Transponder Standing Committee

Stuttgart, Oct. 21, 2019

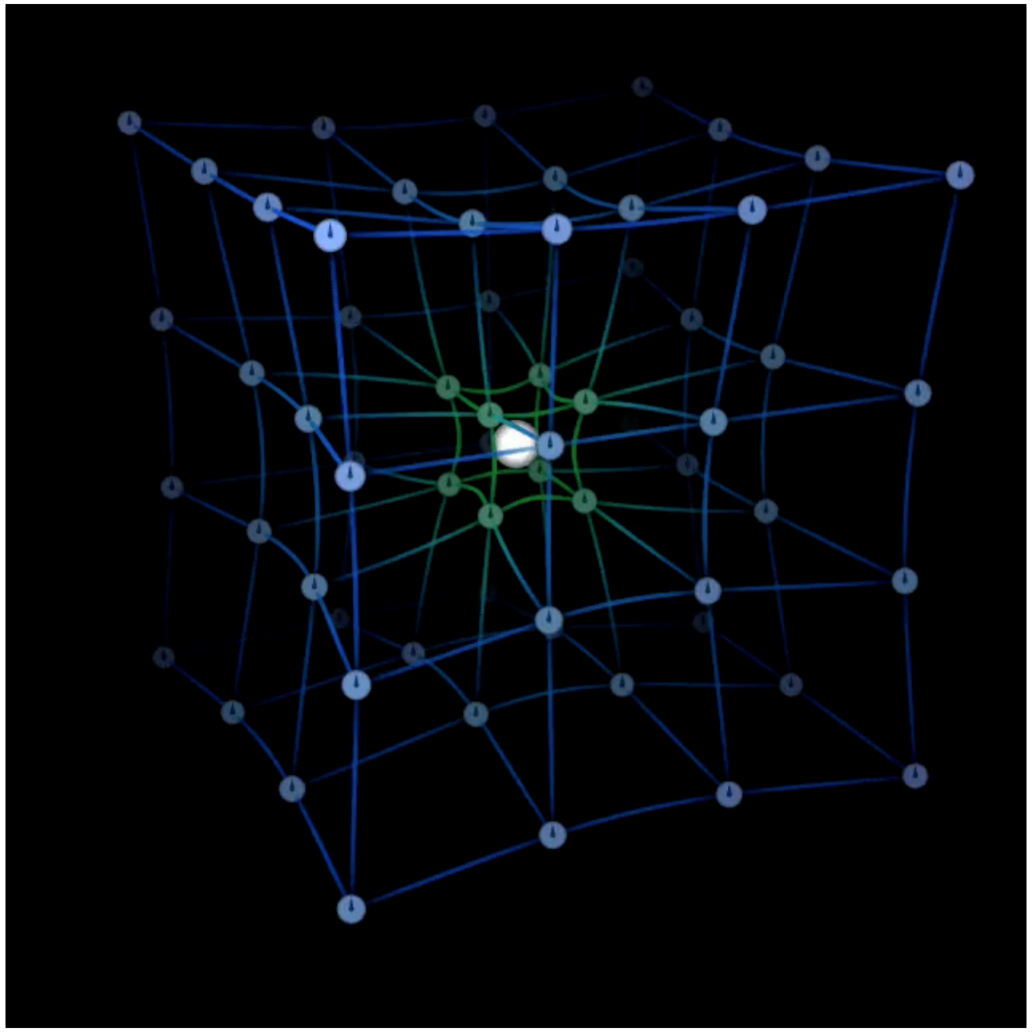
Agenda:

Where are we in terms of projects applications?

- cross-fertilization between Laser Comm. and ranging has not (yet) happened
- LRO (one-way ranging) finished
- T2L2 (time transfer) finished
- ACES (time transfer) upcoming (but very slow)
- New applications? (quantum cryptography…)

