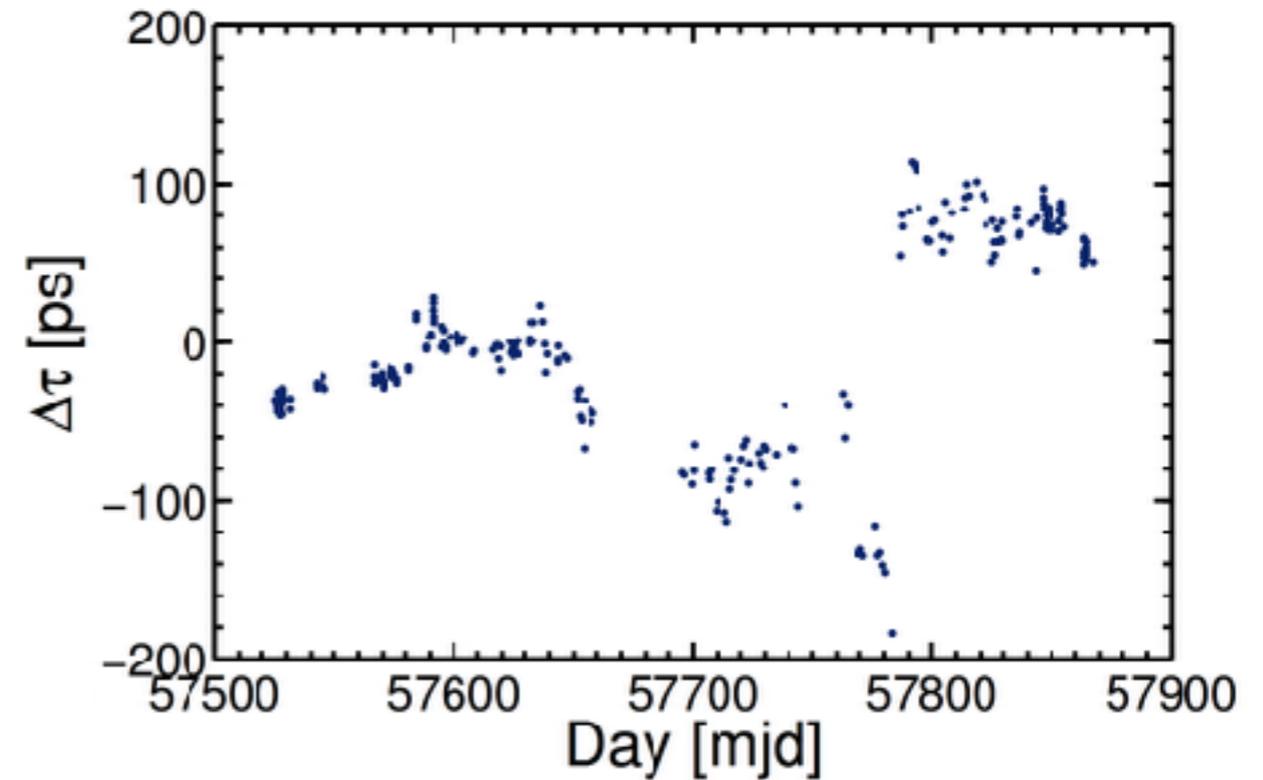
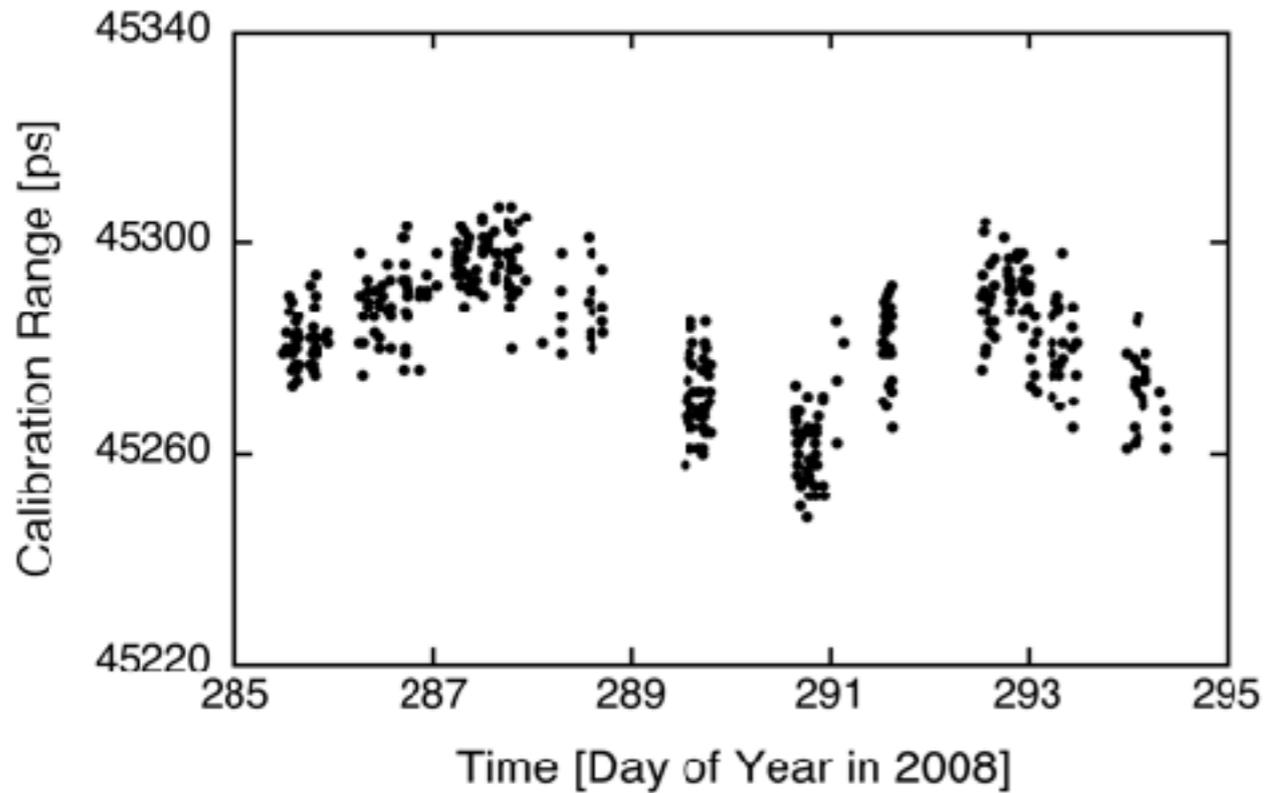
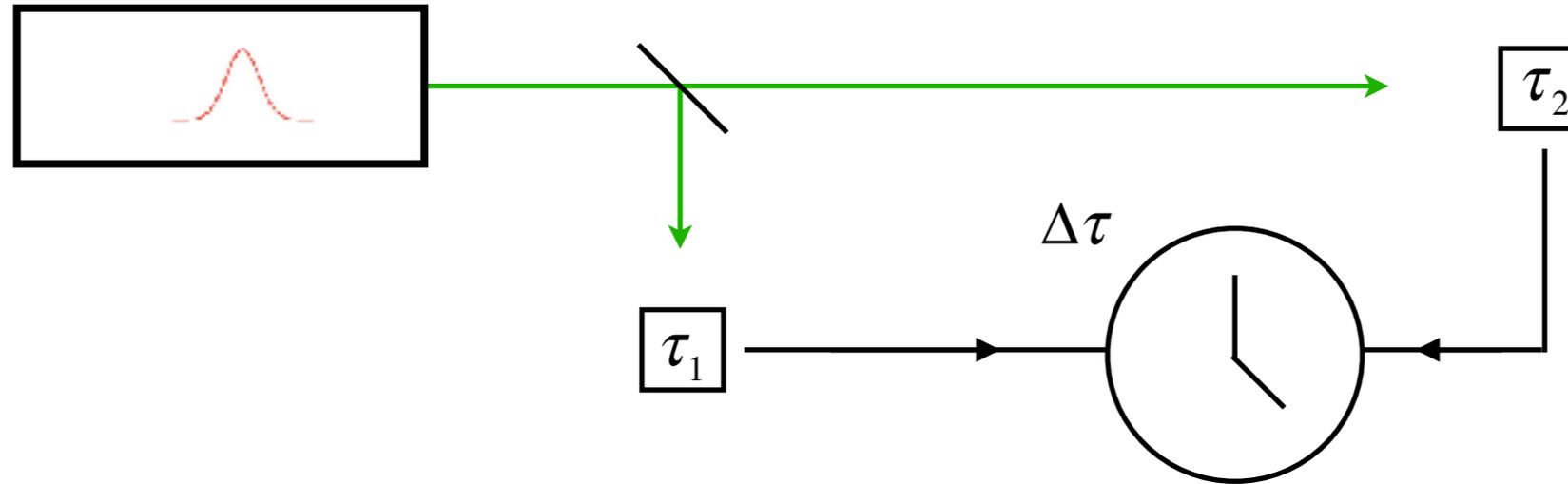
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¹ Technische Universität München, GO- Wettzell

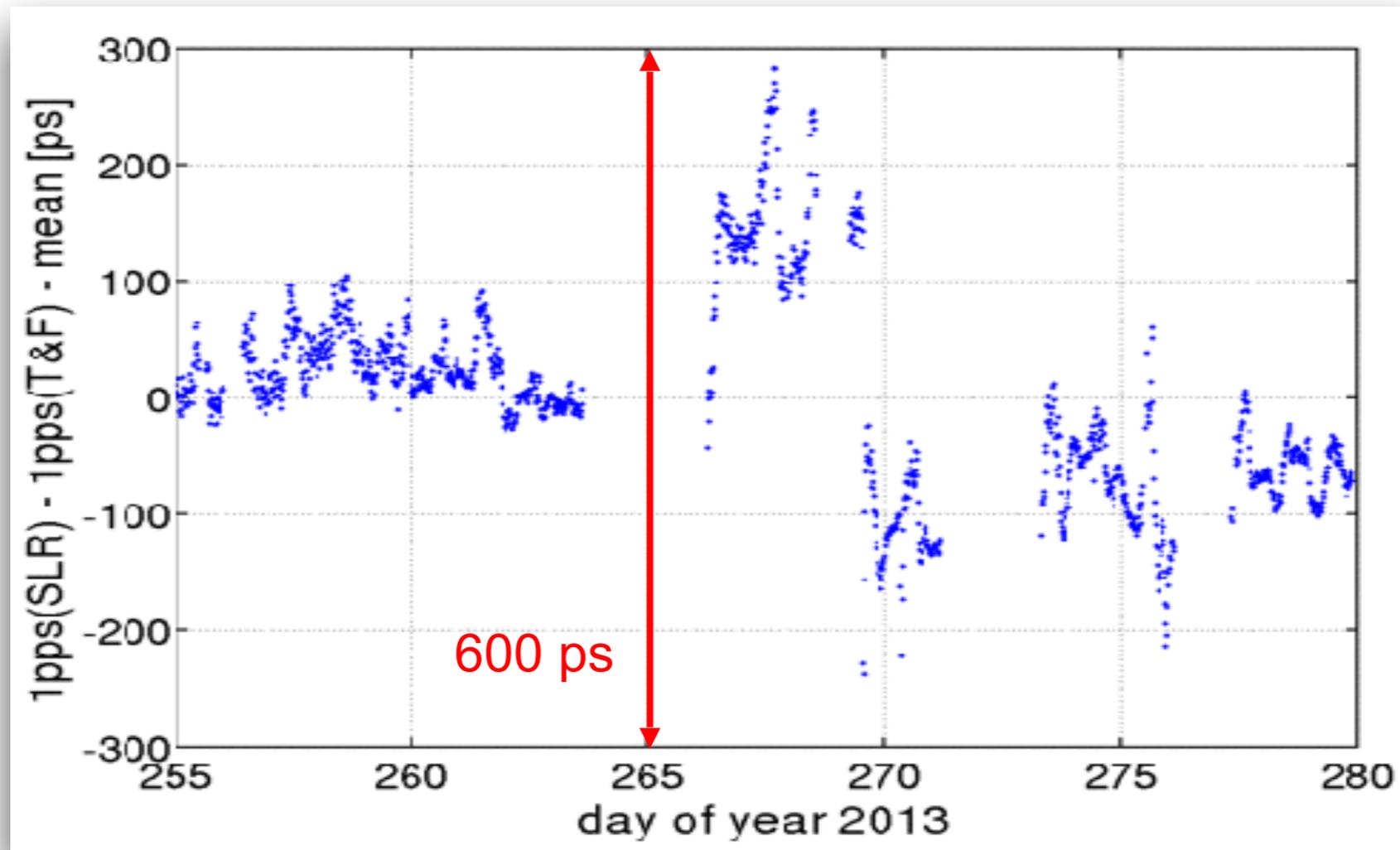
² Bundesamt für Kartographie und Geodäsie, GO- Wettzell

