Delay Compensation for Free Space & Campus Time Transfer

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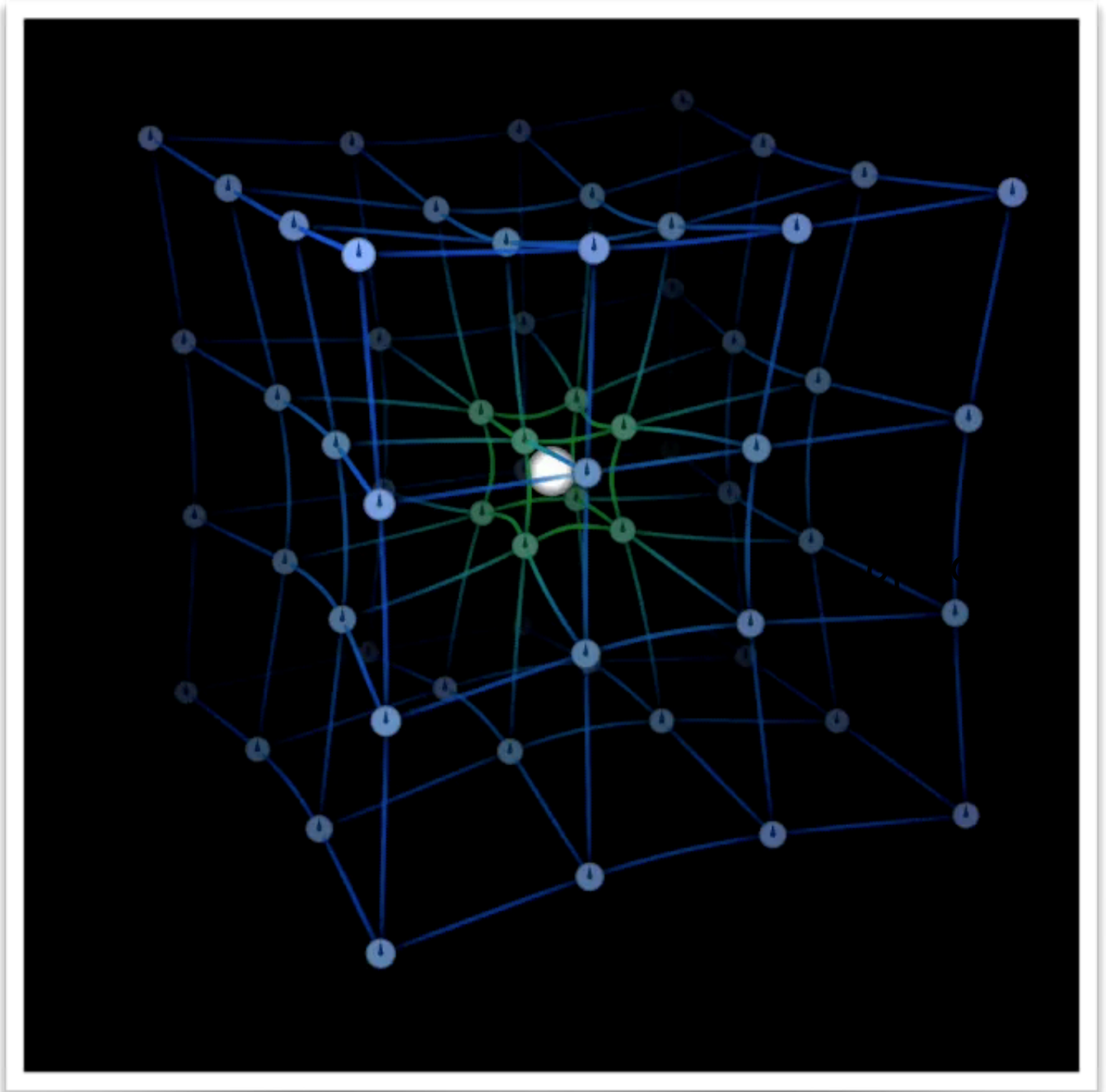
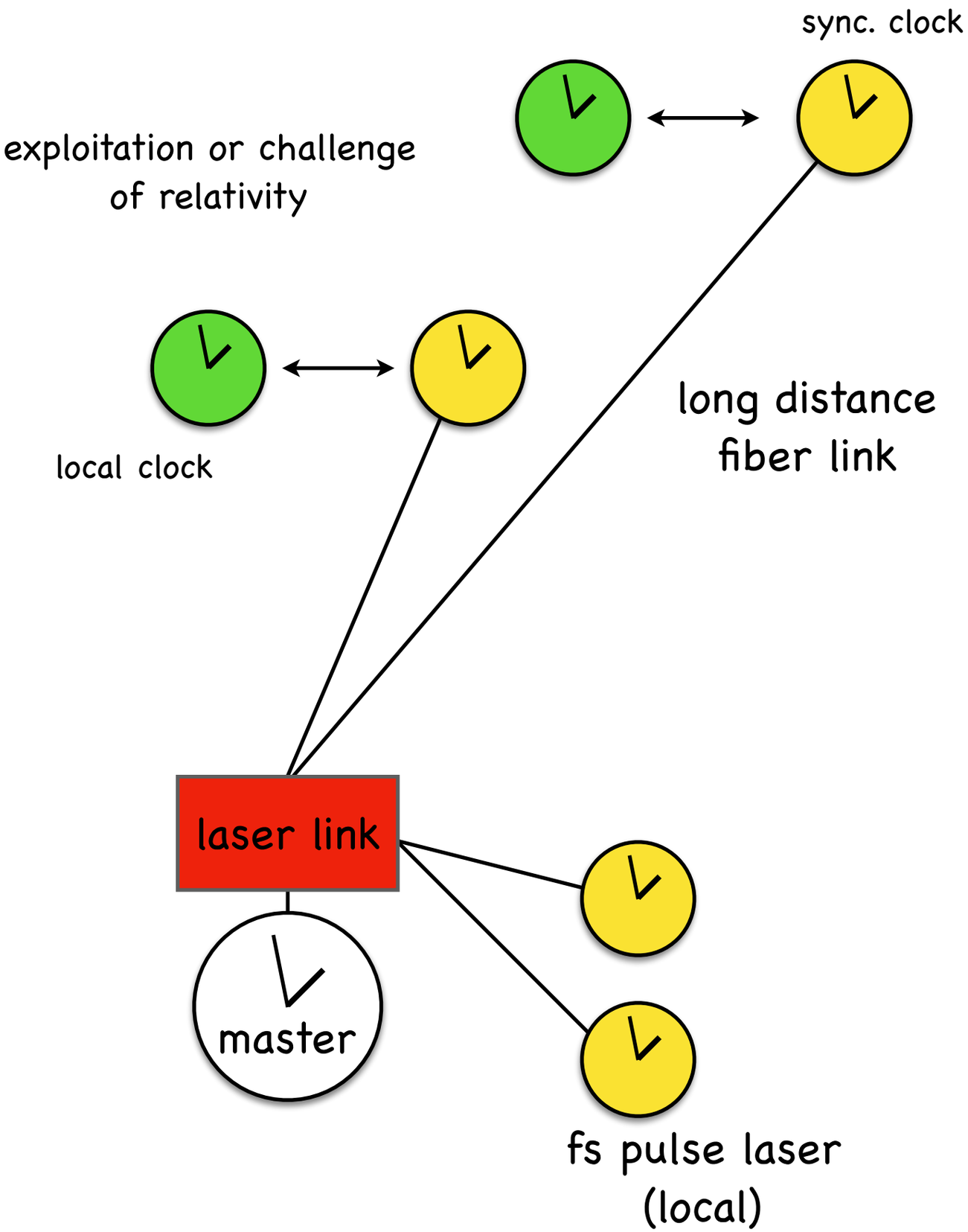


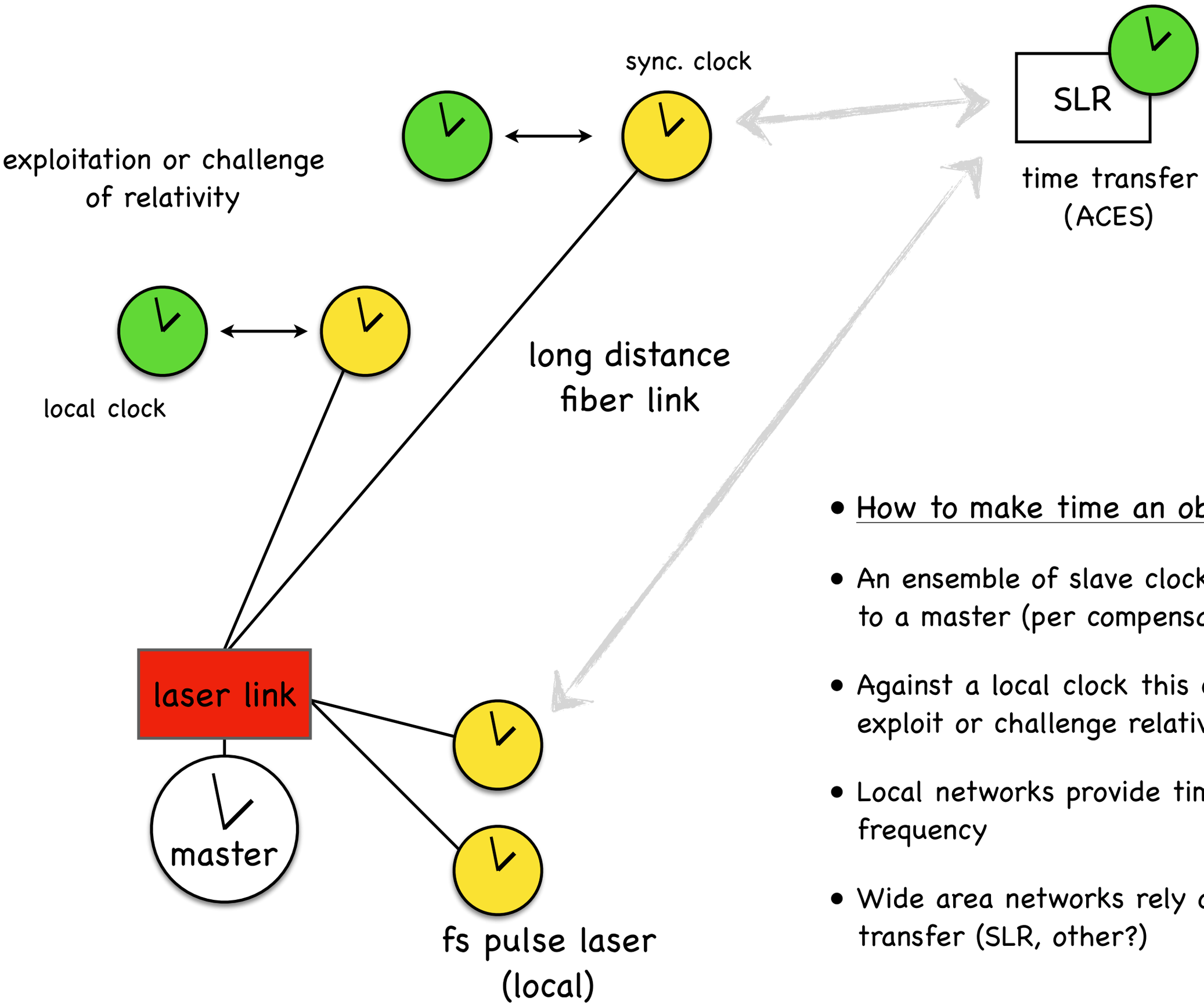
https://imgur.com/RaWqYkV

The value of optical time transfer

- Clocks probe the local physics (gravity and velocity)
- Clock oscillator performance demonstrated to 1 part in 10^{18}
- Frequency transfer over fiber links theoretically stable to 1 part 10^{19}
- Optical time transfer (ground to satellite on T2L2 ≈ 7 ps @ 30s)
- Coherent optical round trip time transfer (2 km free space on ground: 1 fs @ 1000 s)
- 2-way optical time transfer on a compensated fiber link (600 m) achieved stability of 1 ps over a week.