At this point in time we are only dealing with time transfer

Time, frequency and optical time transfer

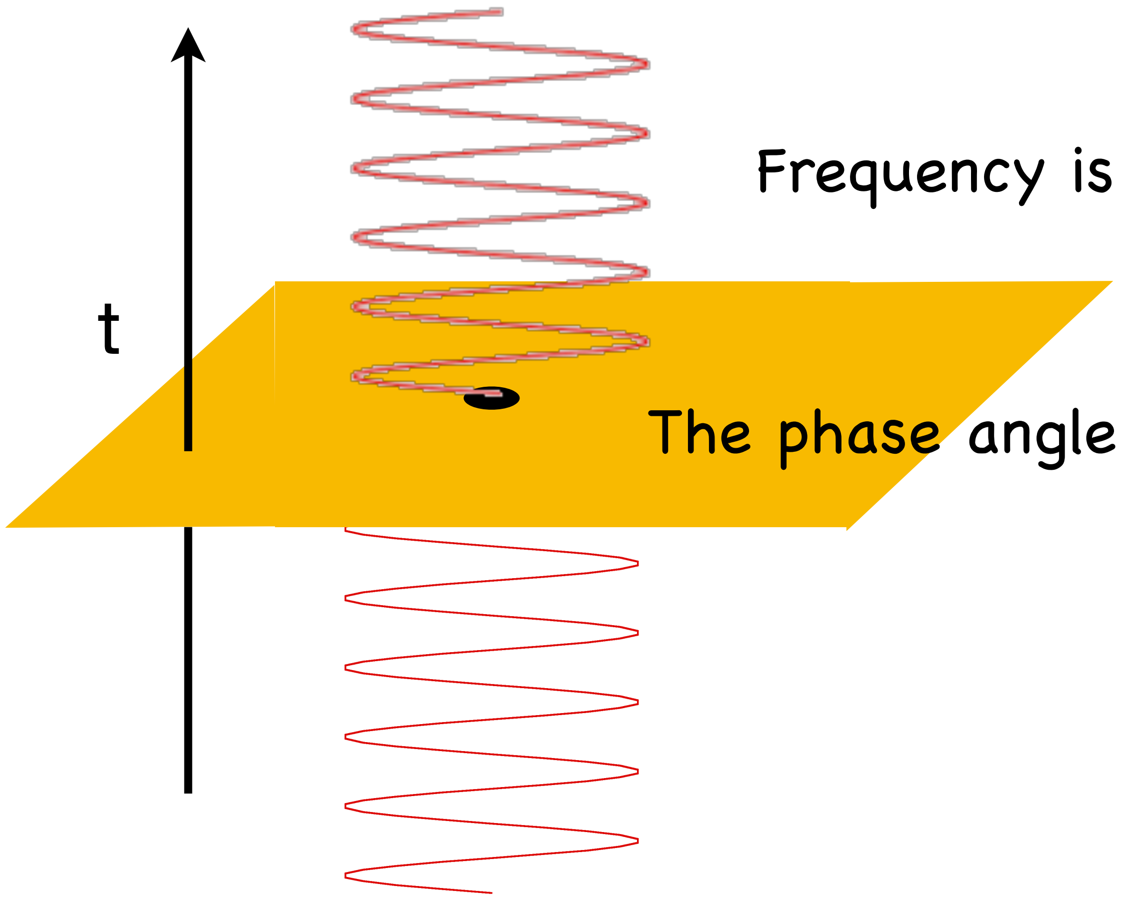


https://imgur.com/RaWqYkV

- 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 several weeks.