In order to achieve a delay compensated time and frequency distribution, we have designed an all optical two-way system, which allows the campus synchronization of a distributed set of geodetic measurement systems in time and frequency with an accuracy of 1 ps. The goal is to make it possible to eventually use time as an observable and not as an adjustment parameter in a non-linear fitting process. With a centralized fs- pulse laser and a star like fiber network it is possible to reference all measurements to the same time scale and to control system biases. This opens the door to accurate closure measurements of system delays within each geodetic measurement technique and from one technique to the next (e.g. from SLR to VLBI).

Observation: Variable Delays at the level of > 2 cm

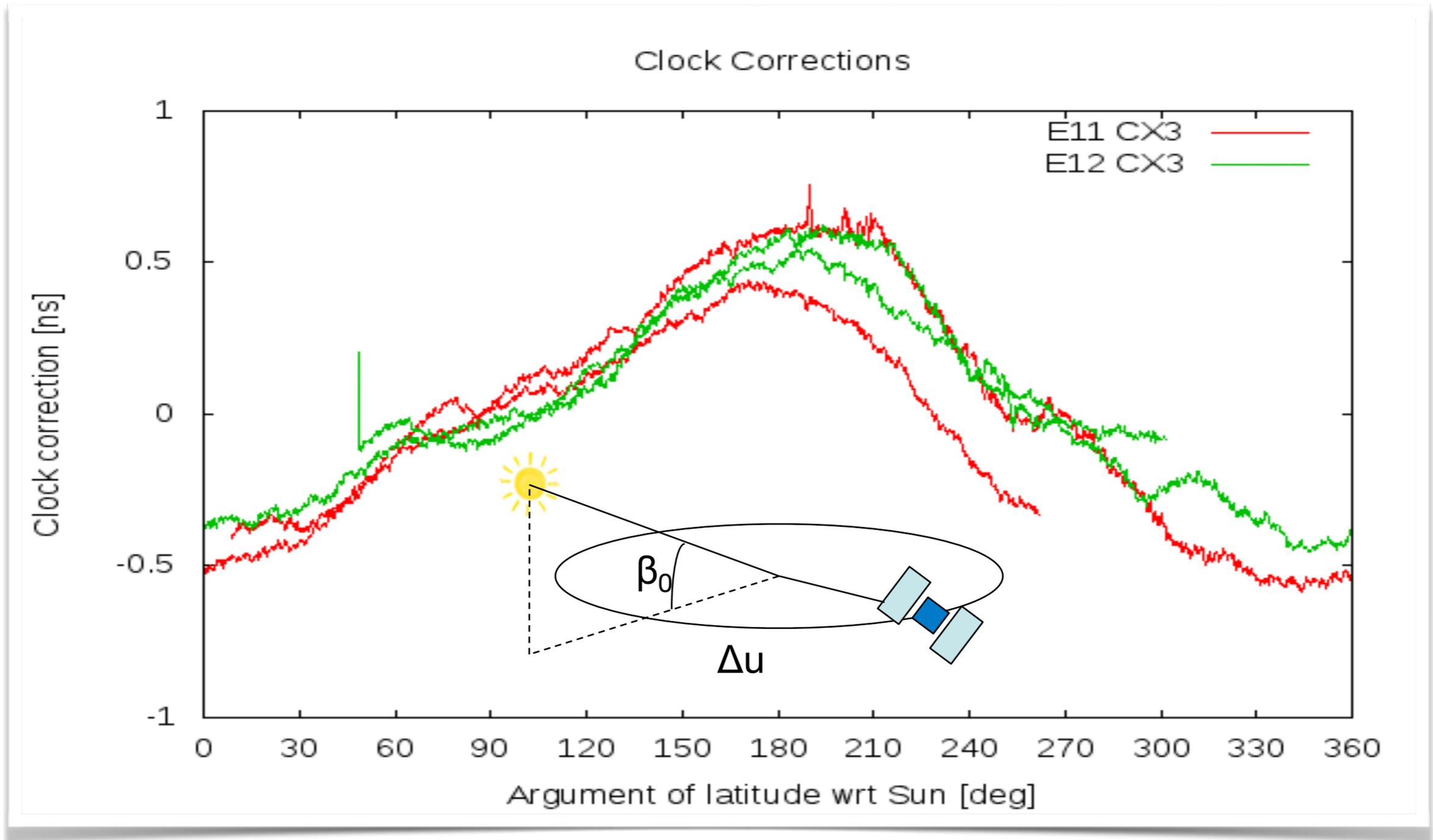


The distribution of the broadband PPS time signal shows variability at the level of several hundred ps.



... over a longer period: $\Delta t \leq 5 \text{ ns}$

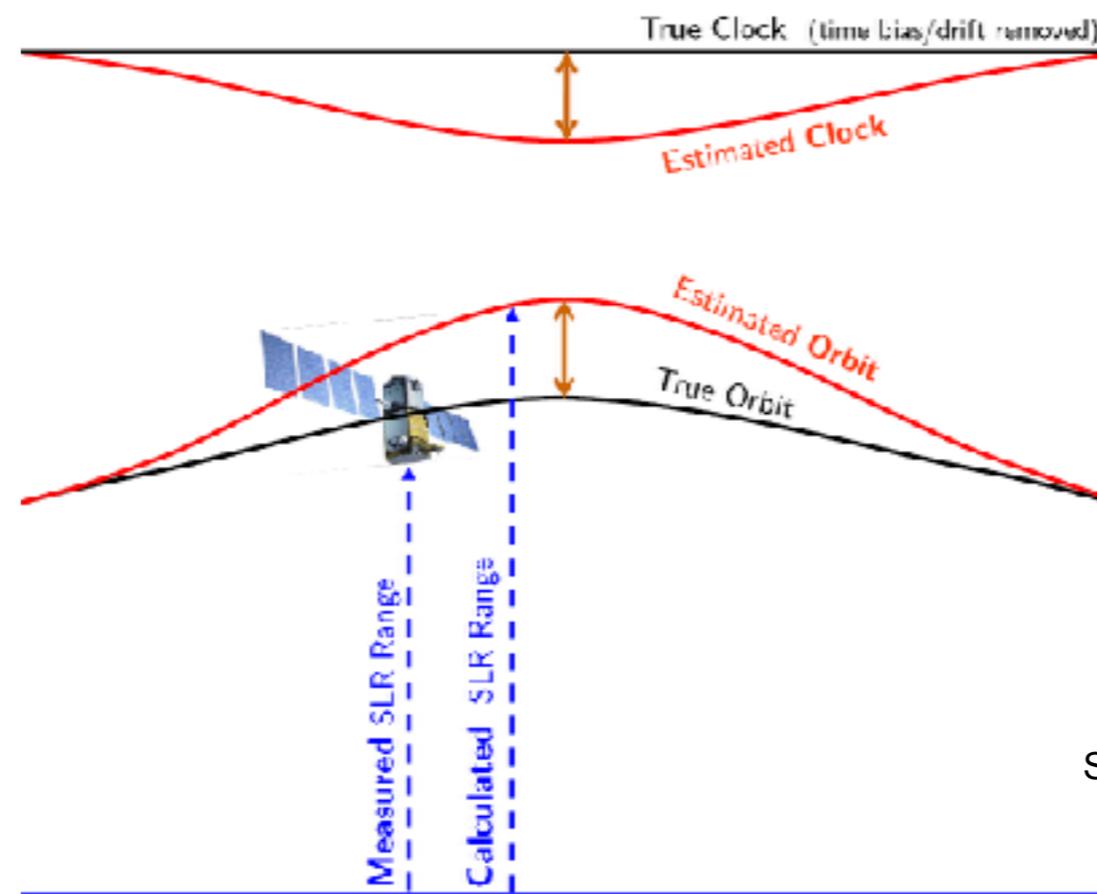
Gallileo IOV satellites: Clock correction vs. angle