- How to make time an observable
- An ensemble of slave clocks are sync'ed to a master (per compensated fiber link)
- Against a local clock this can be used to exploit or challenge relativity
- Local networks provide time and frequency



- How to make time an observable
- An ensemble of slave clocks are sync'ed to a master (per compensated fiber link)
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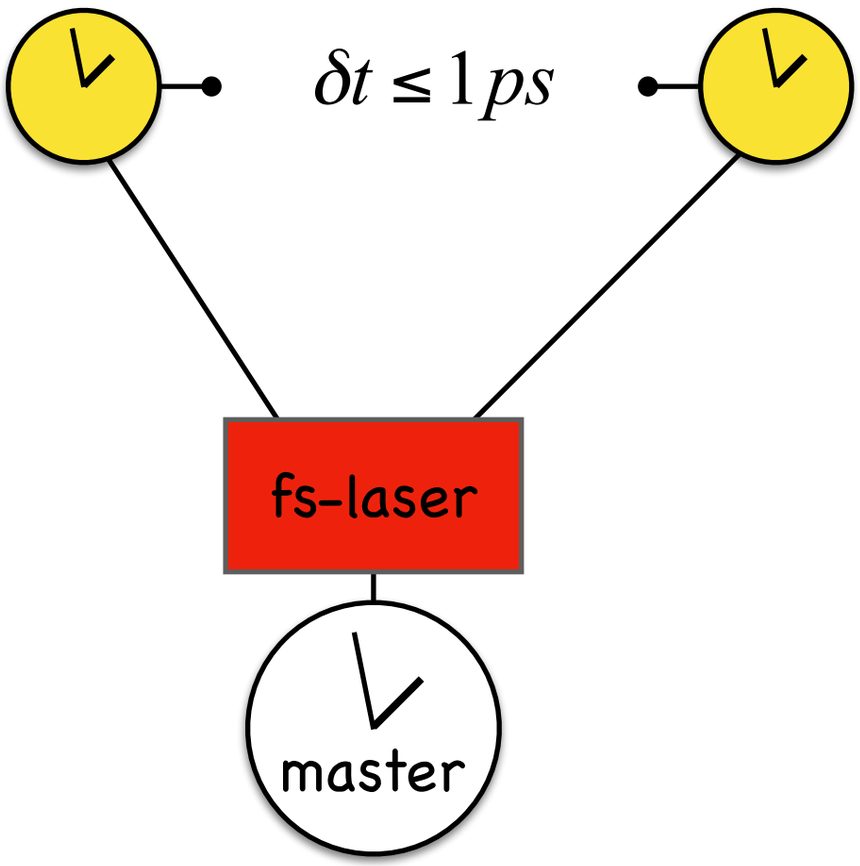
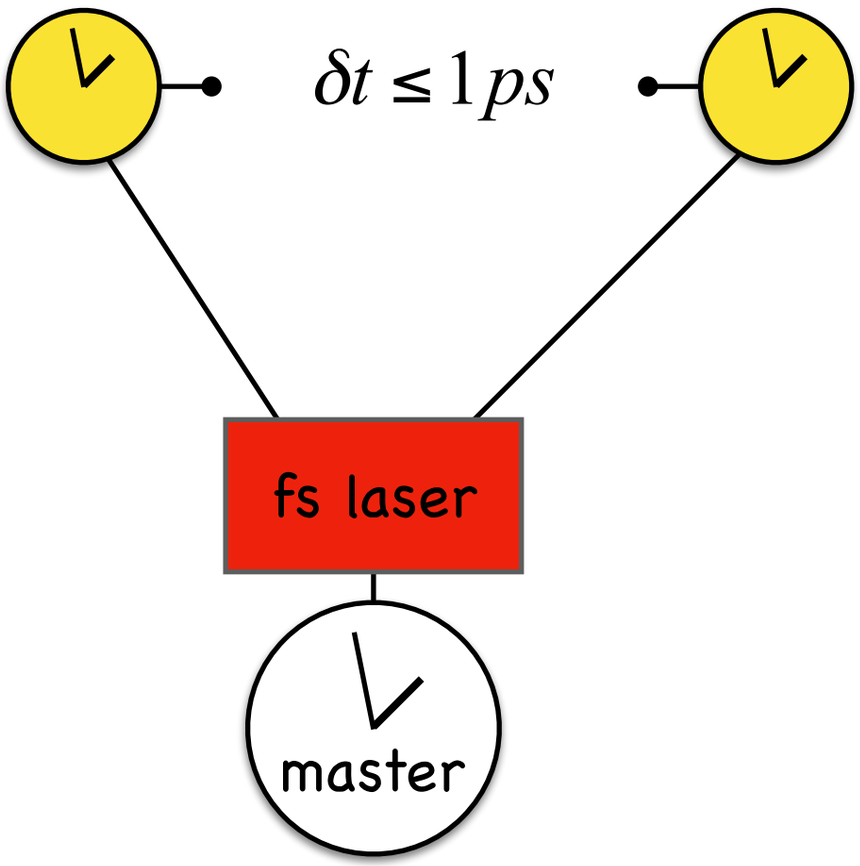
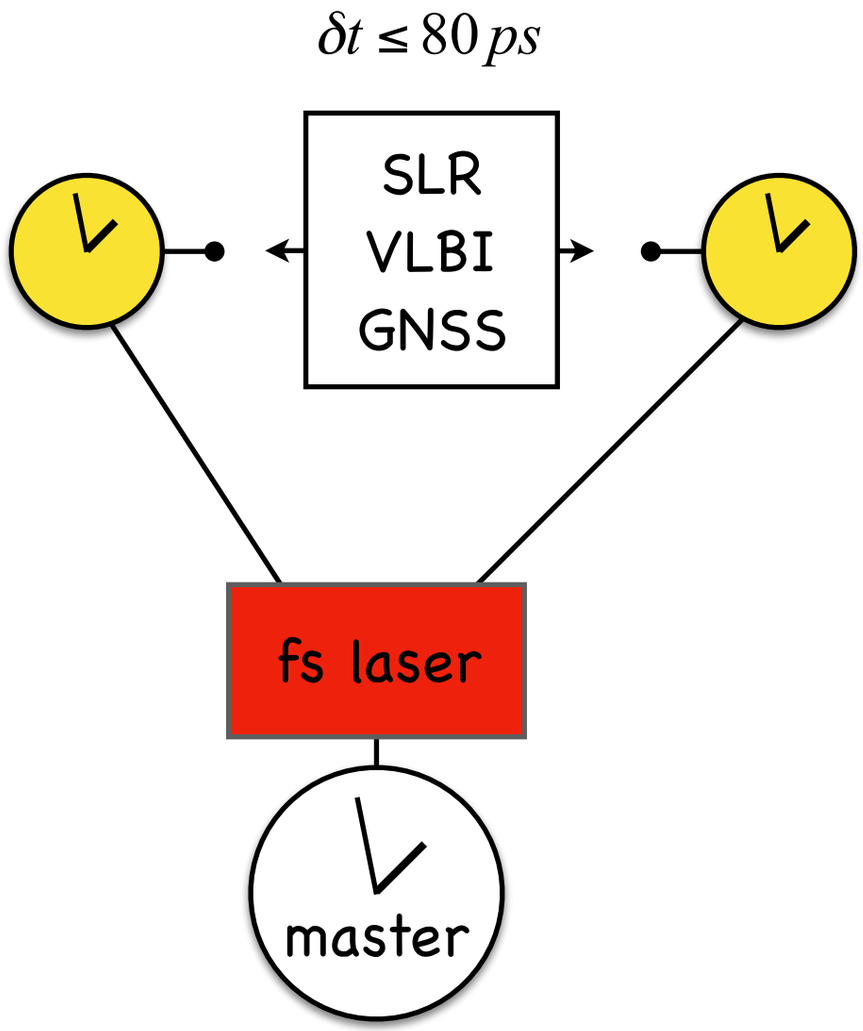
- Local networks provide time and frequency
- Wide area networks rely on optical time transfer (SLR, other?)

Probing System Performance utilizing Time



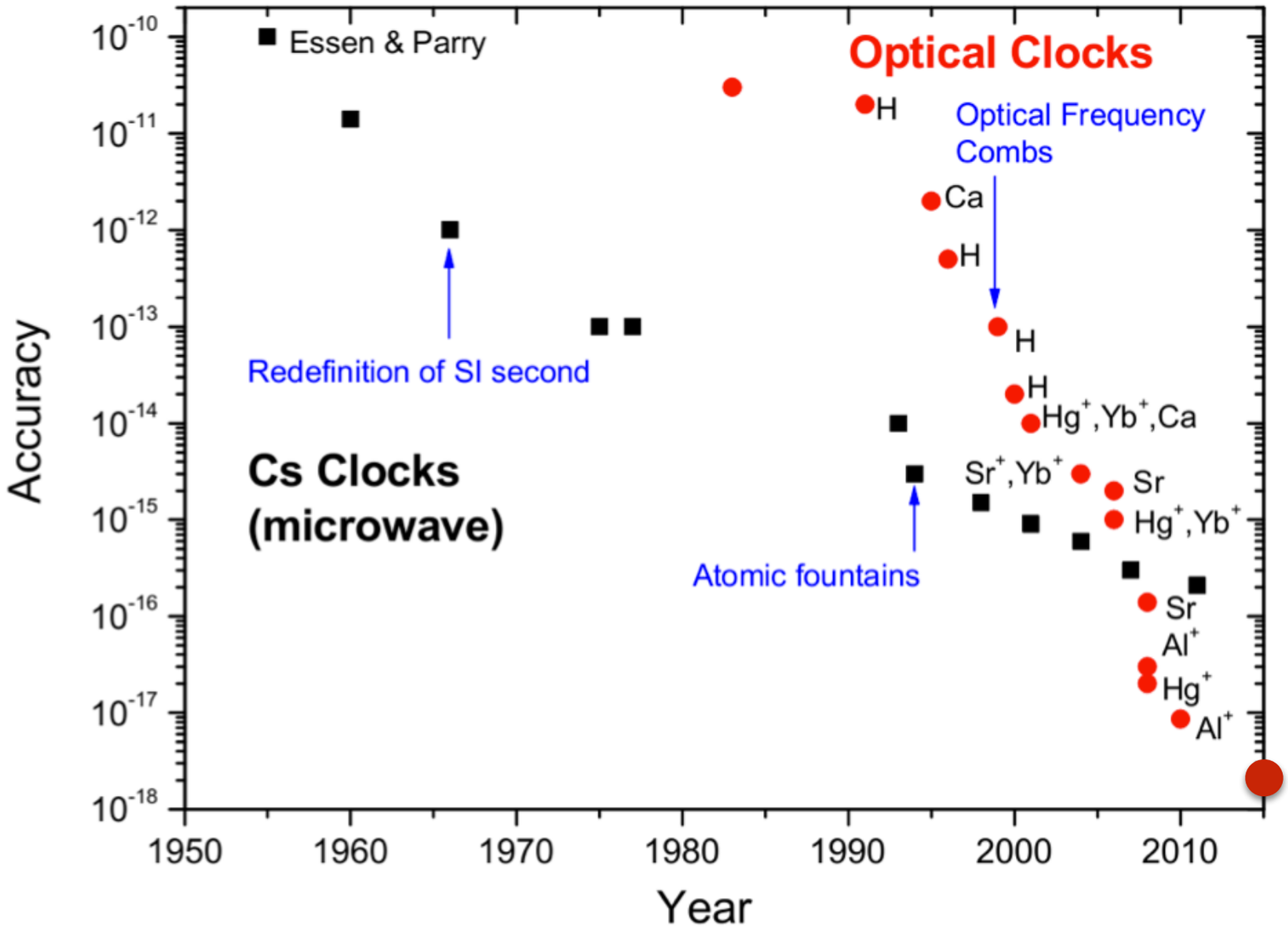
Probing System Performance utilizing Time