… this can be the beginning of a relativistic (space-time) geodesy

The instrumentation of an observatory is not in one spot

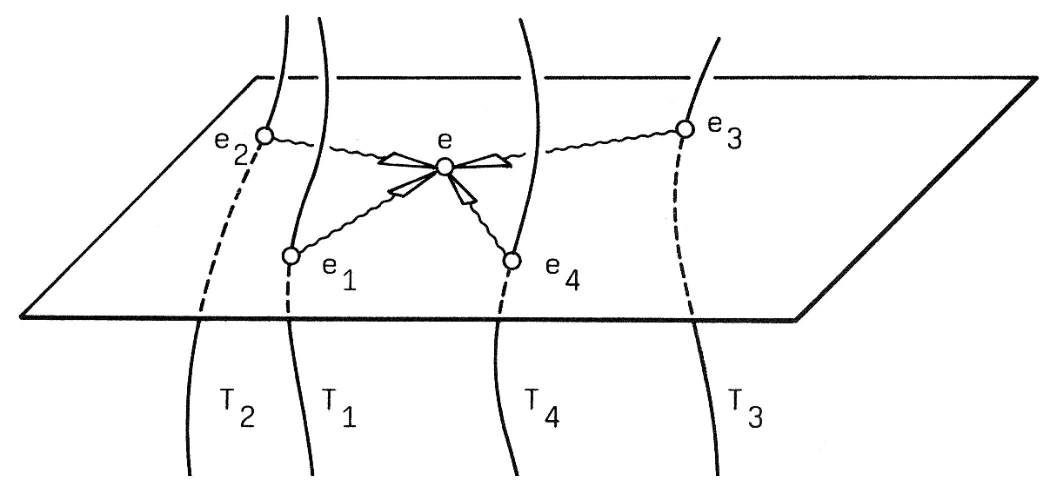


Frequency is used to provide a scale

The phase angle provides the time in one spot

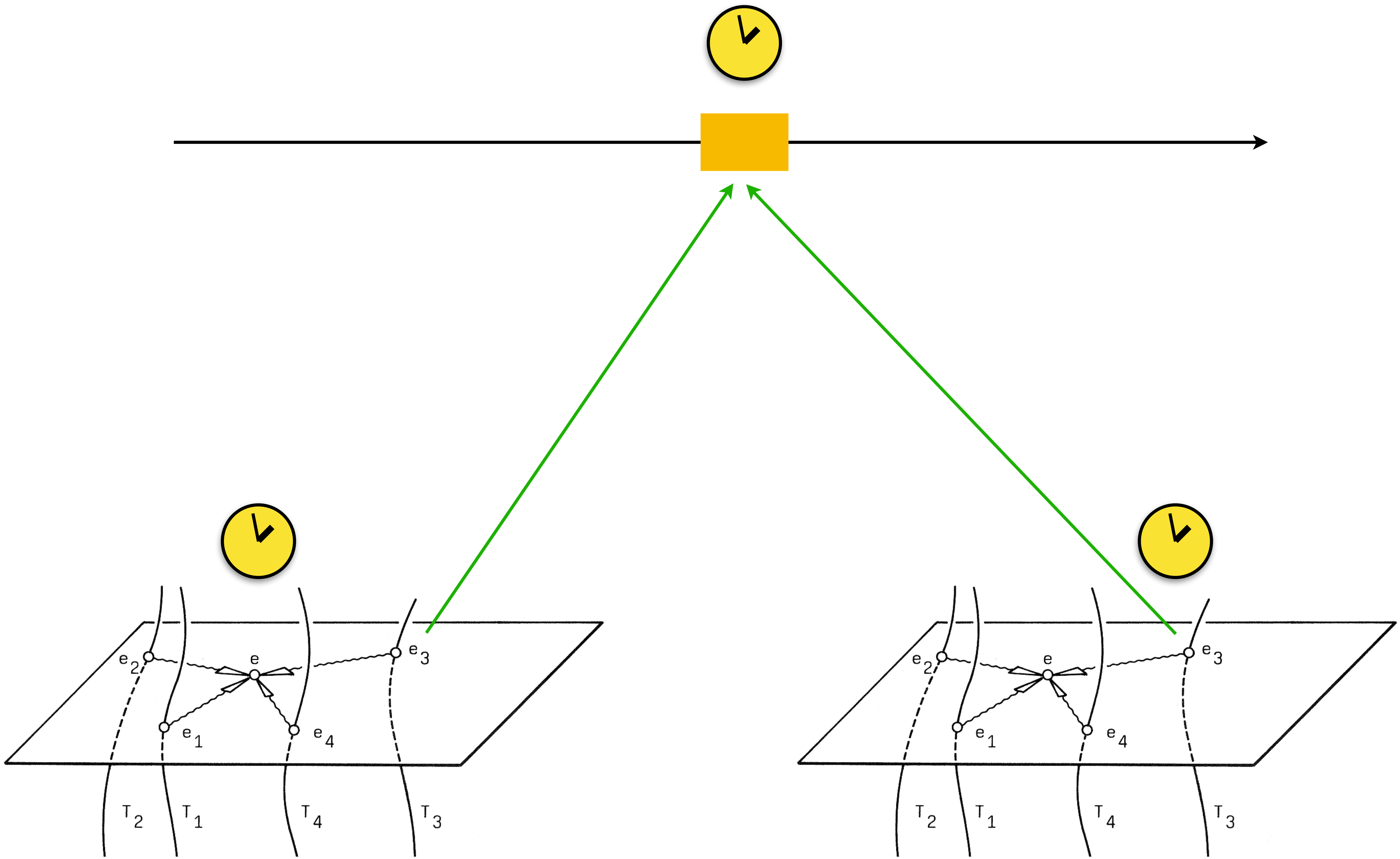
A common clock has the advantage that the instrumentation measures coherently
(no clock adjustments are required)