... orbit error migrates to the clock estimates

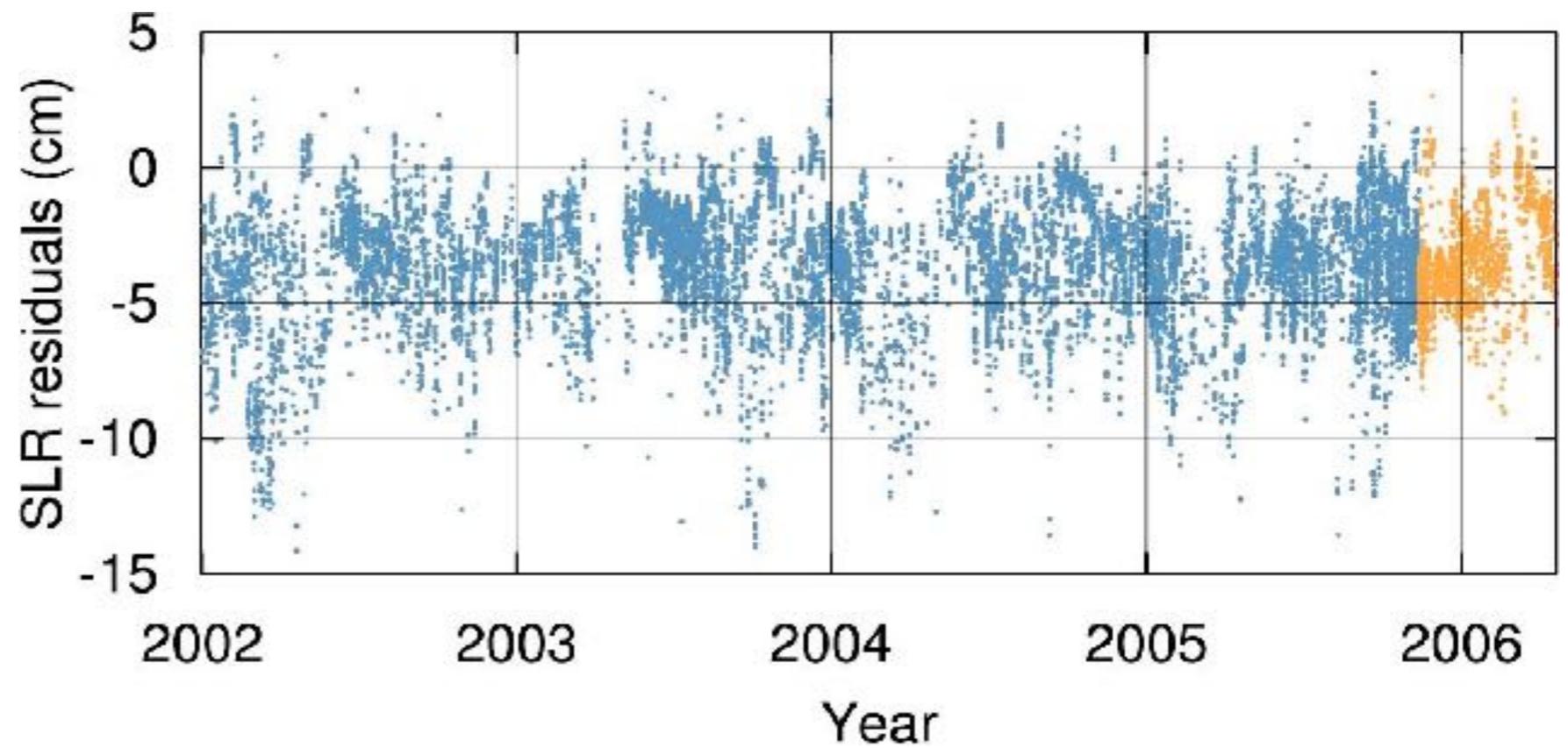
Clock and measured delay τ (orbit) are highly correlated for the 1-way techniques

+ variable and unrecognized system delays are causing biases

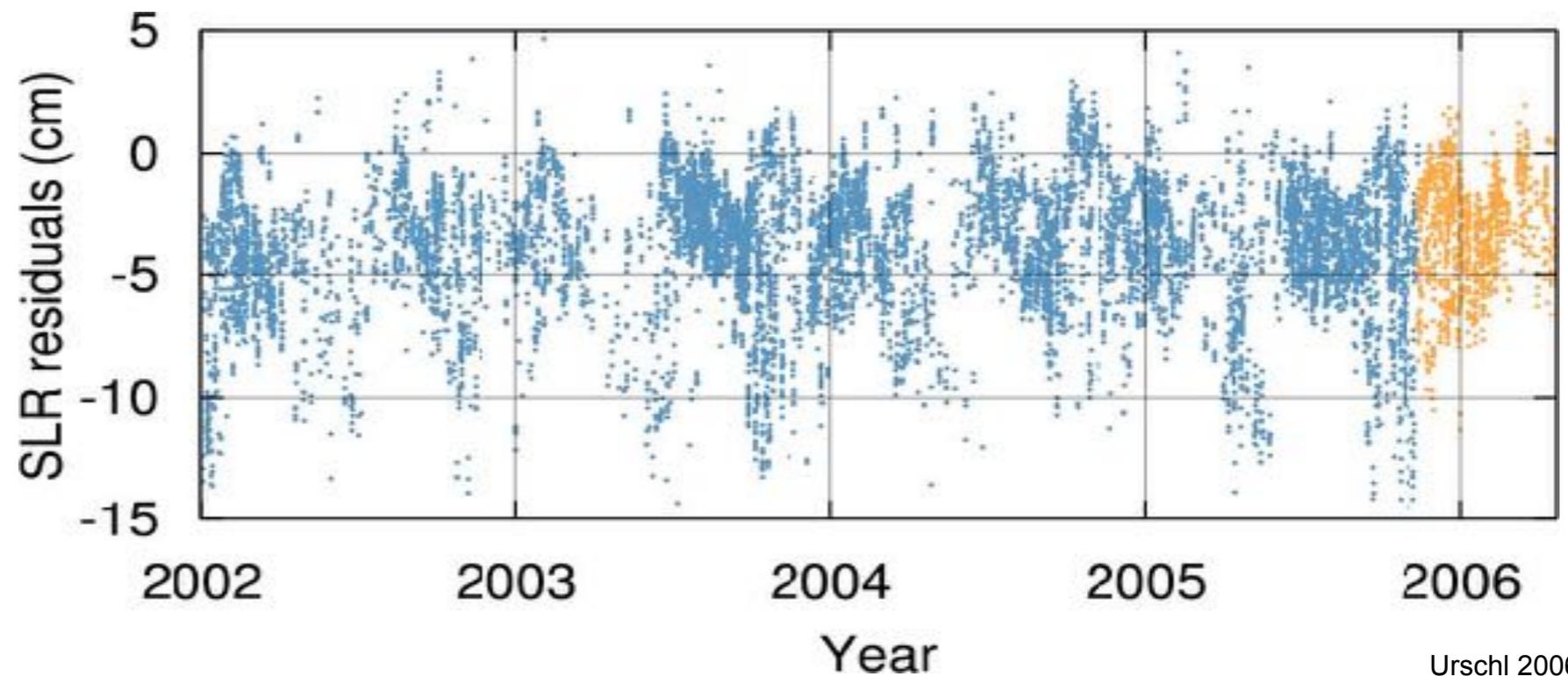


Svehla et al. 2013

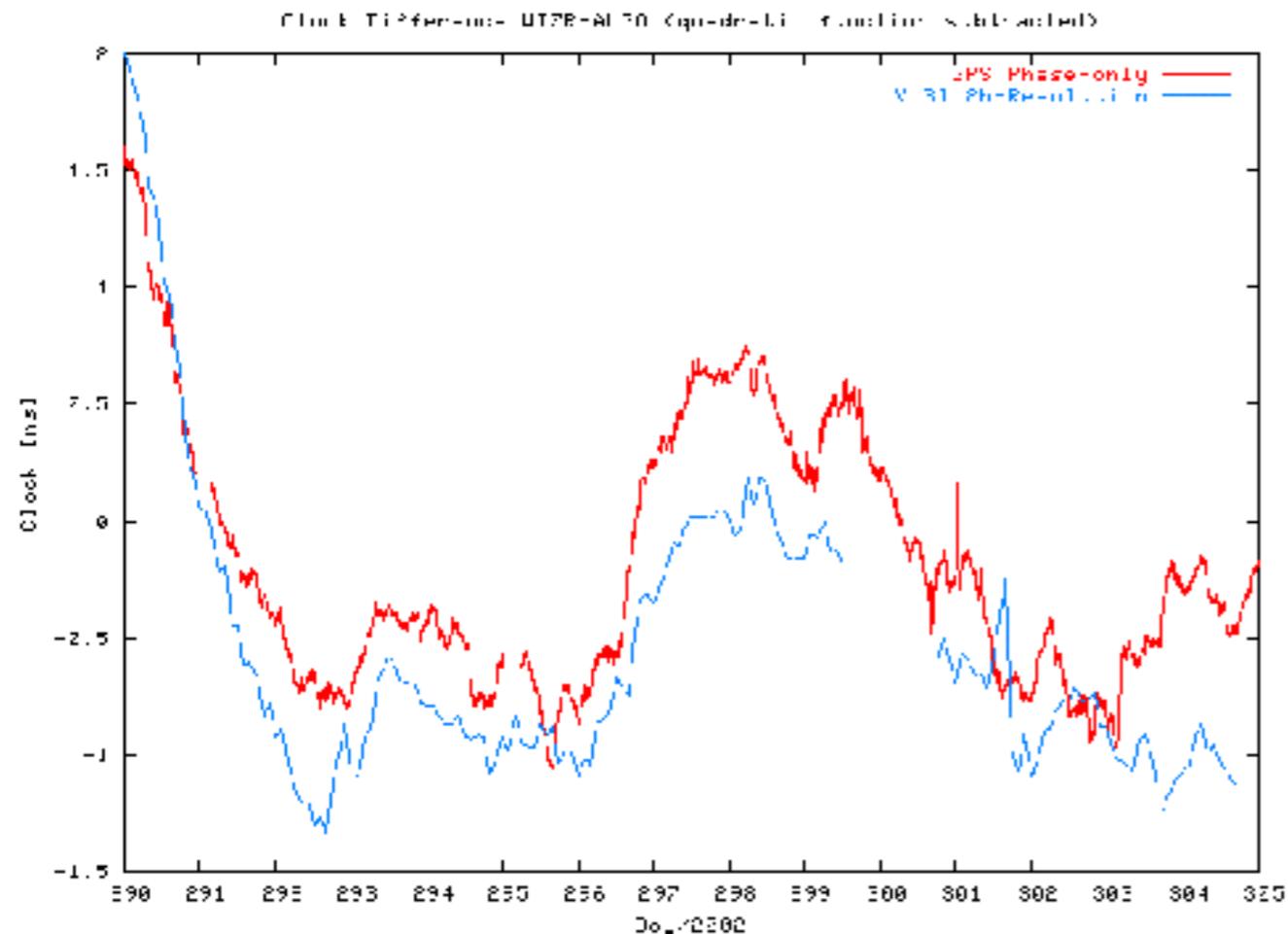
Consequence: Degradation of geodetic product quality



SLR Orbits of GPS 35 and 36 shown against the GNSS derived orbit. Improvements in the radiation pressure model reduced the observed discrepancy around the end of 2005.



Closure measurements are powerful tools



Observation: Clocks accumulate all sorts of systematics (Delays) of the various techniques.

Therefore clock parameters are showing technique specific delays. This applies for inter- and intra- technique comparisons.