Building Block 1

Highly accurate clocks exploit frequency to utilize GR for a height system:

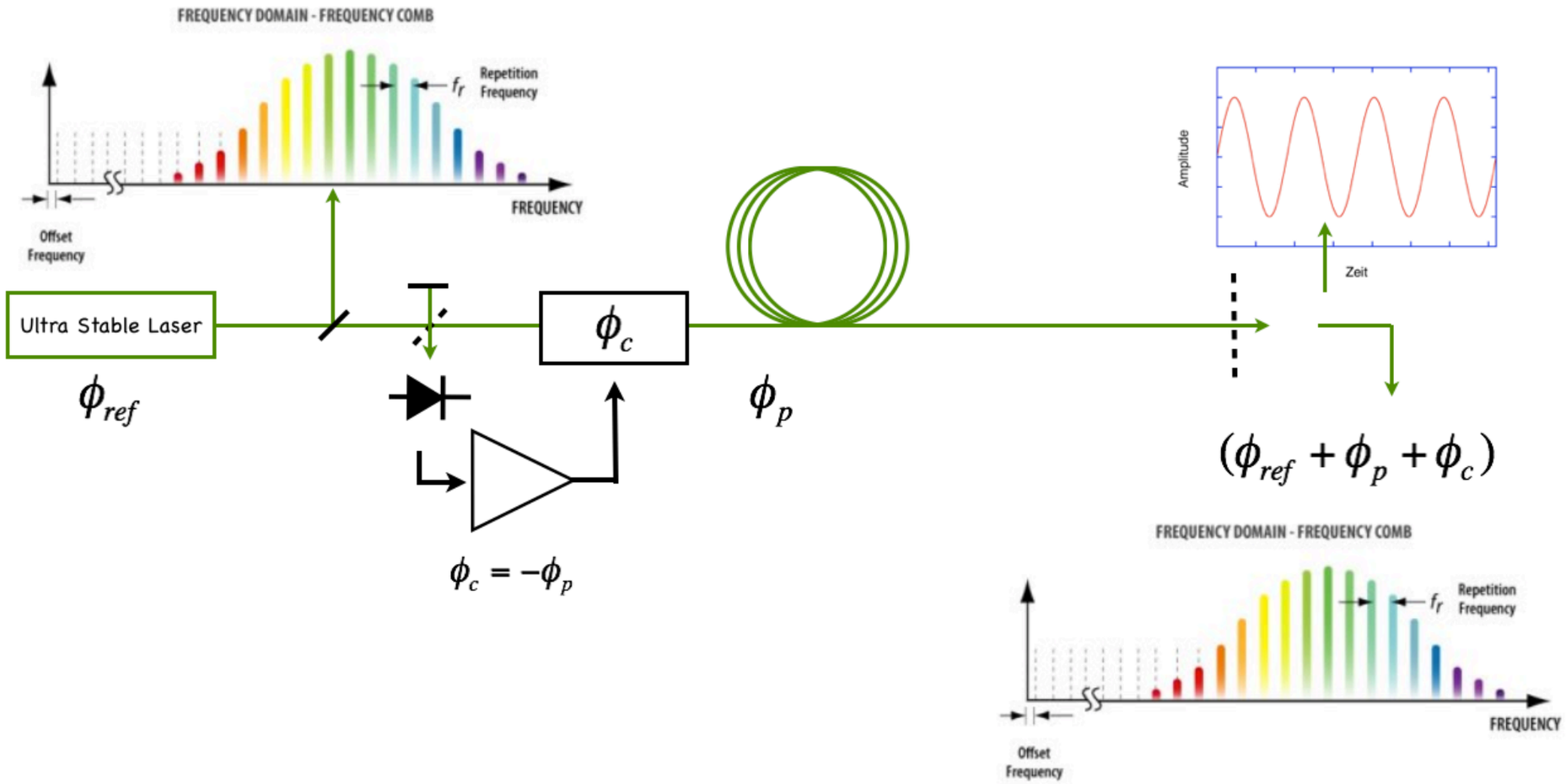


$$\Delta t' = (1 + \frac{g \cdot h}{c^2})\Delta t$$

"clock geodesy" -> Contribution of Chr. Lisdat

Building Block 2

Accurate Comparison of remote optical oscillators by fiber link



Lossless Fiber Links -> Contribution by G. Vishnyakova

How to compare two remote clocks... Einstein Synchronization!

3. *Zur Elektrodynamik bewegter Körper;* *von A. Einstein.*

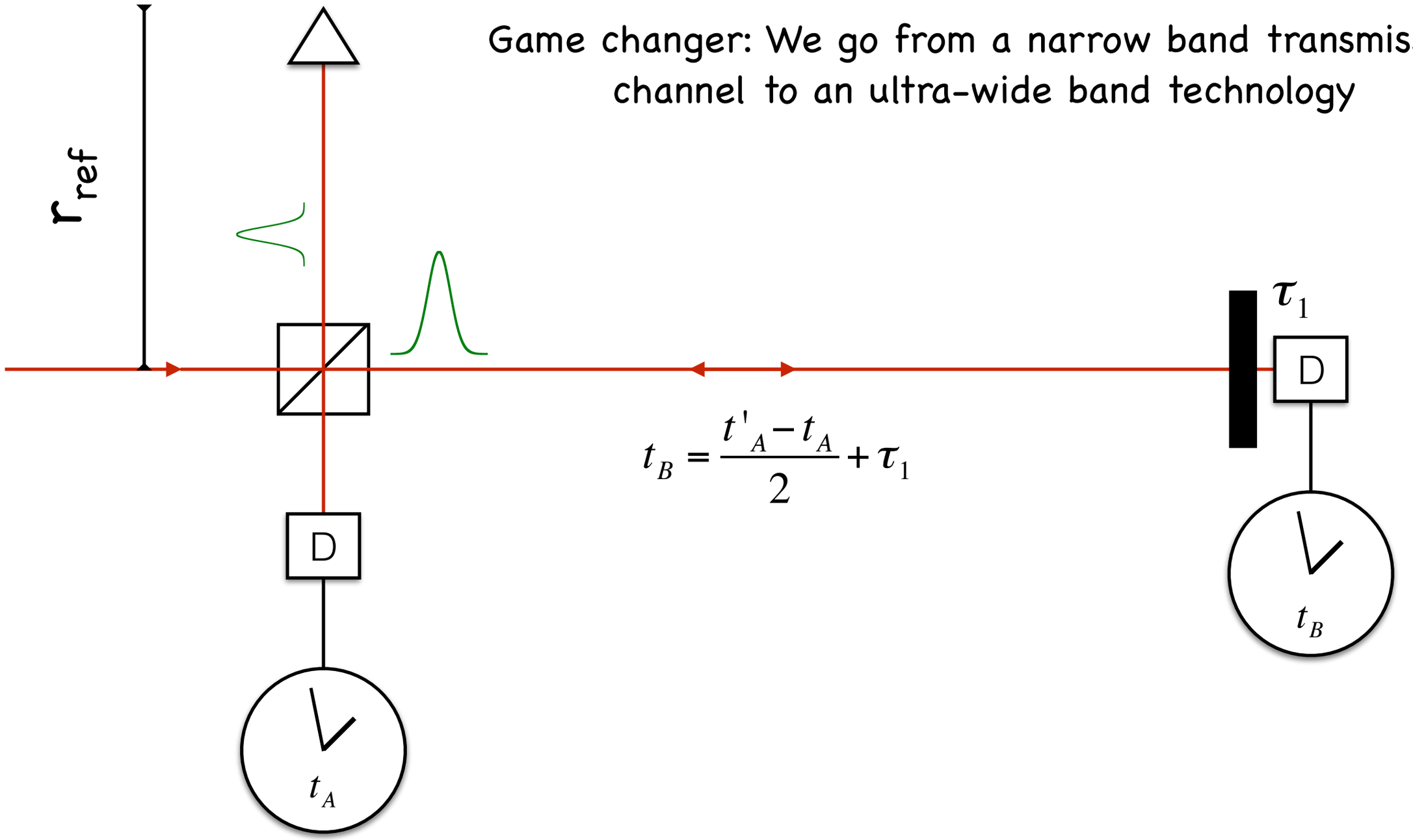
nun definiert werden, indem man *durch Definition* festsetzt, daß die „Zeit“, welche das Licht braucht, um von A nach B zu gelangen, gleich ist der „Zeit“, welche es braucht, um von B nach A zu gelangen. Es gehe nämlich ein Lichtstrahl zur „A-Zeit“ t_A von A nach B ab, werde zur „B-Zeit“ t_B in B gegen A zu reflektiert und gelange zur „A-Zeit“ t'_A nach A zurück. Die beiden Uhren laufen definitionsgemäß synchron, wenn

$$t_B - t_A = t'_A - t_B.$$

Annalen der Physik. 17, 1905, S. 891–921

Isotropy of the speed of light!