Goal: It would be desirable to operate a "Common (super) Clock" for all techniques within an observatory and link the instrumentation with a

"super-conductor for time" and

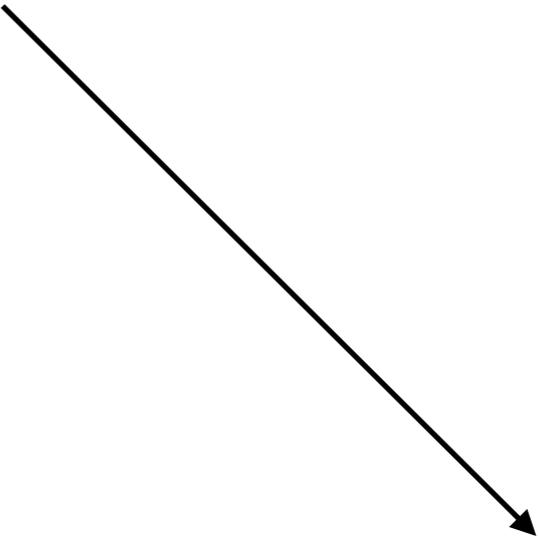
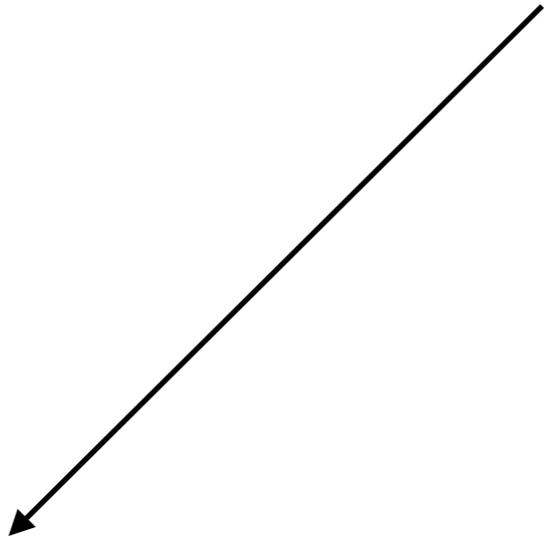
tie all techniques to a single point regardless of their nature

Systematics

SLR: ranging in the optical domain

SLR: timing in the microwave domain

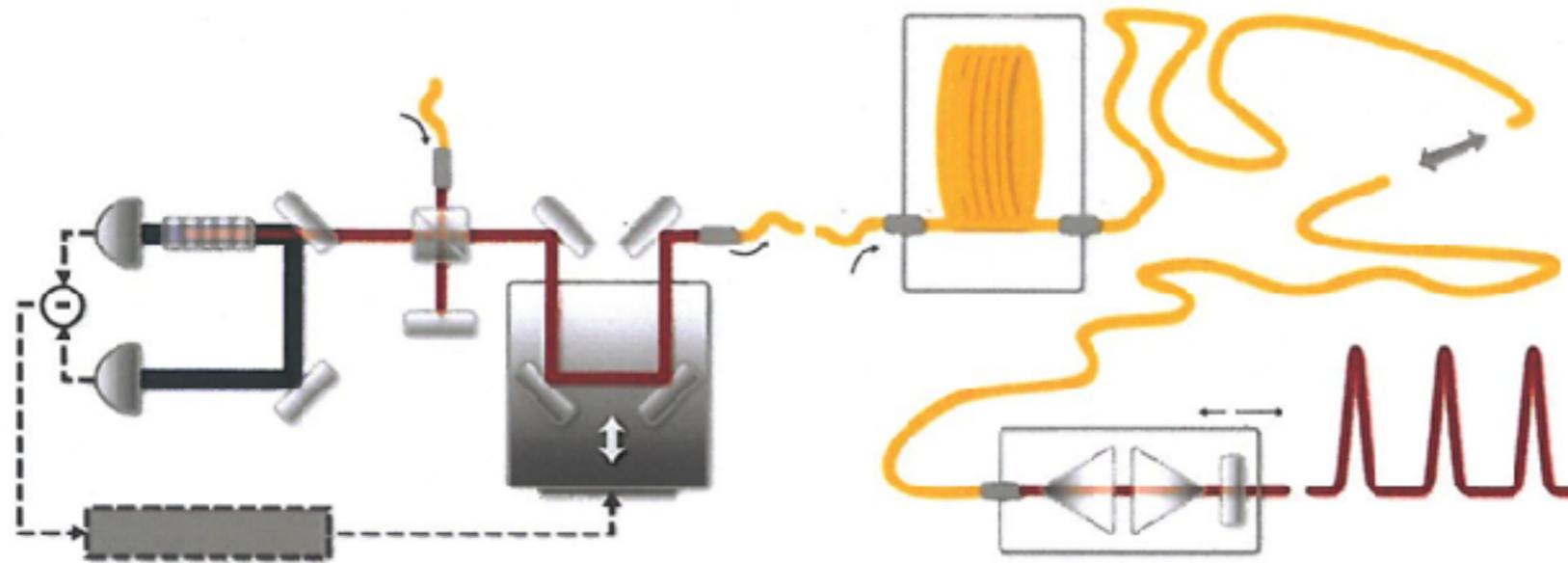
Mode-locked
fs- lasers



ultra-low noise optical pulse trains

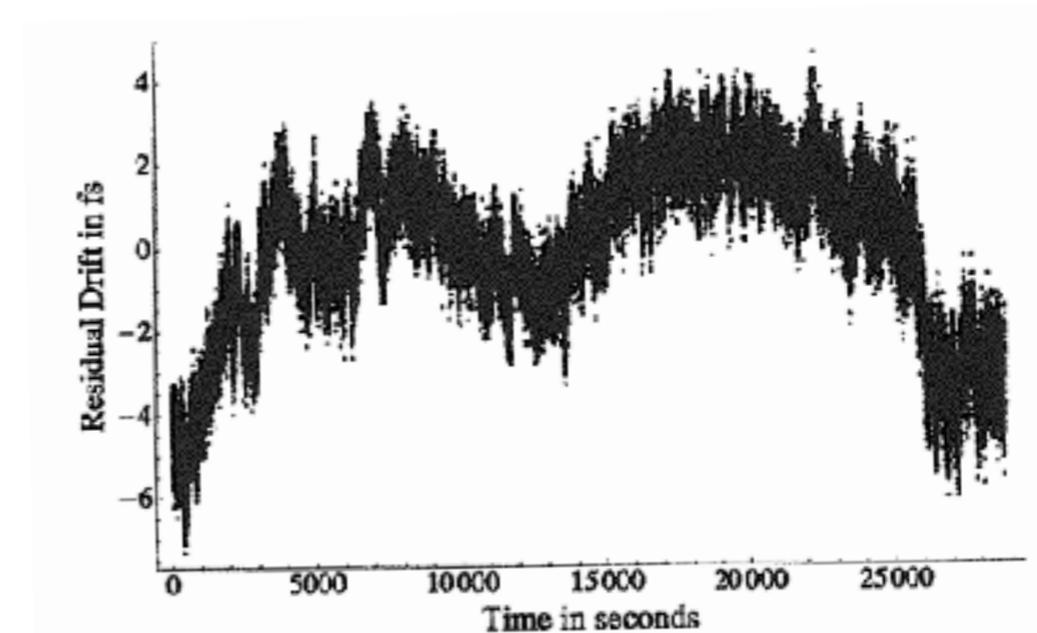
ultra-low noise microwave signals

Two-Way Timing Techniques (local)



Example: FEL in Trieste

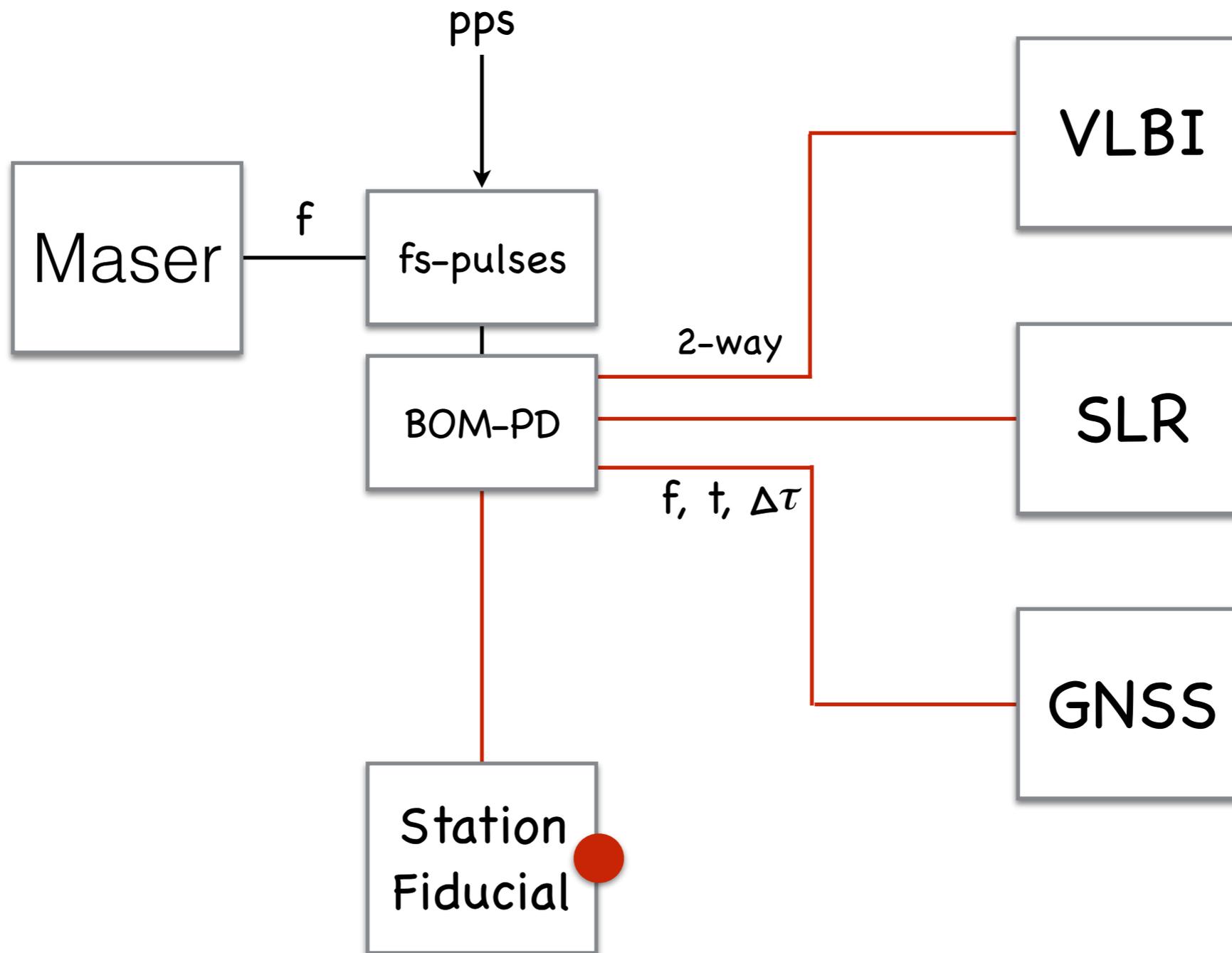
- 2-Way compensation technique only possible in the optical domain
- required broadband signal available from fs-pulse lasers only
- Expected uncertainty < 100 fs: ≈ 5 orders of magnitude gain over current situation
- Consequences for Local Survey: $1 \text{ mm} = 3 \text{ ps}$