SLR is the practical Realization of the Einstein Synchronization…



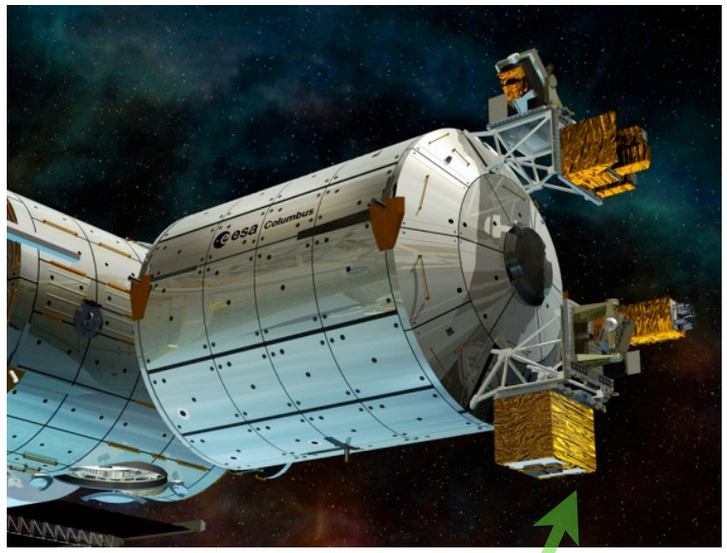
Game changer: We go from a narrow band transmission channel to an ultra-wide band technology

$$t_B = \frac{t'_A - t_A}{2} + \tau_1$$

… including the unavoidable System- Delays

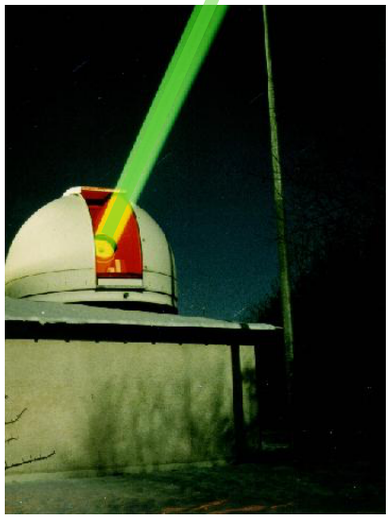
Building Block 3

Accurate distribution of time (Einstein Synchronization)



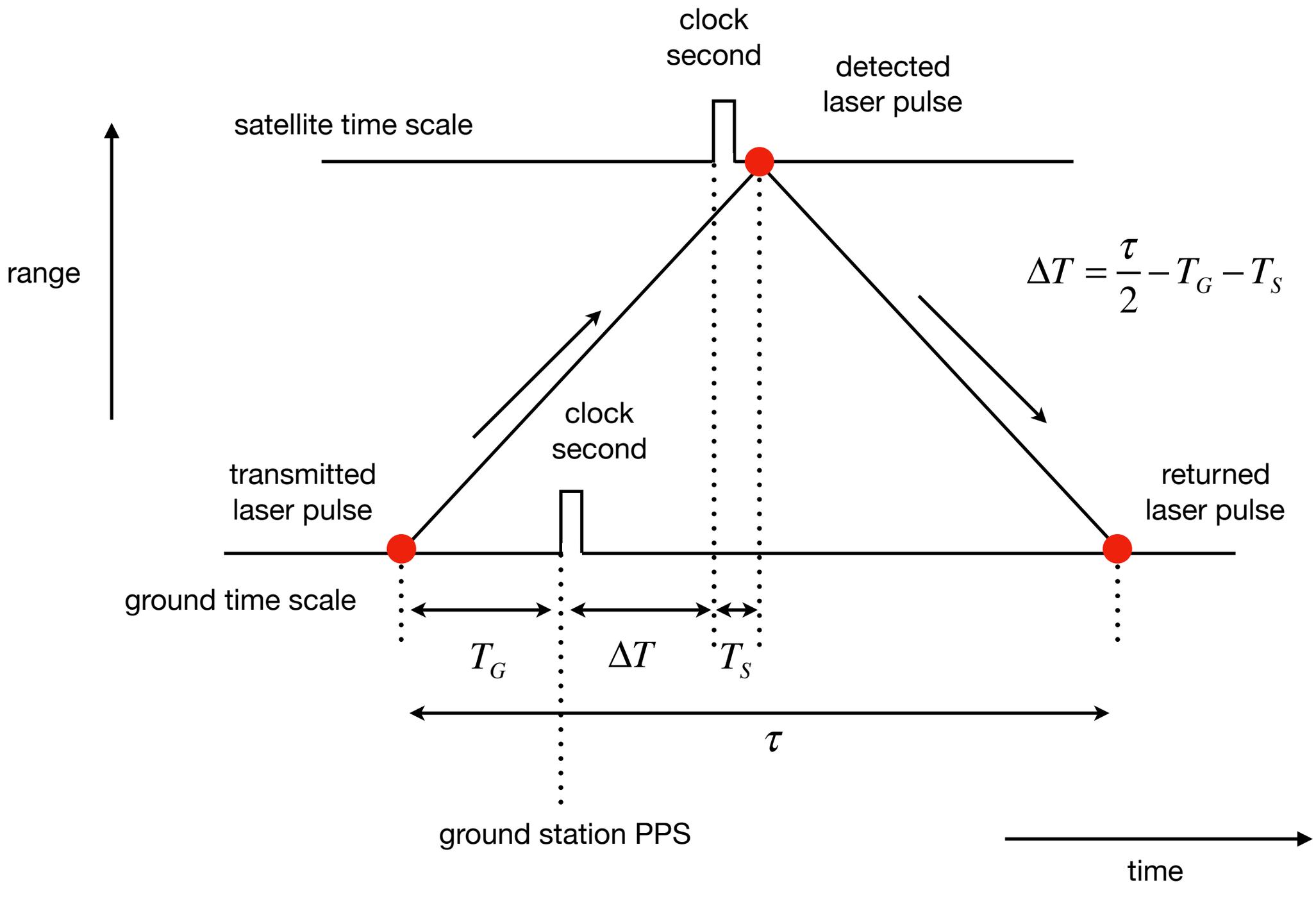
satellite clock
(interpolator)

geodetic
reference point
(time)

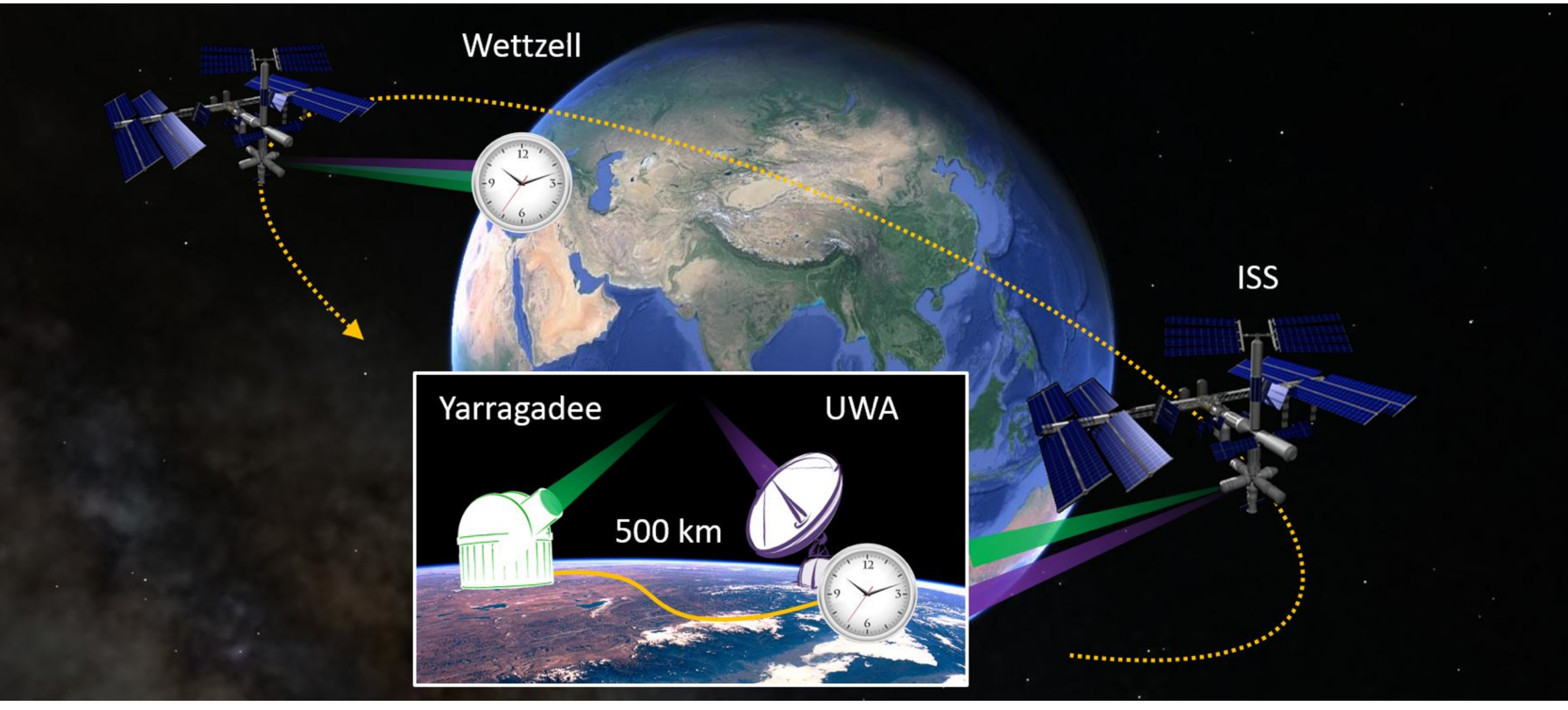


- Time is associated with a well defined geodetic coordinate
- The satellite is in fast motion and under changing gravity
- In order to preserve time, the orbit must be known
- Internal delays have to be knocked down

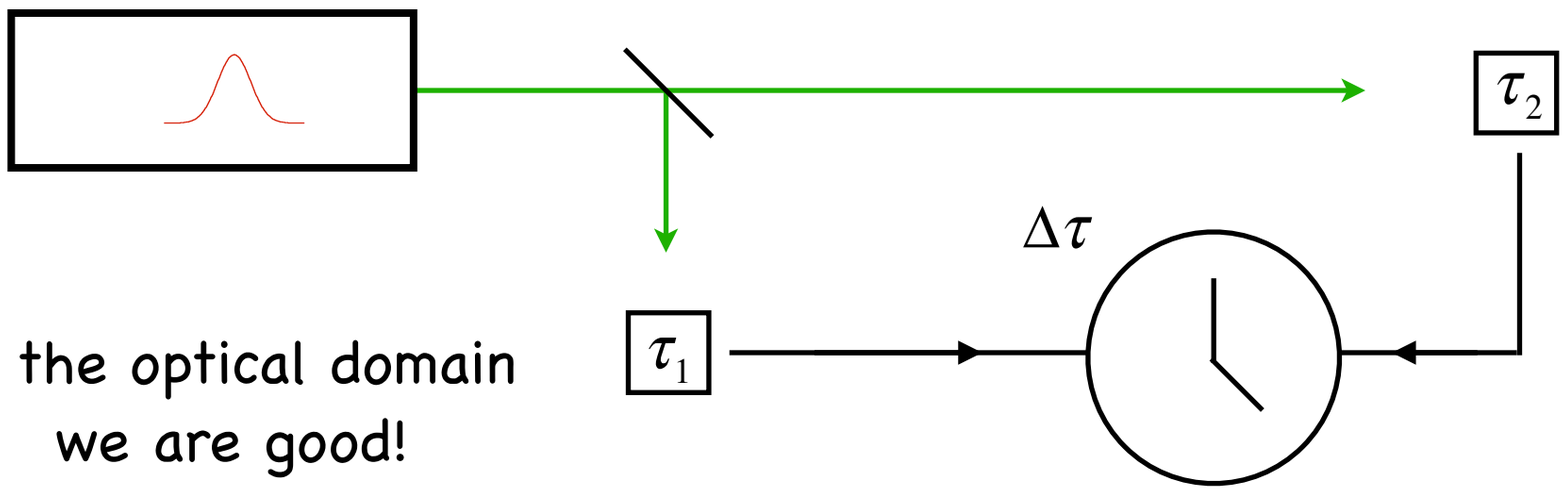
Connecting a "local clock" to the world - The ACES mission