lossless distribution

Interpolator

Geodetic Techniques



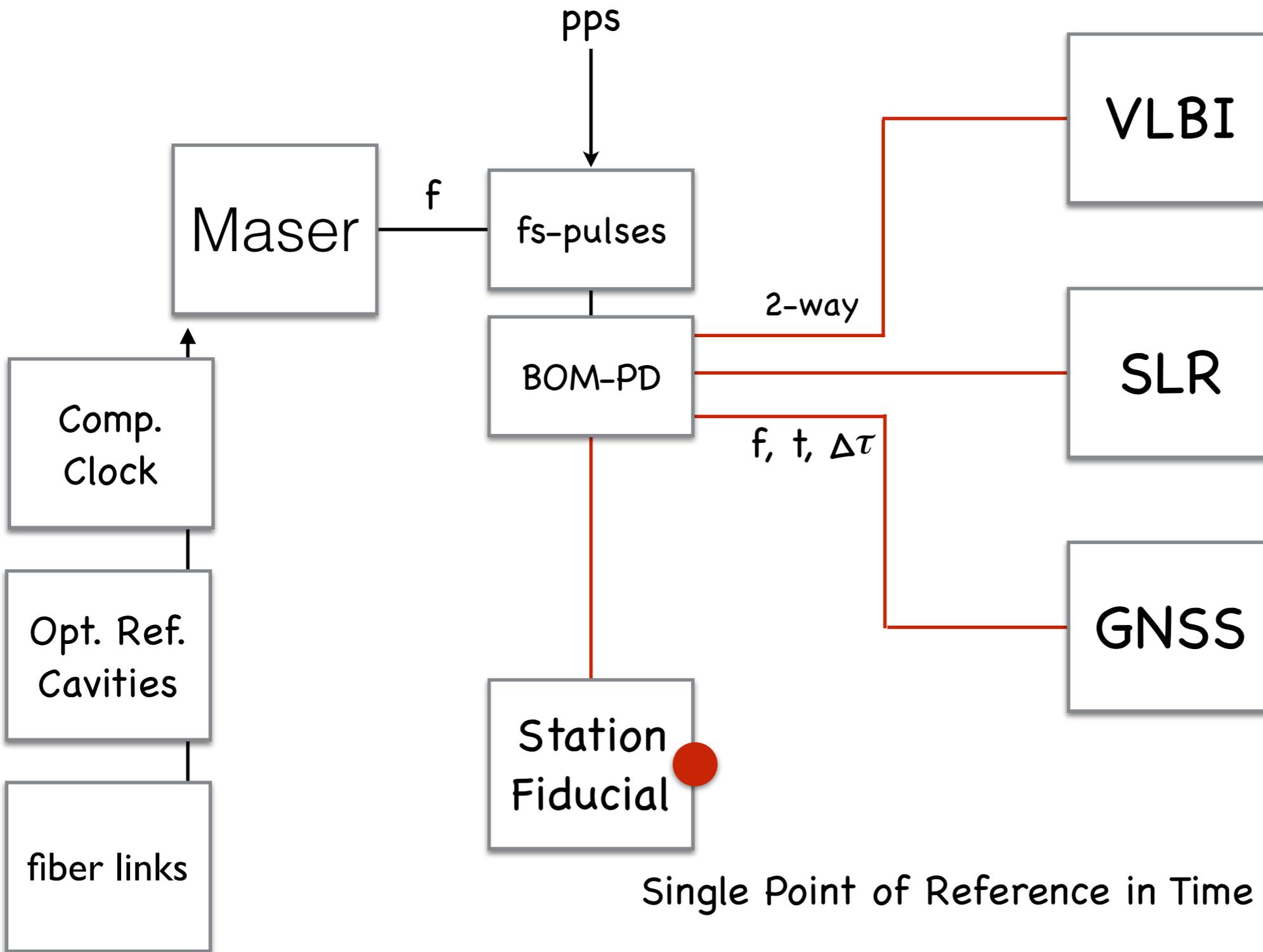
Consistency Check by "Closure-" Techniques

Single Point of Reference in Time and Space

lossless distribution

Interpolator

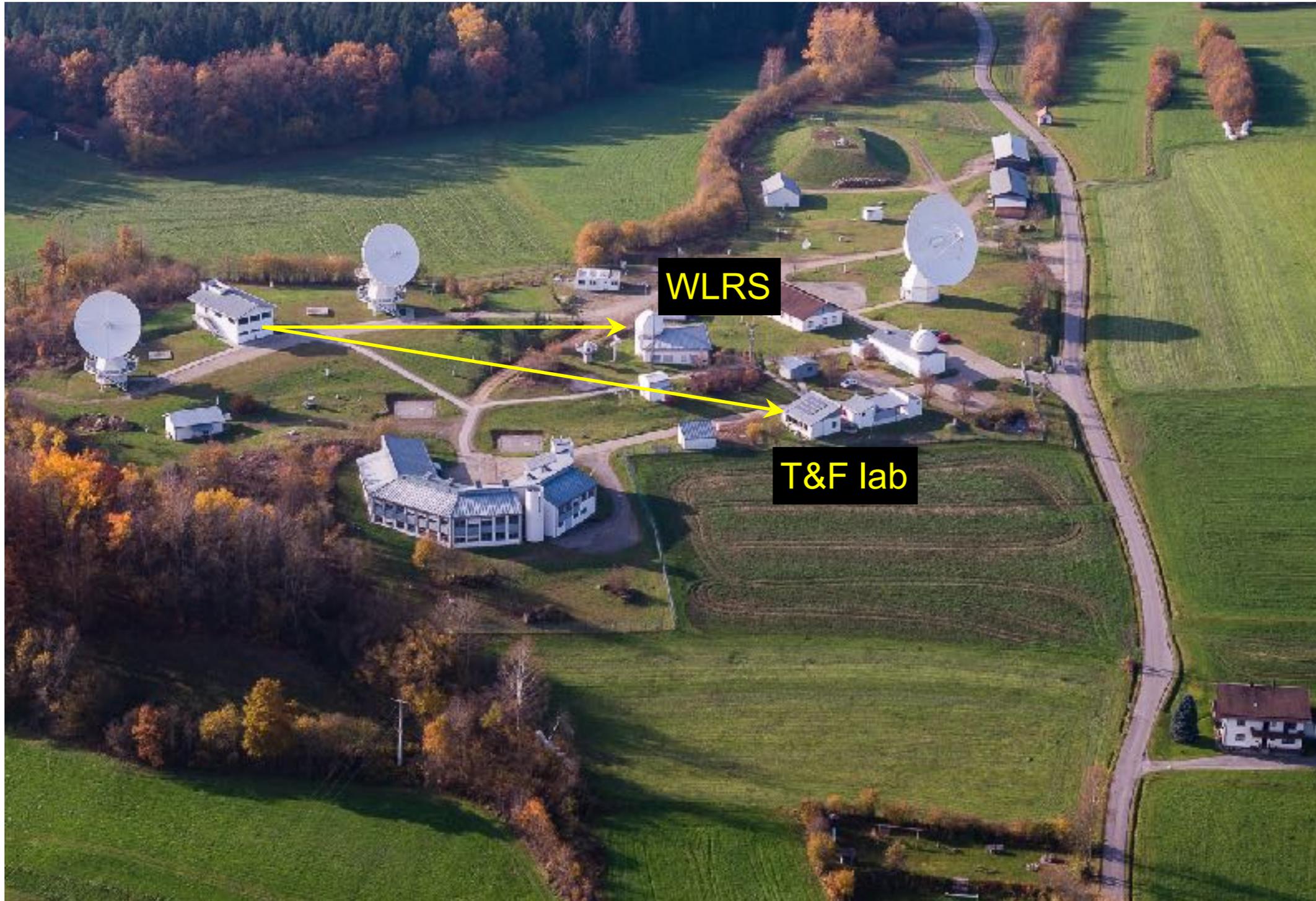
Geodetic Techniques



Consistency Check by "Closure-" Techniques

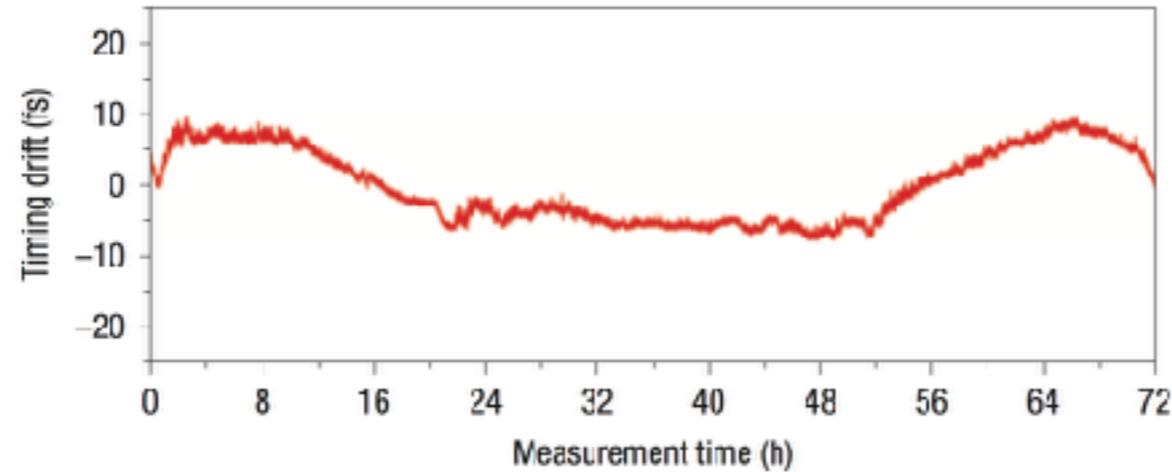
Single Point of Reference in Time and Space

ELT (Time Transfer via ACES)



Common Clock for Space Geodetic Techniques

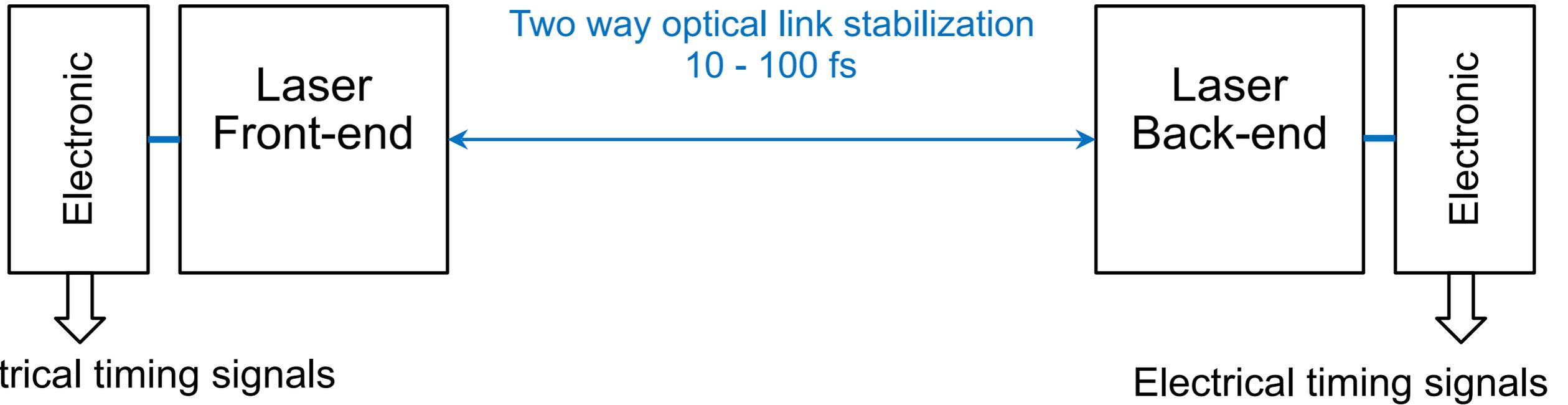
optical cross- correlation of
2 fiber lines (300 m)



6.4 fs r.m.s.