Inter Continental Time Transfer via ACES

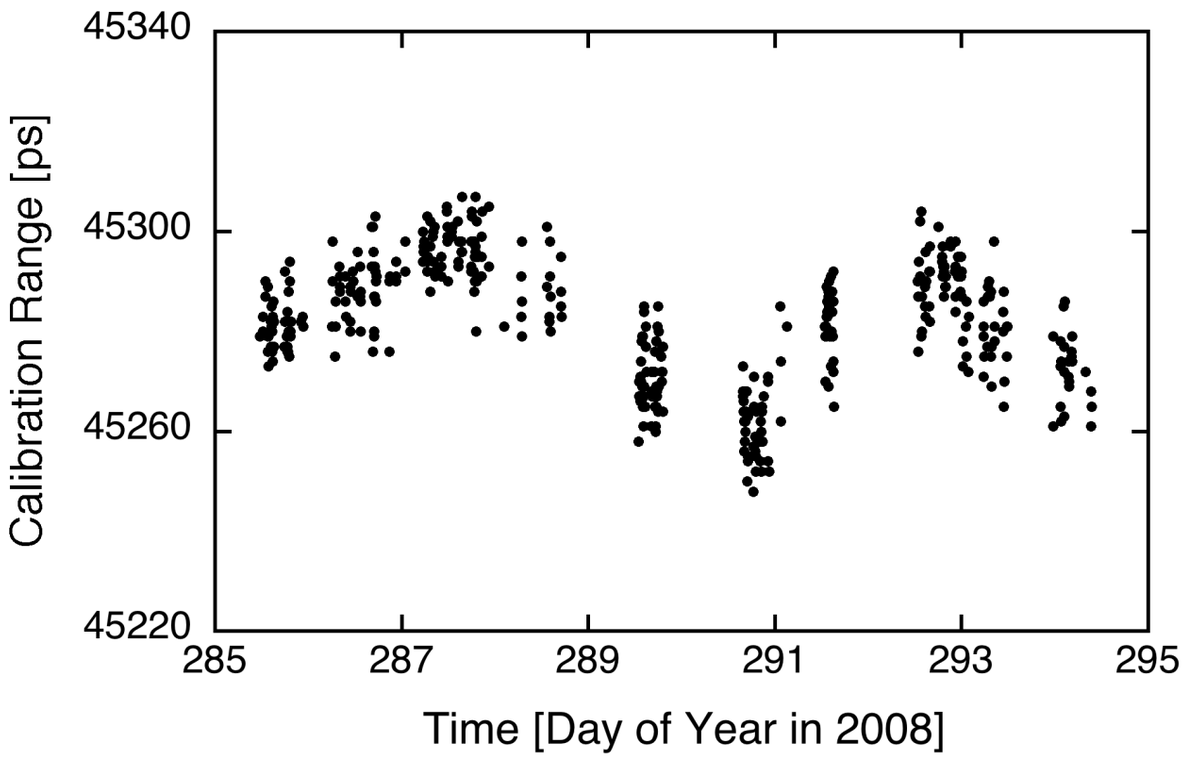


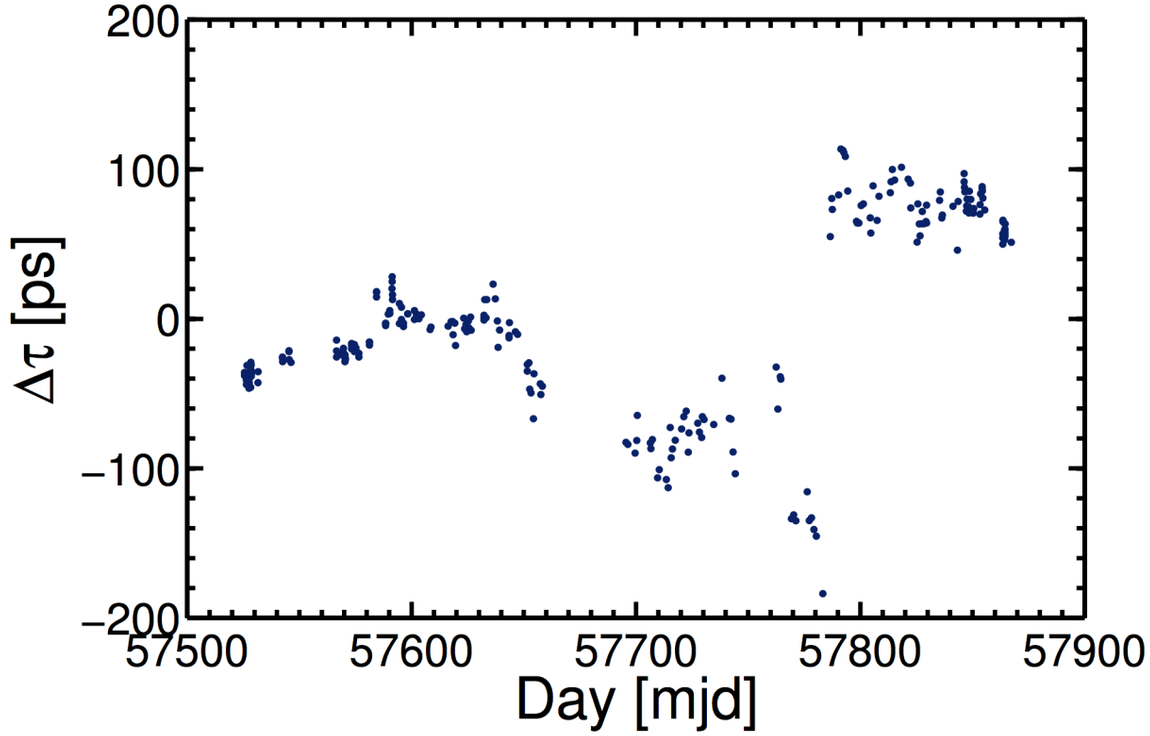
Observation: Variable delays due to electronics

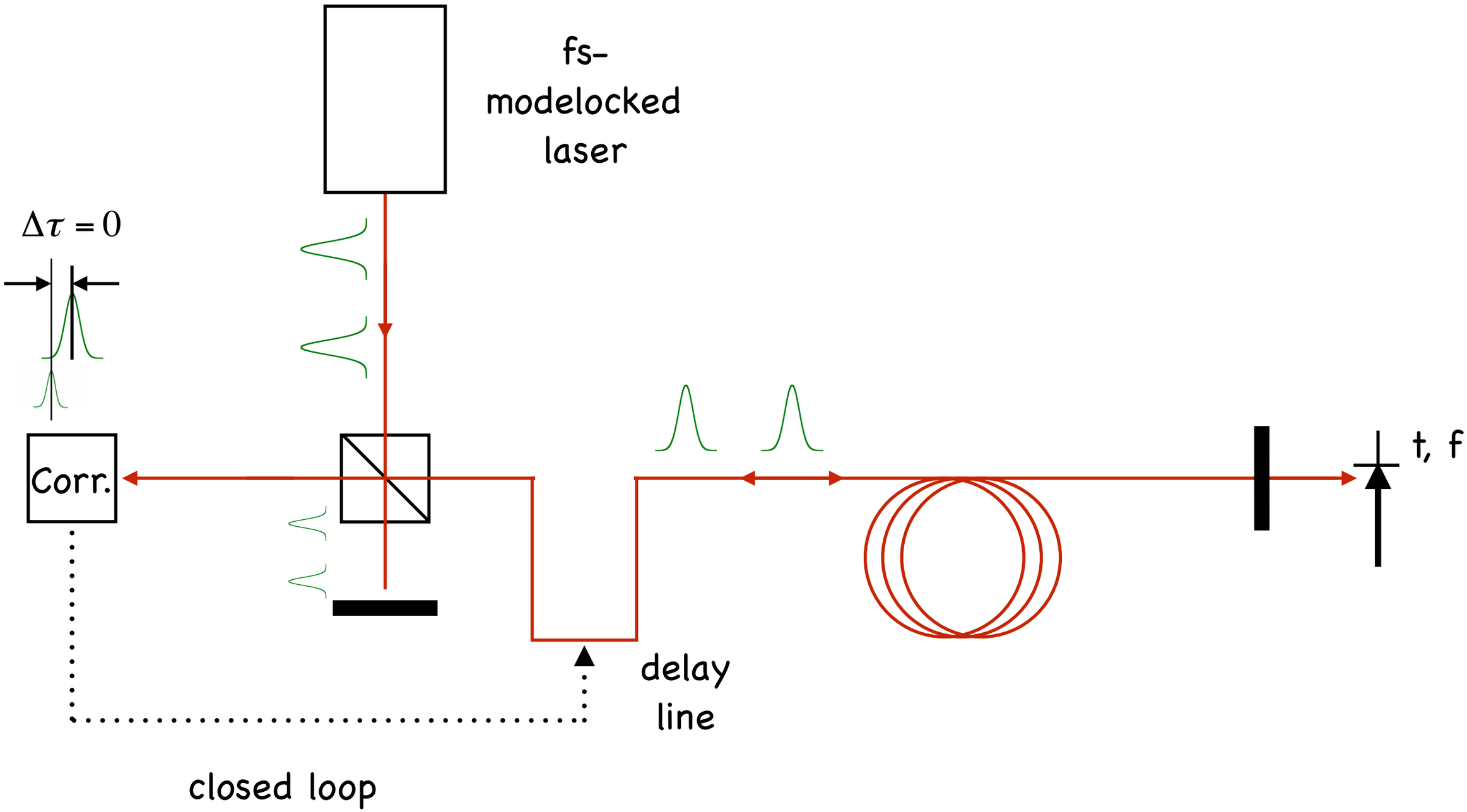


in the optical domain
we are good!

asymmetry of
clock channels







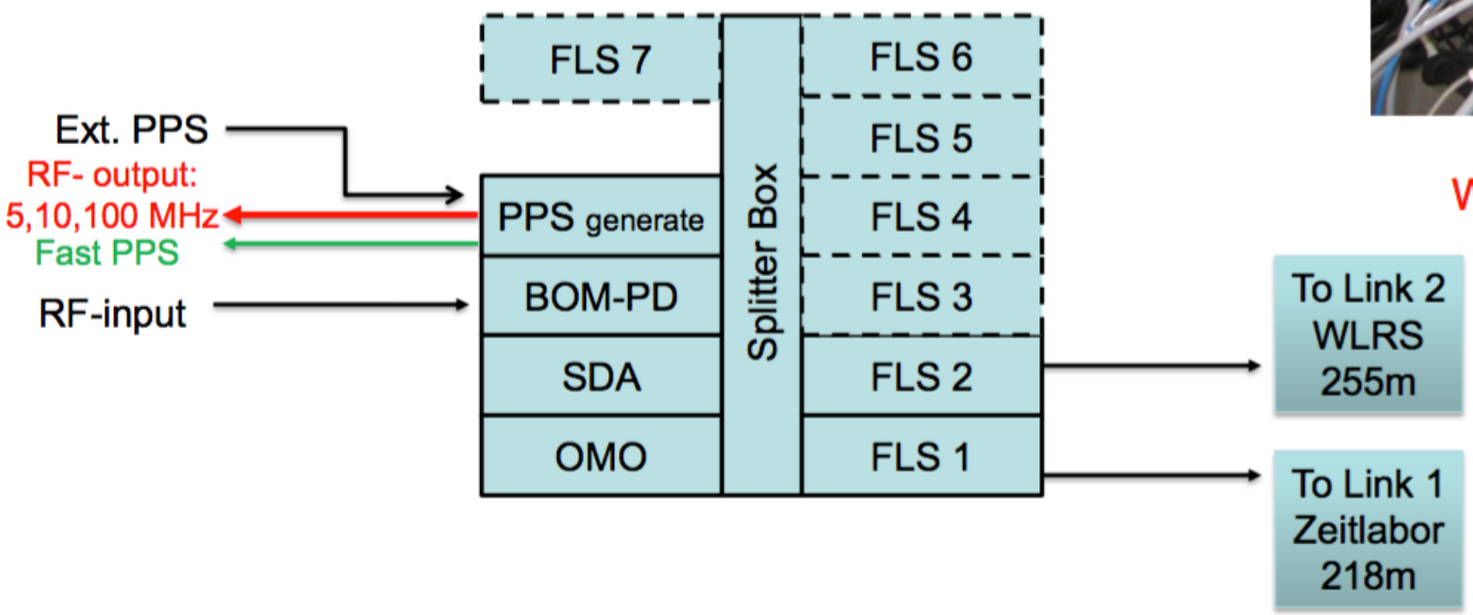
Schreiber et al.: Space Science Reviews, **214** (1), p. 1371, (2017)

Campus Distribution for accurate Time

Menlo Systems | Syncronization ASOPS Systems

Timing Distribution System (TDS): **Final setup**

Mechanical devices



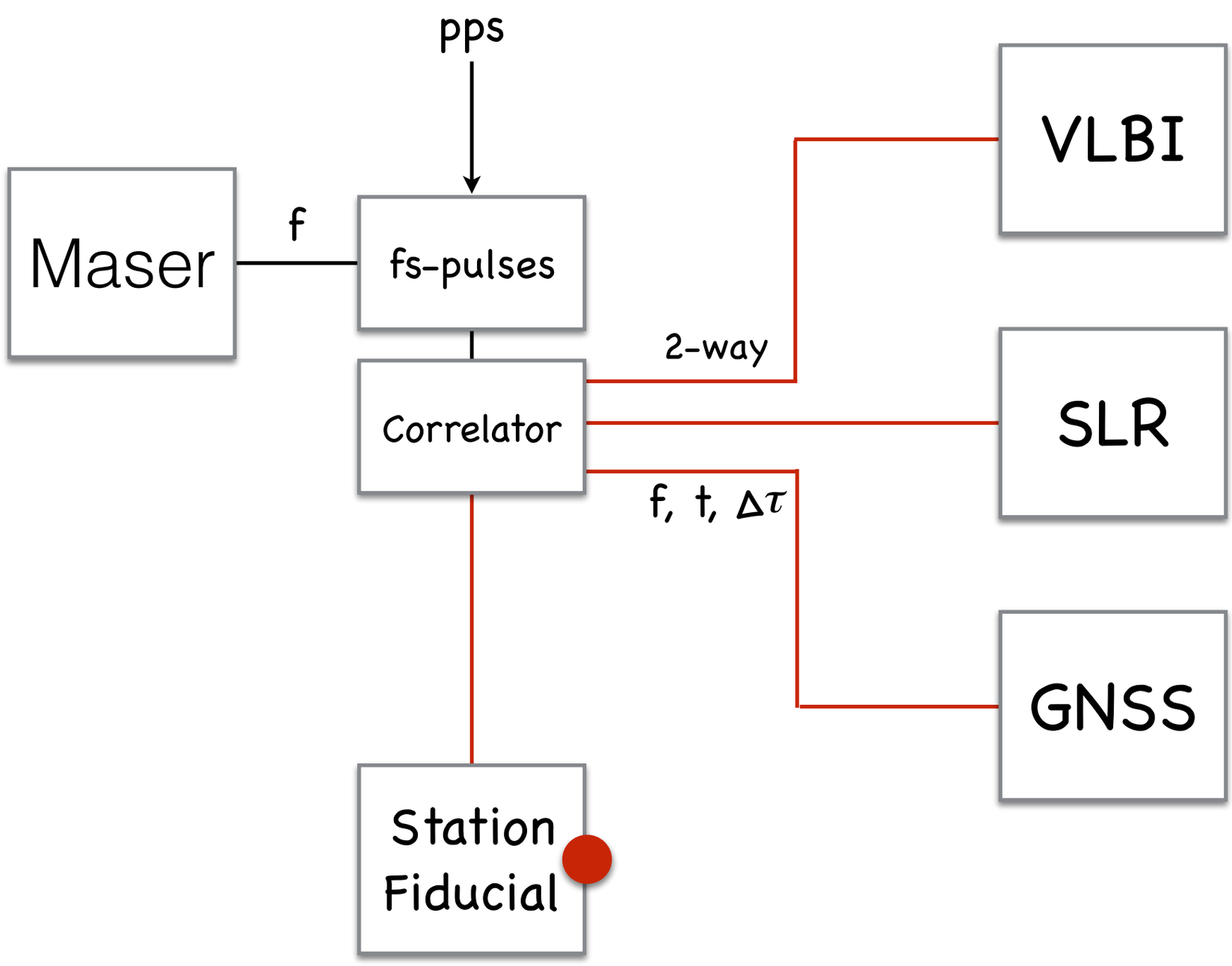
Timing Distribution System (TDS) (Wettzell)

Water cooled base plate

lossless distribution

Interpolator

Geodetic Techniques



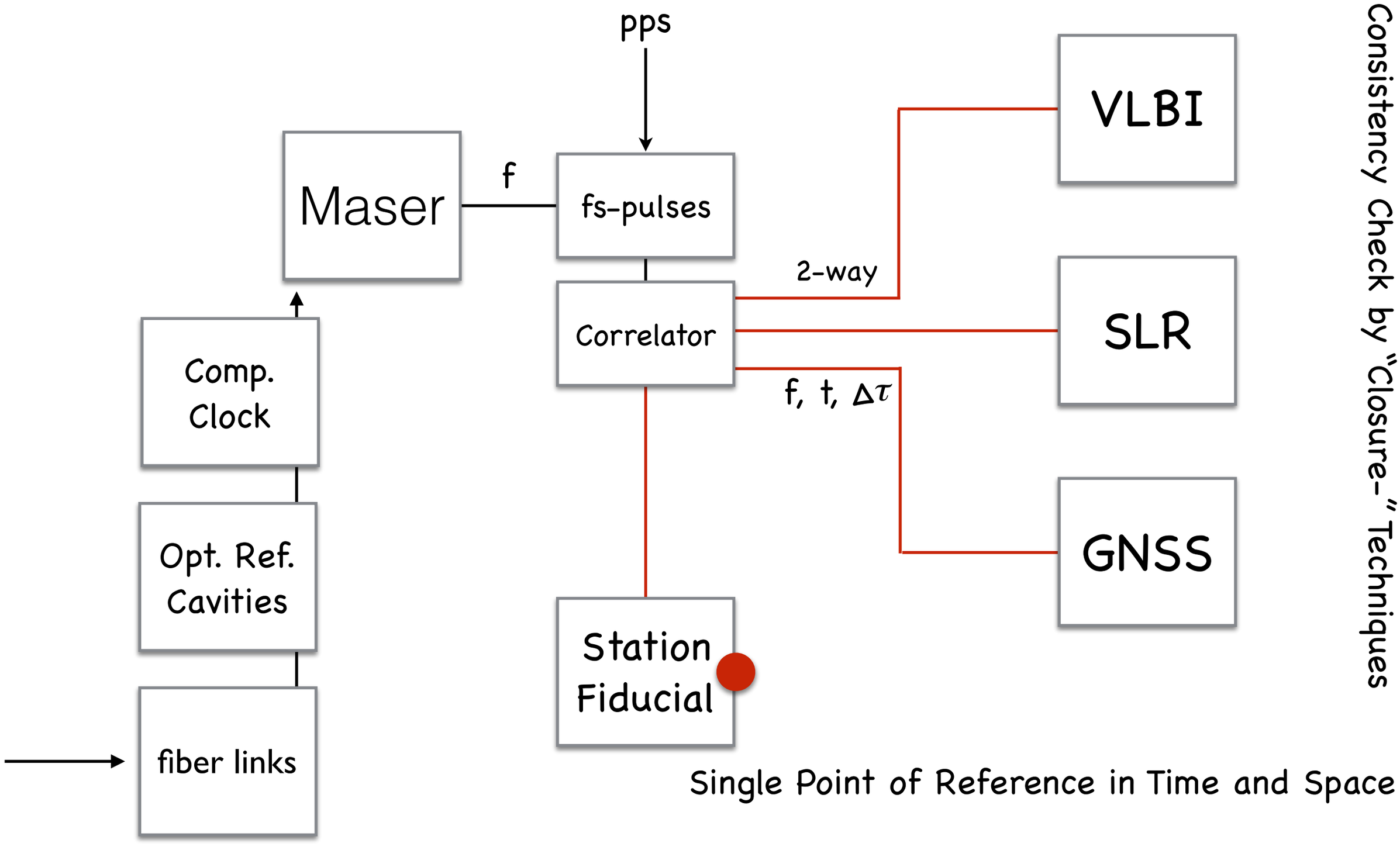
Consistency Check by "Closure-" Techniques