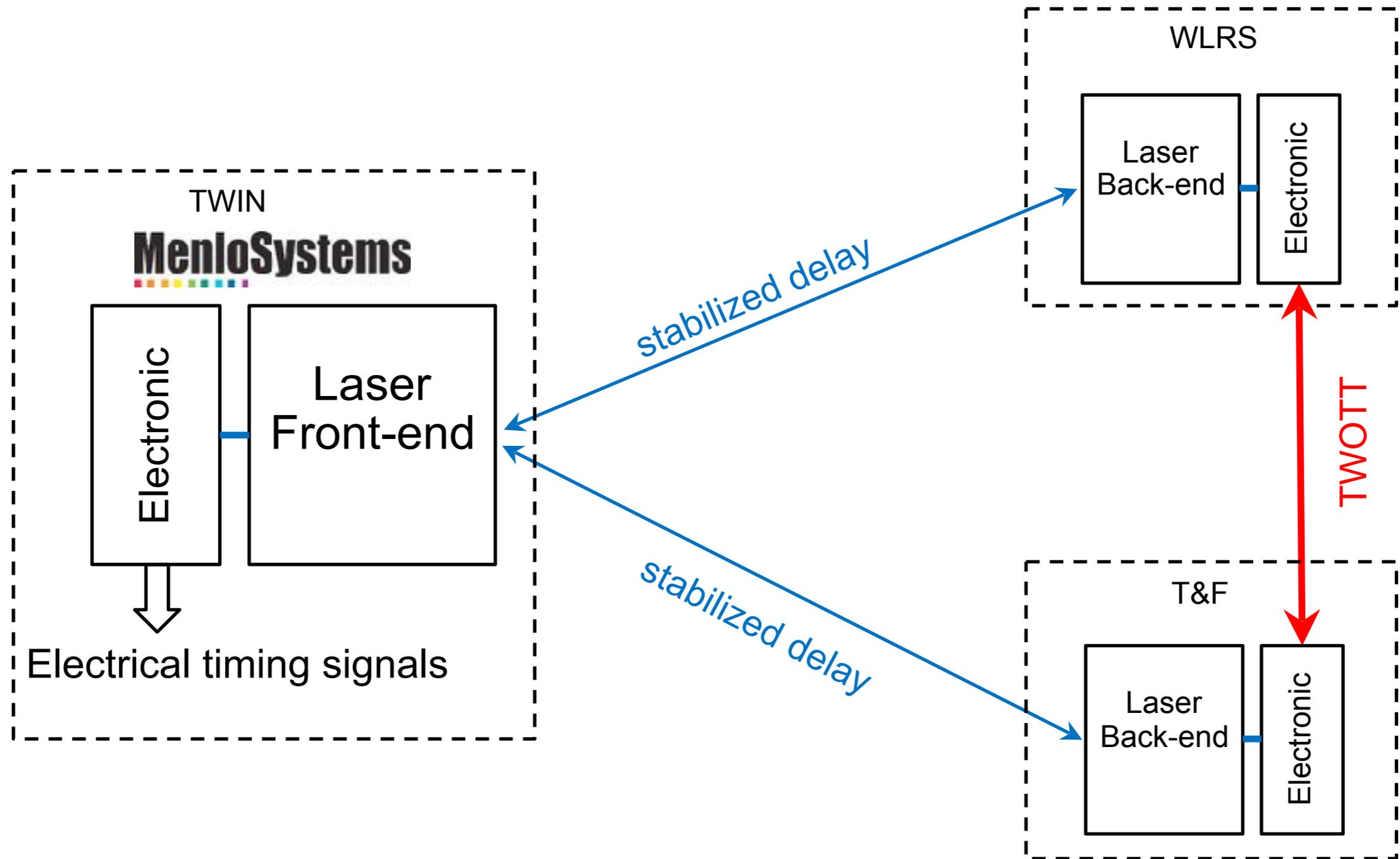
Kim et al. Nature Photon, **2**(12), 733–736, (2008)