Single Point of Reference in Time and Space

lossless distribution

Interpolator

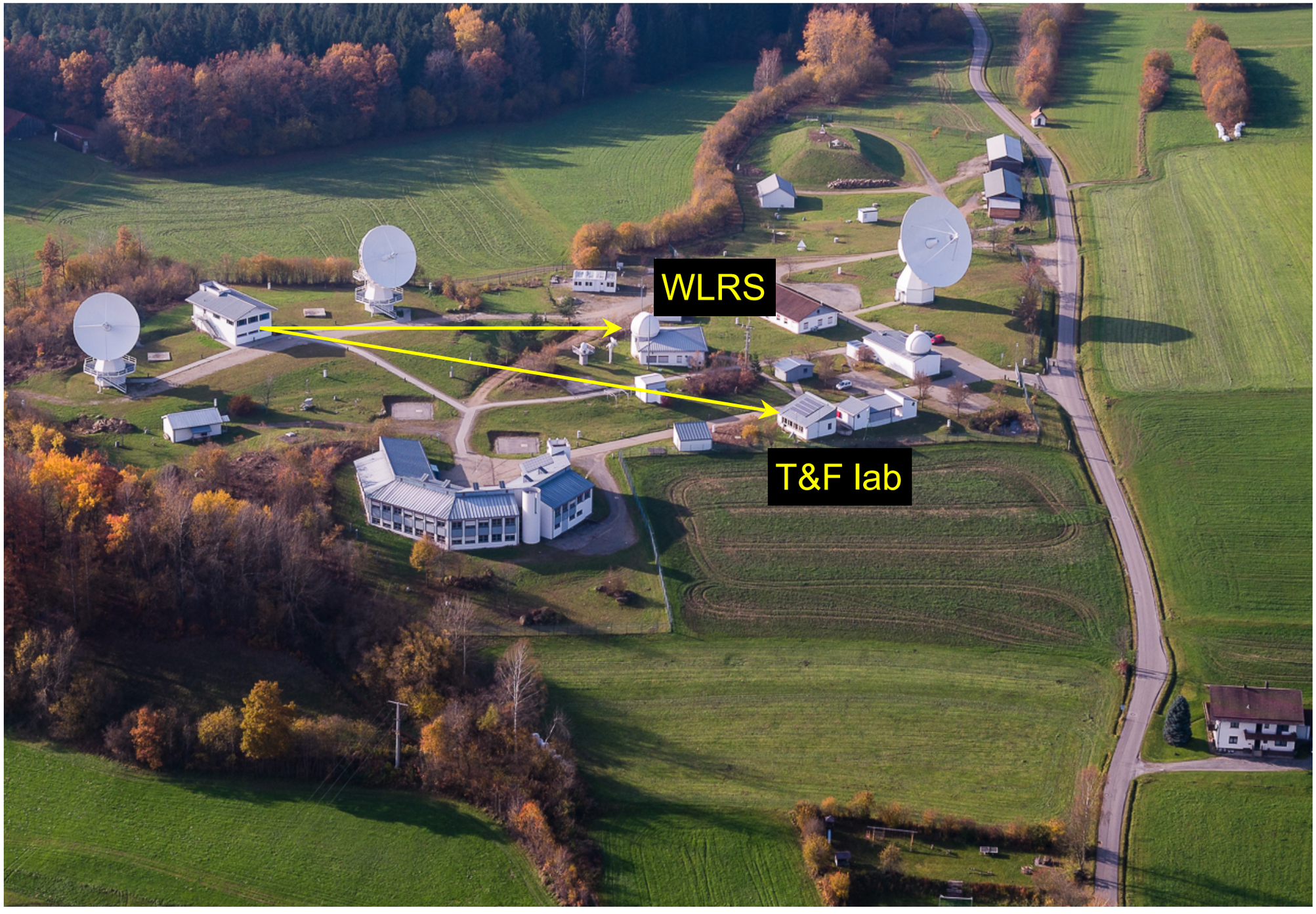
Geodetic Techniques



Consistency Check by "Closure-" Techniques

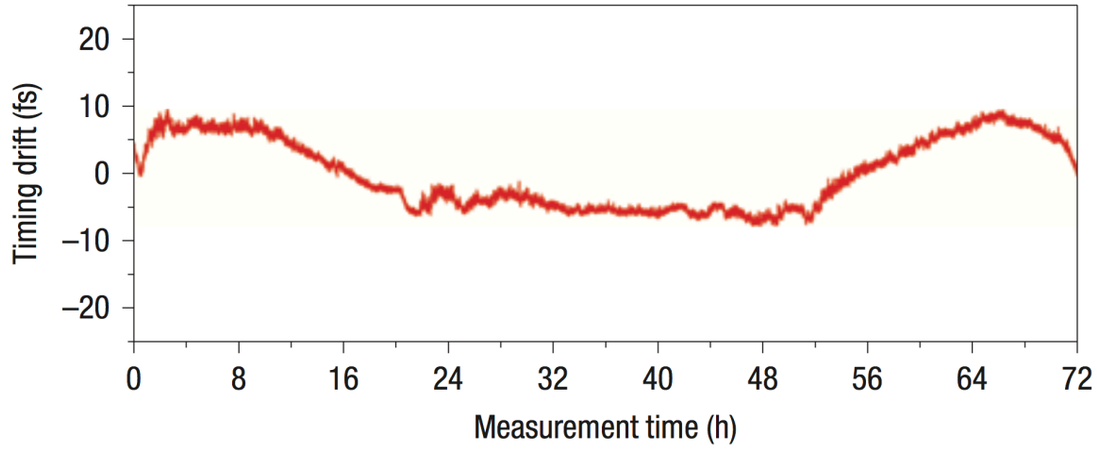
Single Point of Reference in Time and Space

Link Verification



Common Clock for Space Geodetic Techniques

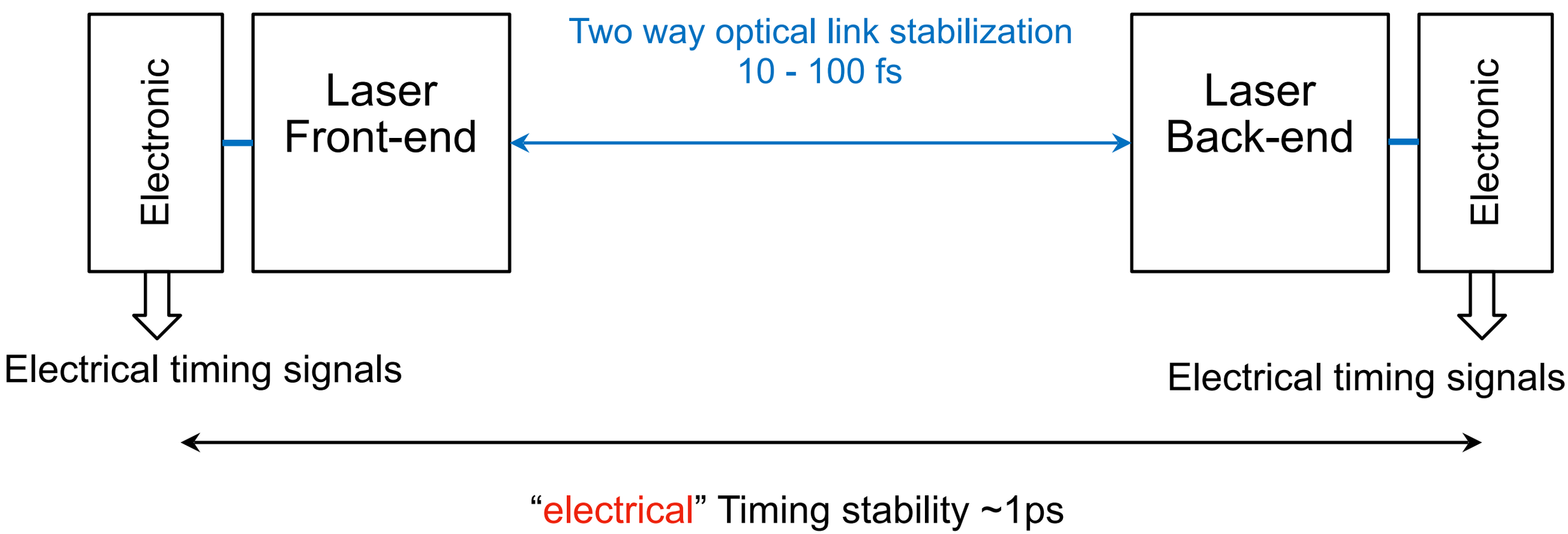
optical cross- correlation of
2 fiber lines (300 m)



6.4 fs r.m.s.

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

MenloSystems



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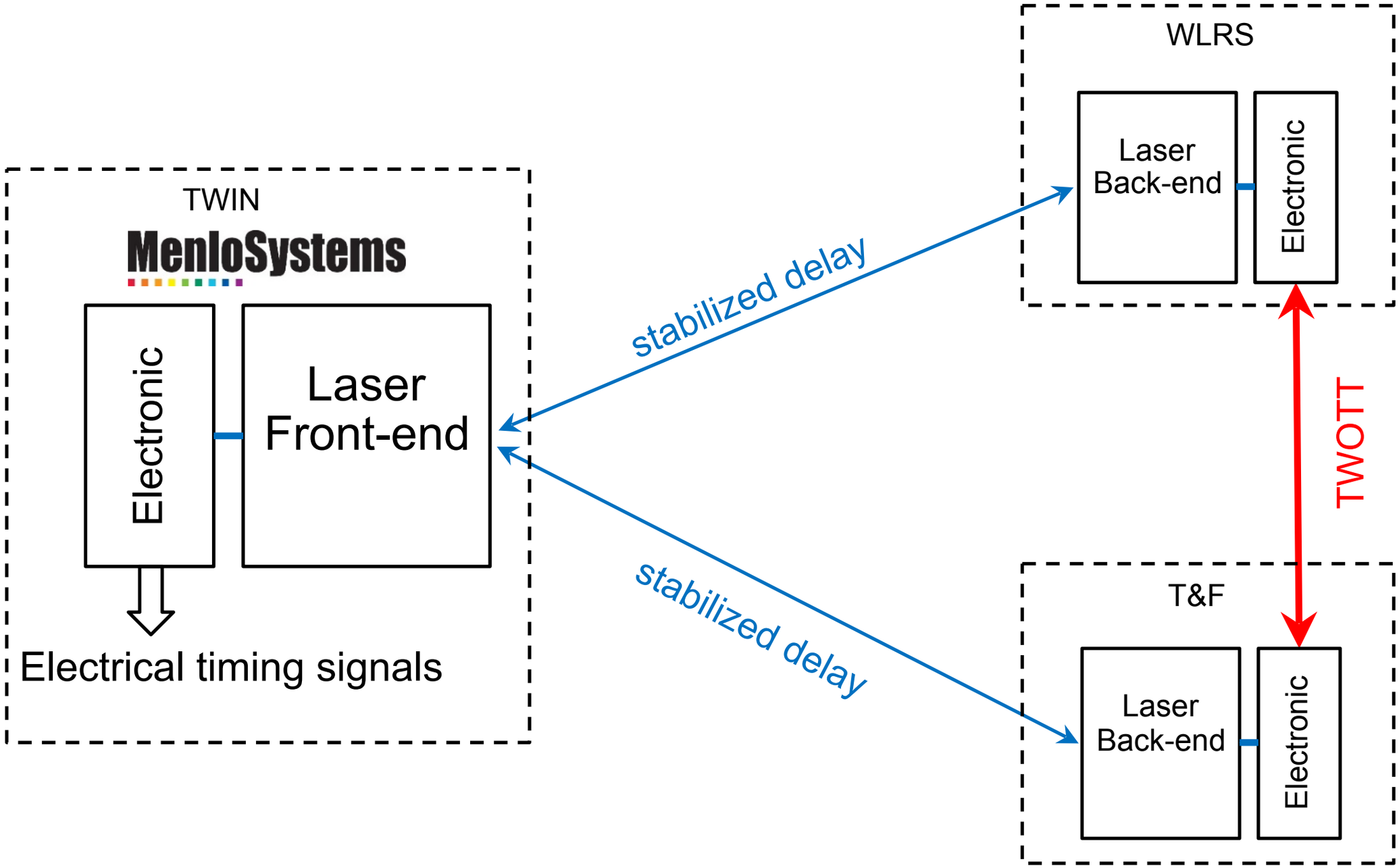
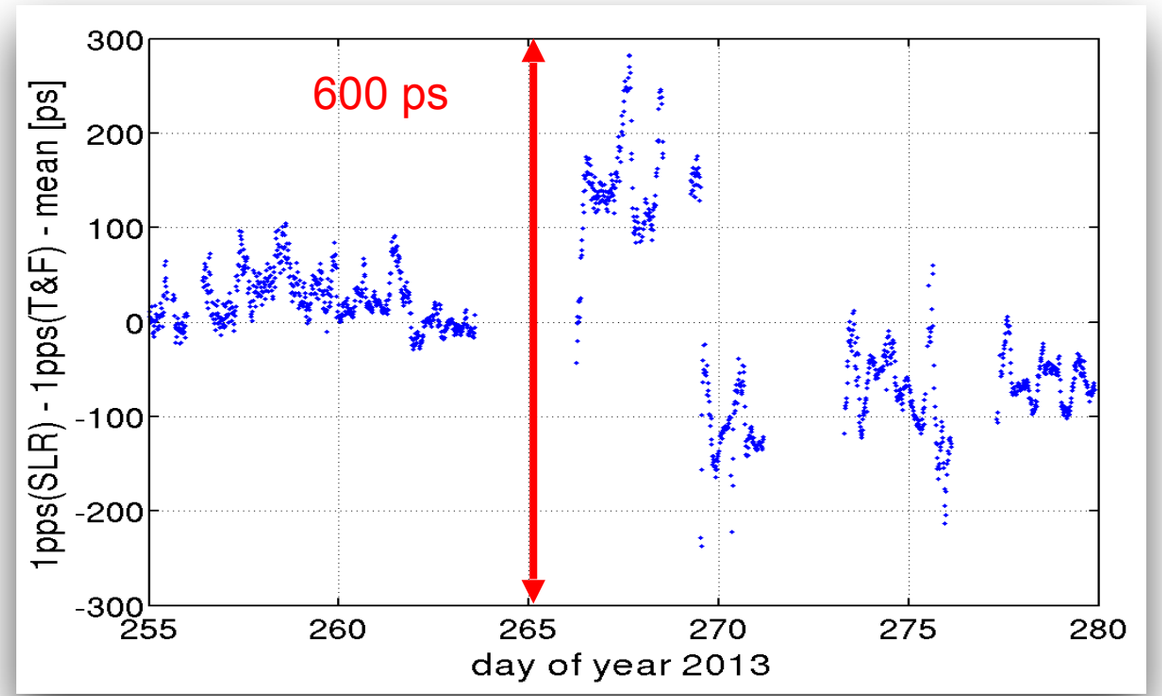
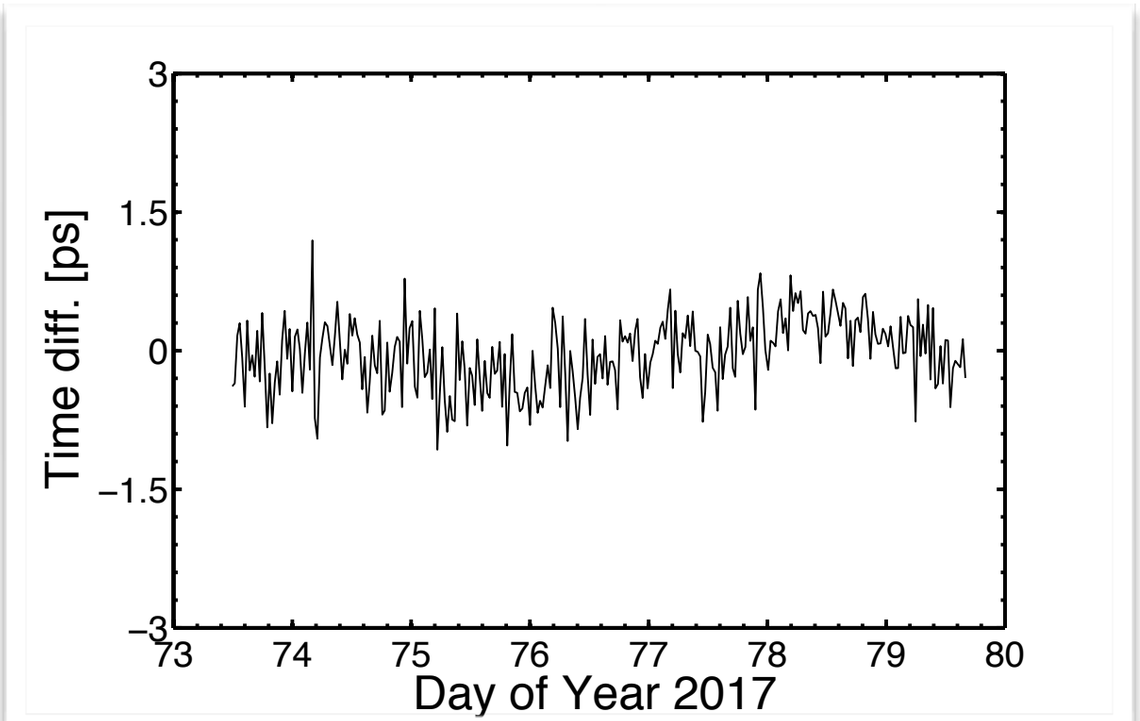


The distribution of the broadband PPS time signal over cable and electronic devices shows variability at the level of several hundred ps - and next to none over a compensated fiber link

cable based



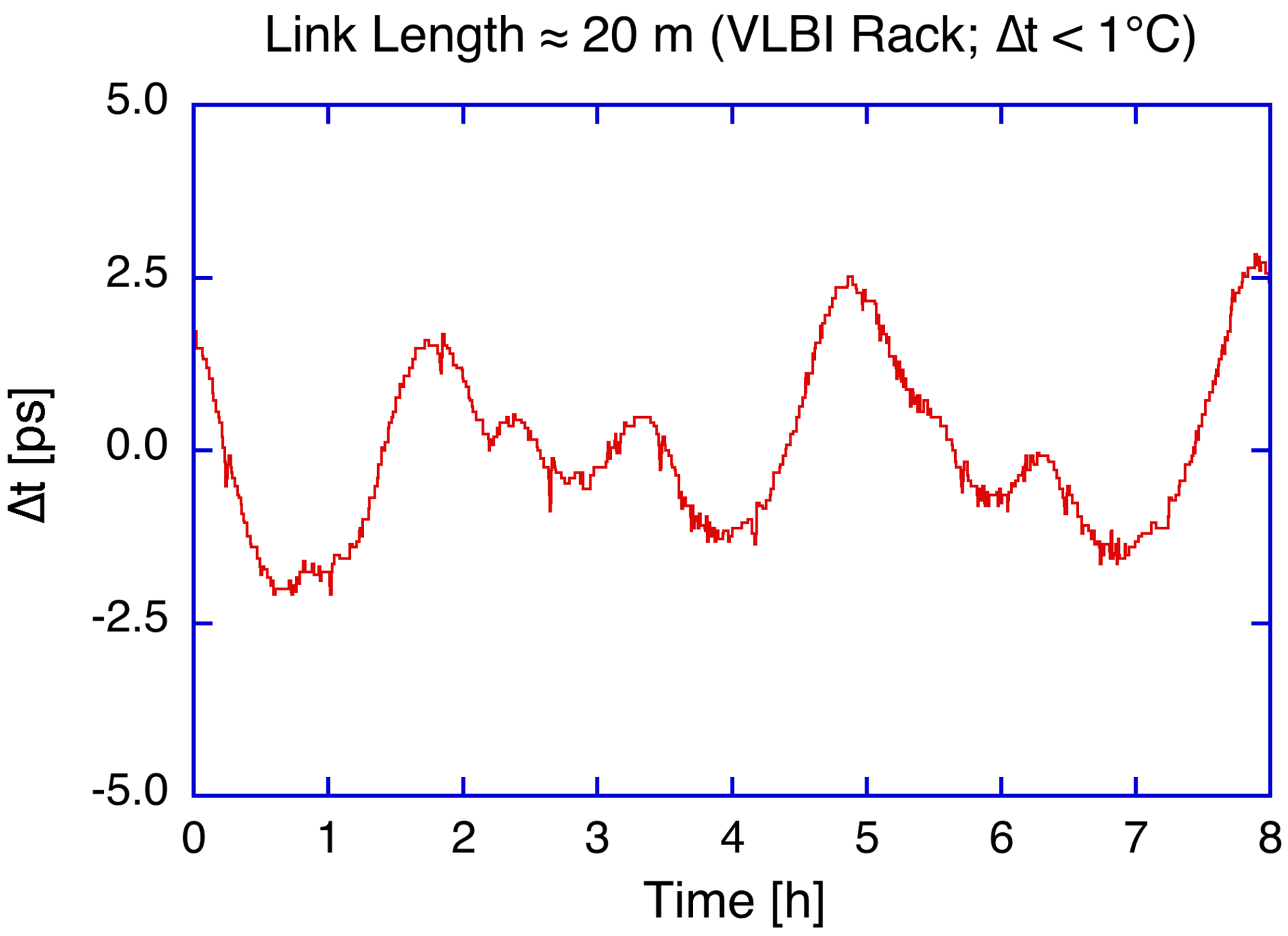
fiber based



… over a longer period: $\Delta t \leq 5$ ns

?

Error Signal for the closed loop fiber stretcher



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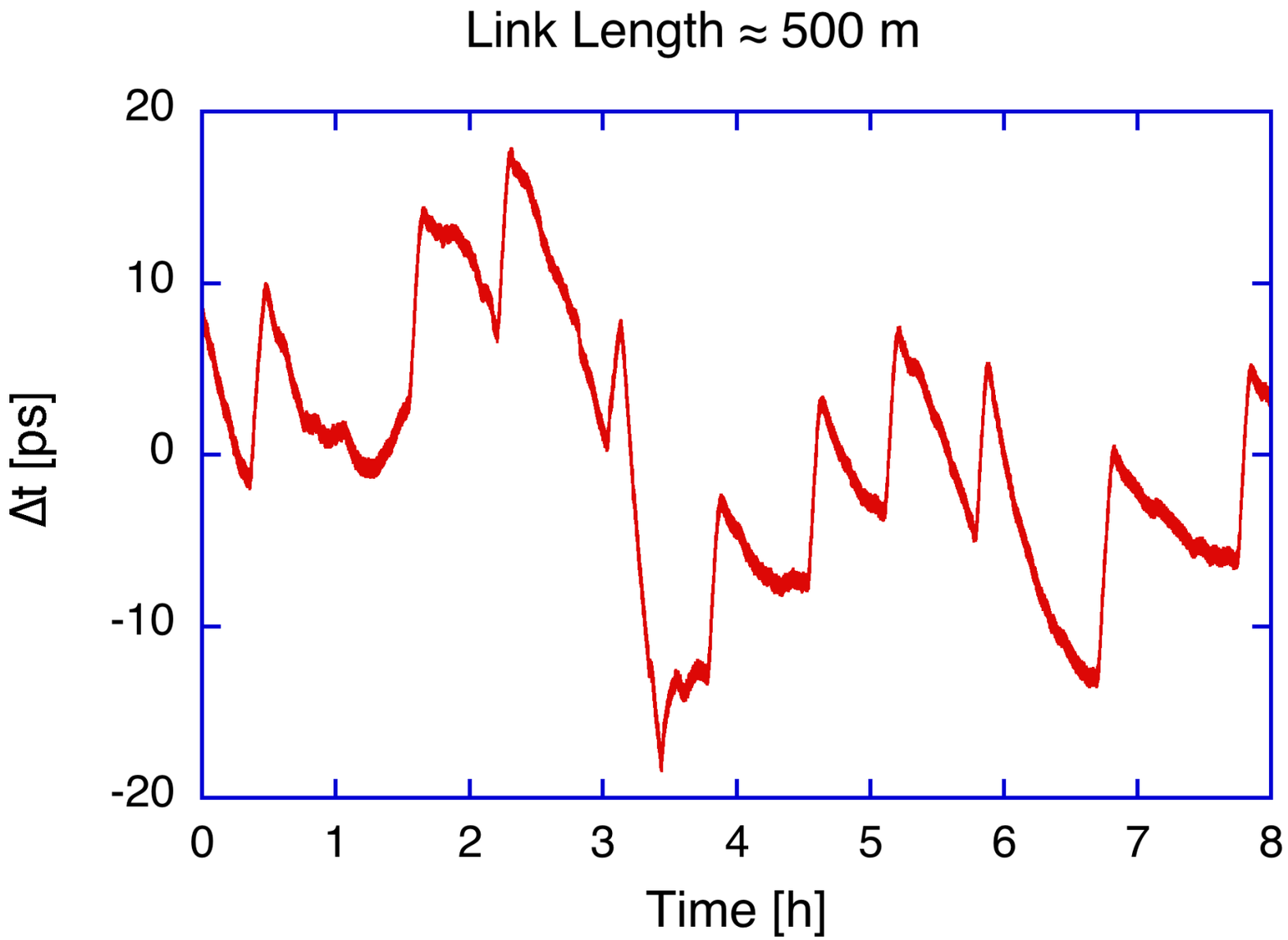

Most of the excursions appear to be caused by the air conditioning