MenloSystems

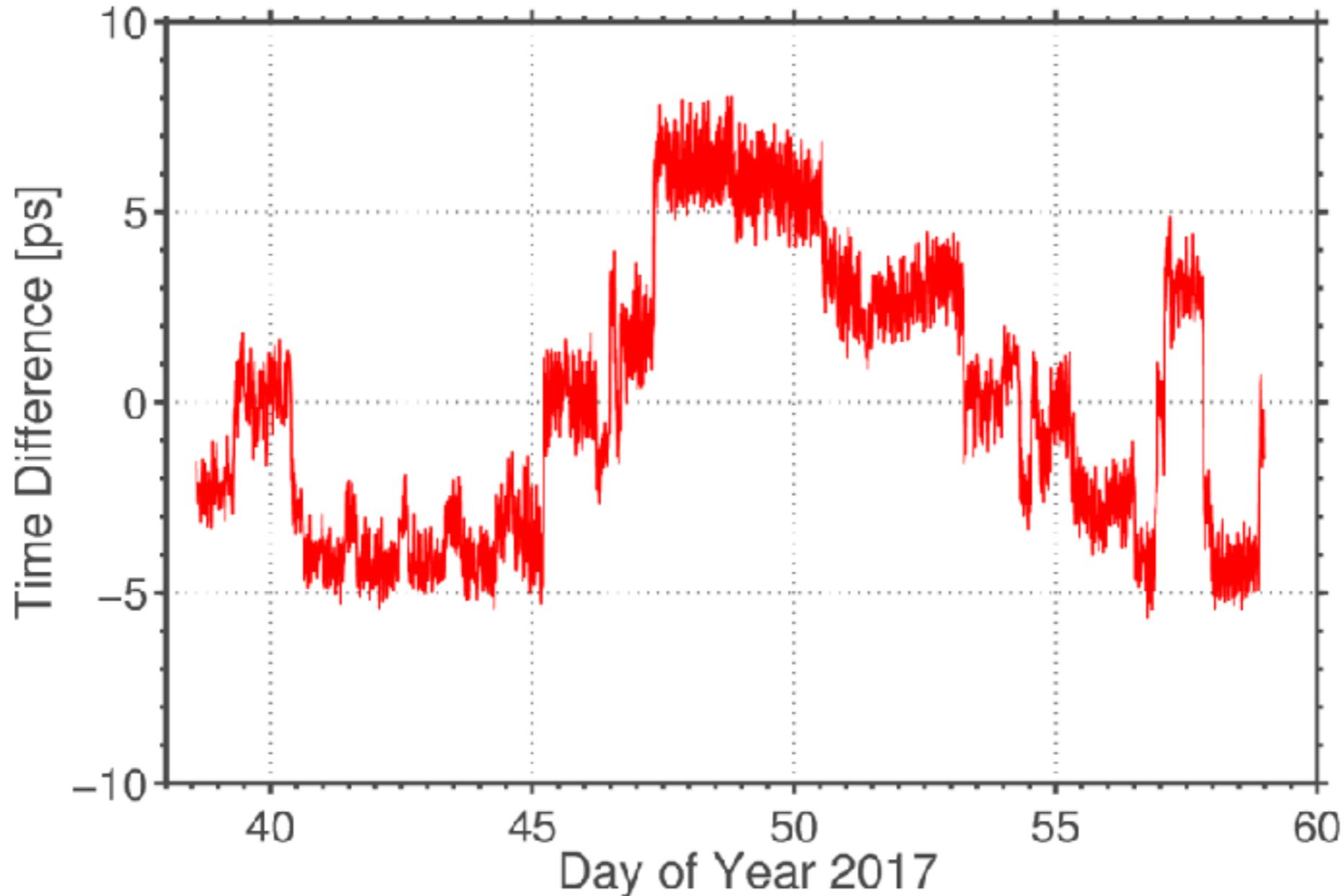


“electrical” Timing stability ~1ps

Common Clock for Space Geodetic Techniques

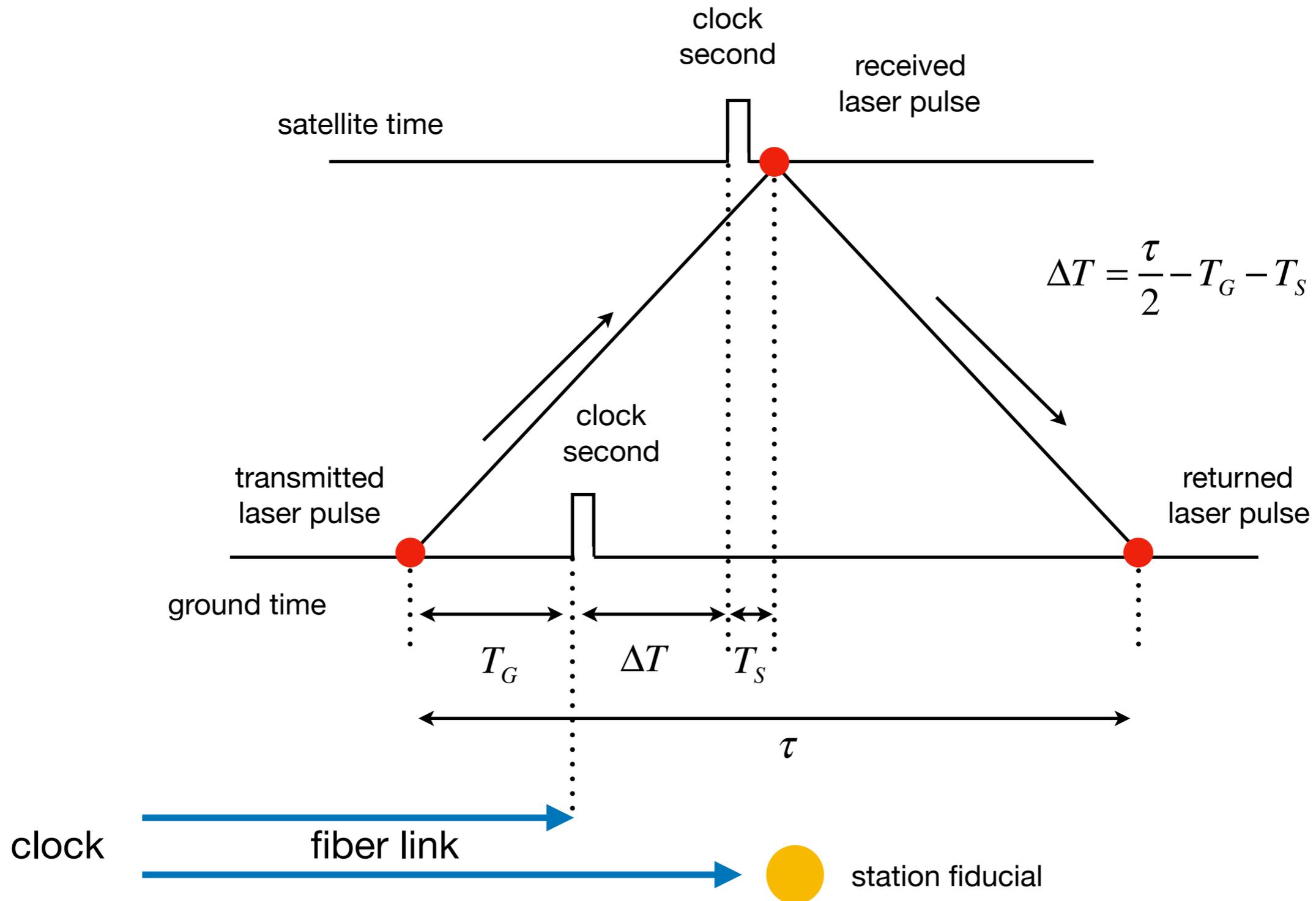


Comparison of Time: T&F - WLRS



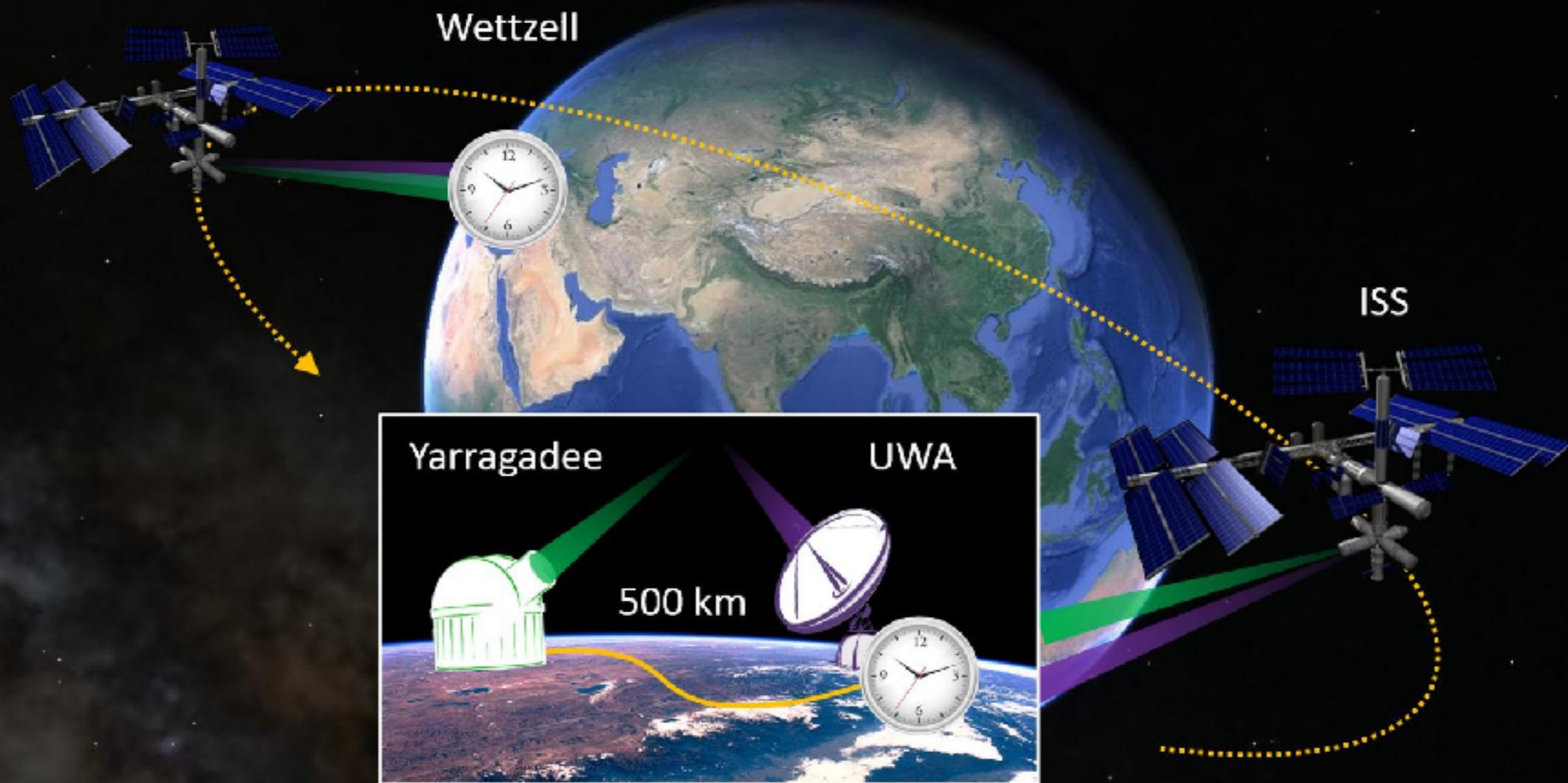
Scatter higher because of undue temperature variation in the time laboratory. Origin of jumps still unclear (Candidates: Plugs)

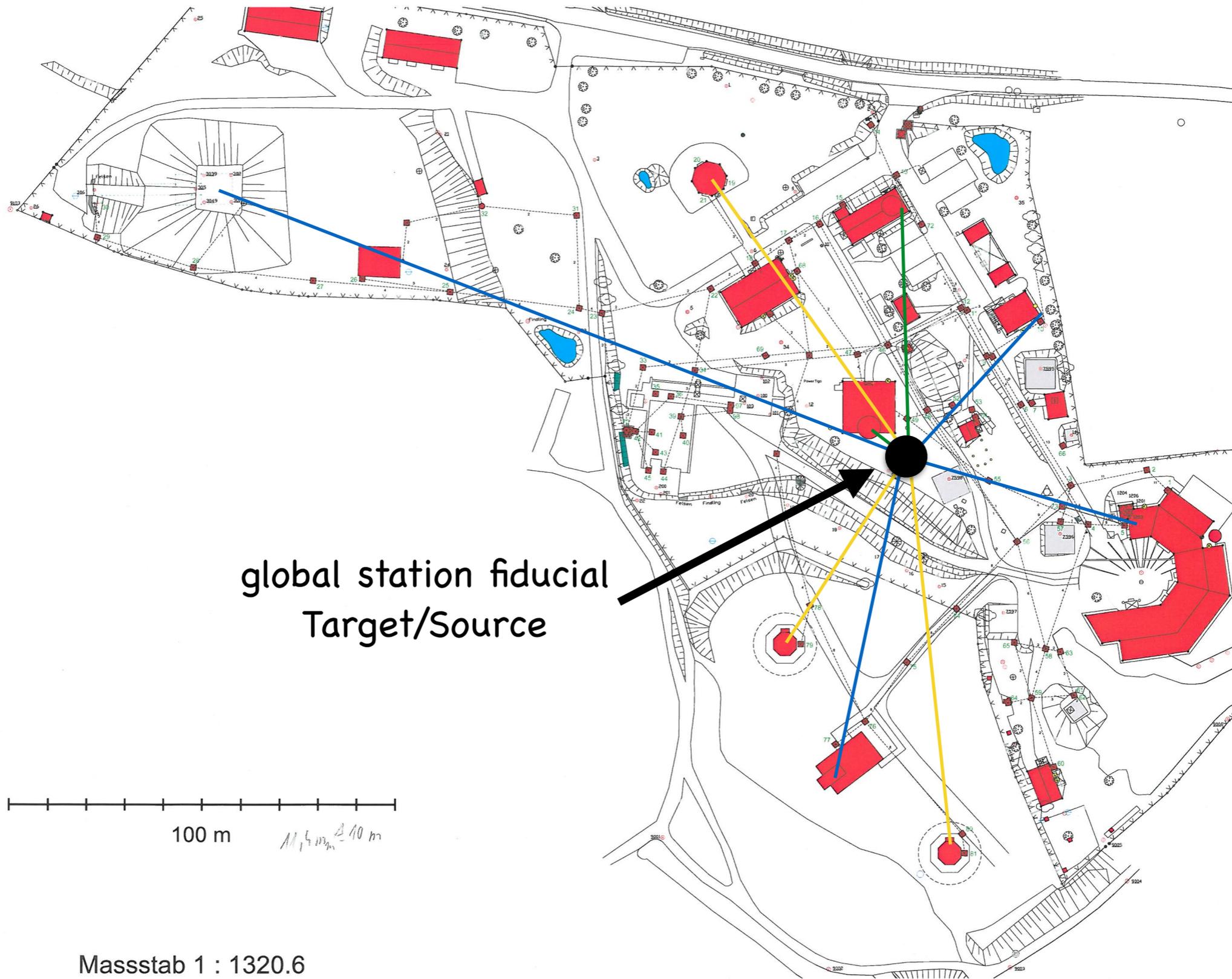
Connecting a "local clock" to the world - The ACES mission



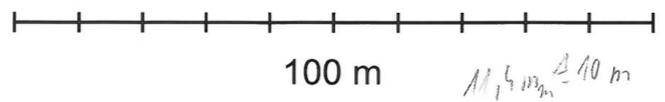
see P. Exertier et al: *Optical Laser Time Transfer for accurate Clocks in Space*
 see J. Eckl et al.: *Ground station requirements for optical Time Transfer*

Inter Continental Time Transfer via ACES

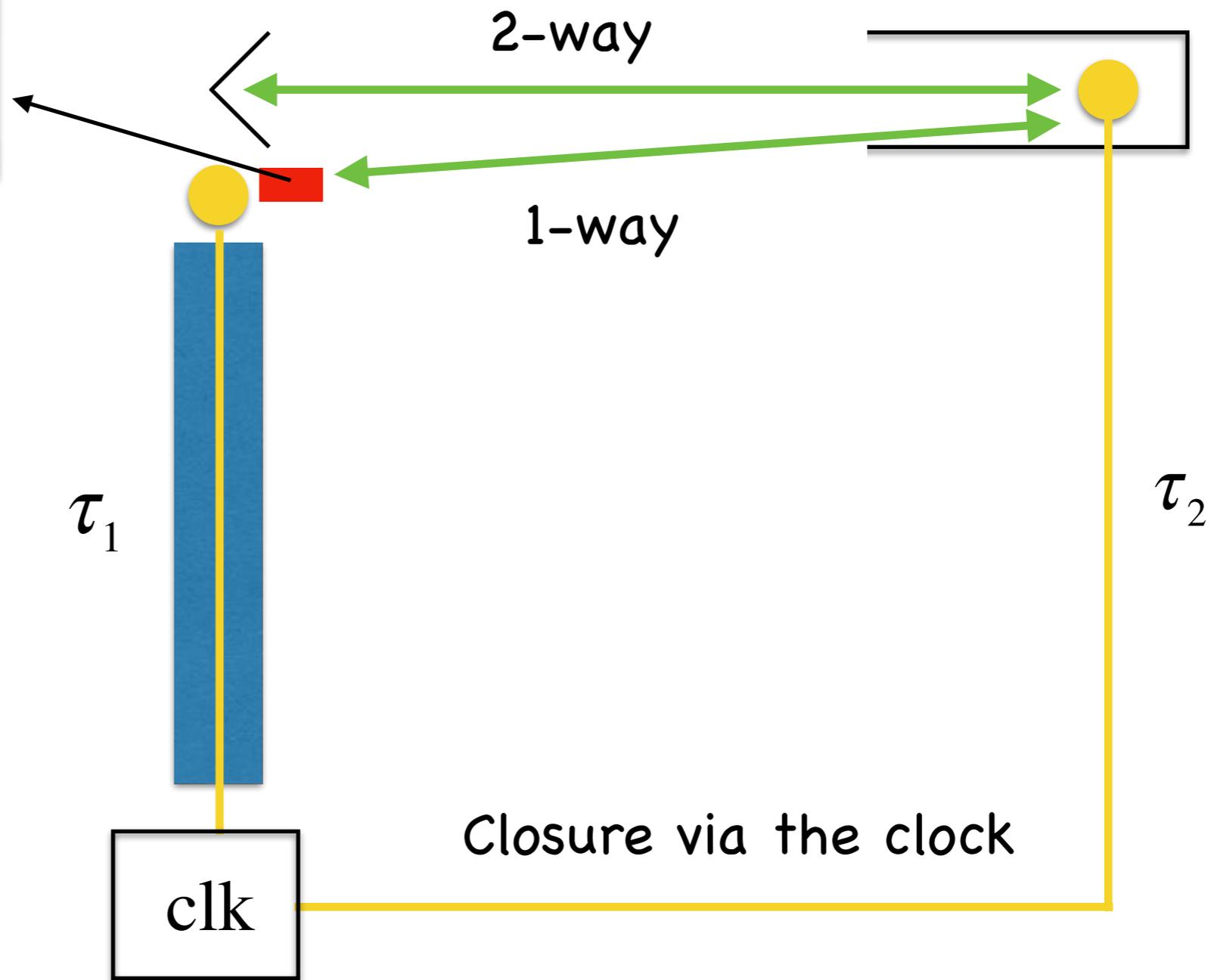




global station fiducial
Target/Source



Masstab 1 : 1320.6

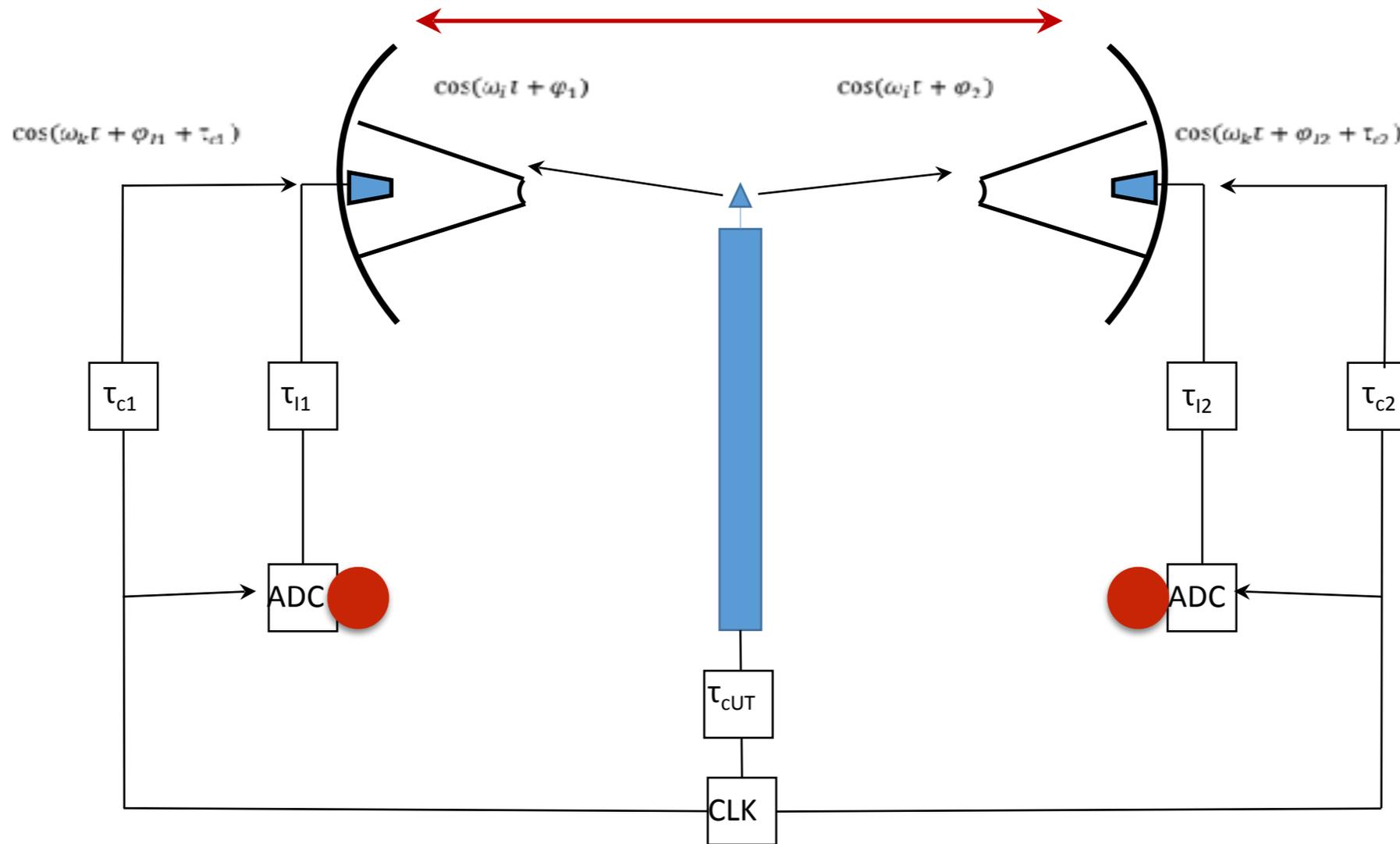


see Kodet et al.: *Optical Time Transfer and its Impact on System Biases*

Station Fiducial VLBI Concept

$\Delta\varphi = \varphi_1 - \varphi_2 = \text{const.}$
 When $\tau_{\text{cut}} = \text{const.} \Rightarrow$
 φ_1 and $\varphi_2 = \text{const.}$

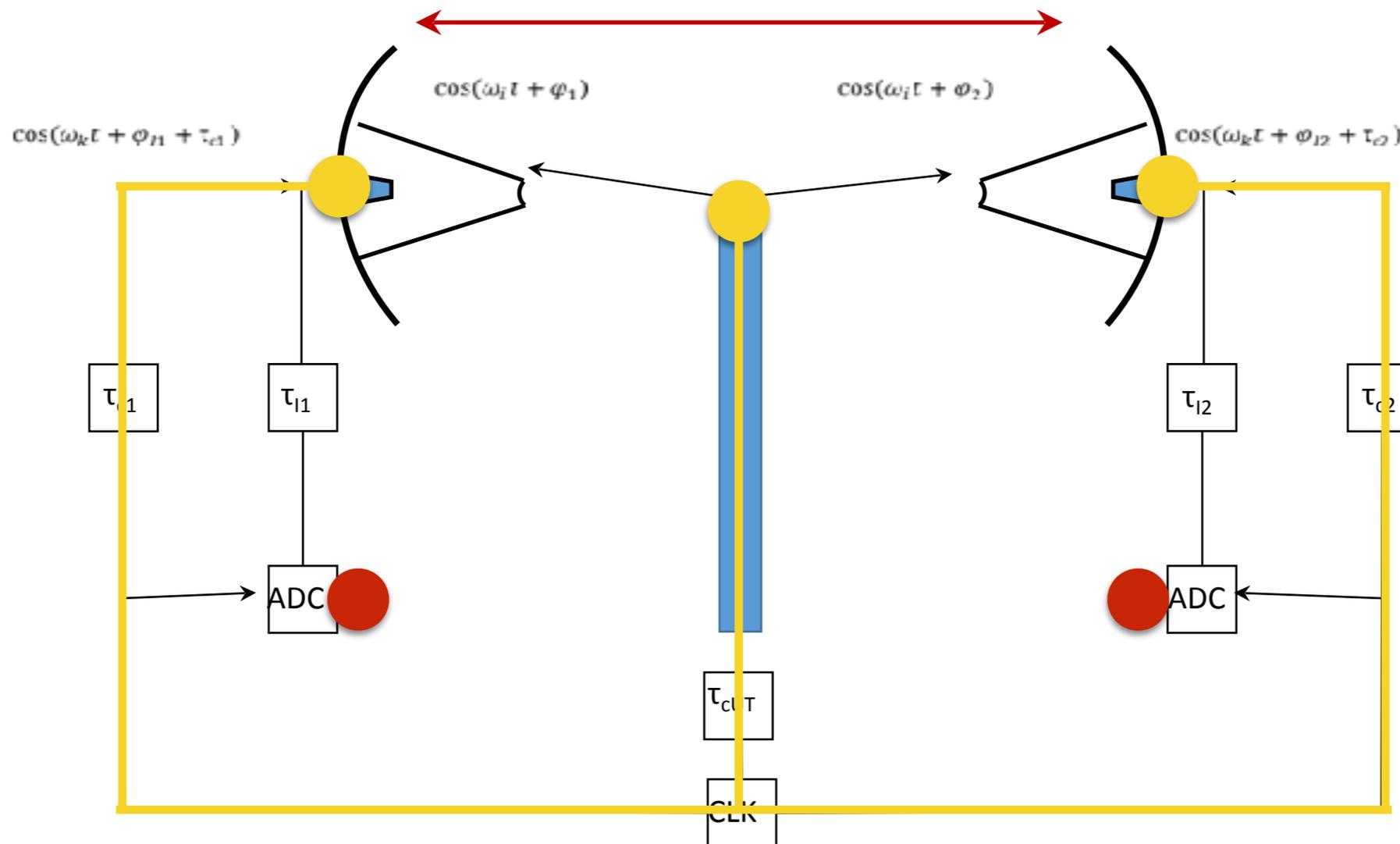
$\Delta\tau_g = \tau_{g1} - \tau_{g2} = \text{const.}$
 $\Delta\tau_H = \frac{d\varphi_1}{d\omega} - \frac{d\varphi_2}{d\omega} = \text{const.}$
 When $\tau_{\text{cut}} = \text{const.} \Rightarrow$
 τ_{g1} and $\tau_{g2} = \text{const.}$



Universal Target VLBI Concept

$\Delta\varphi = \varphi_1 - \varphi_2 = \text{const.}$
 When $\tau_{\text{CLK}} = \text{const.} \Rightarrow$
 φ_1 and $\varphi_2 = \text{const.}$

$\Delta\tau_g = \tau_{g1} - \tau_{g2} = \text{const.}$
 $\Delta\tau_M = \frac{d\varphi_1}{d\omega} - \frac{d\varphi_2}{d\omega} = \text{const.}$
 When $\tau_{\text{CLK}} = \text{const.} \Rightarrow$
 τ_{g1} and $\tau_{g2} = \text{const.}$



Closure via the clock

IAG: Sub-Commission 1.1.

Coordination of Space Geodetic Techniques

WG 1.1.1 Co-location usings Clocks and New Sensors

The establishment of accurate local ties of different space geodetic techniques at fundamental geodetic observatories poses a long-standing problem. While geometric ties can be determined at sub-millimeter-level, the relation to physical phase centers of the instruments and temporal stability of such offsets are usually known with significantly lower precision. Novel ways for inter-technique calibration at a geodetic site need to be developed using existing and new sensors and technologies, such as highly accurate time and frequency transfer, ultra-stable clocks, and co-location targets. Complementary to such development the tying of techniques shall be exploited to their limits at the analysis level e.g. to using common clock and troposphere parameters.