Closure measurements allow the determination of (variable) biases

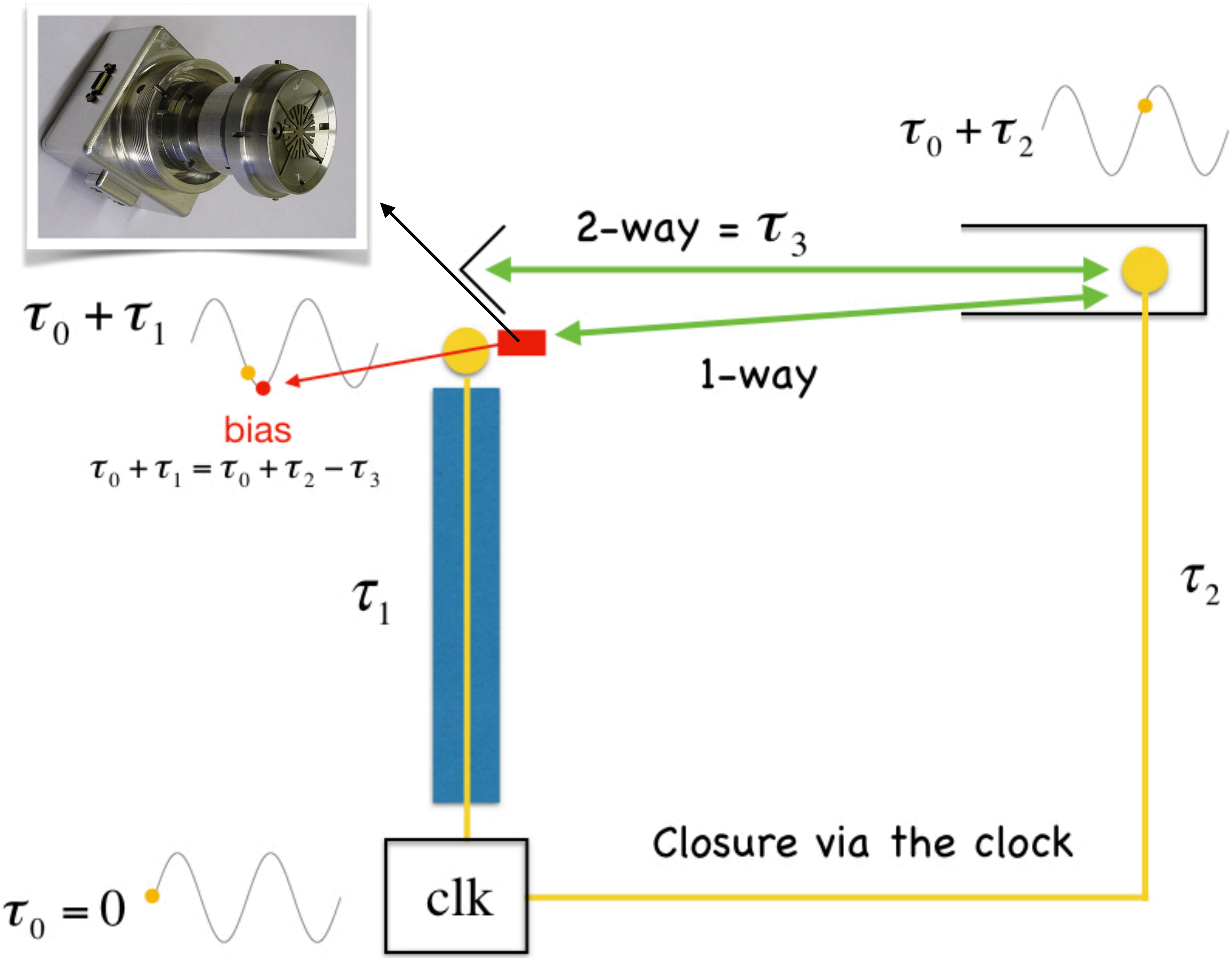


Coherence is given then the different delays e_i are always known to:

$$\tau_i(t) \le \frac{\partial e_i}{\partial t}$$



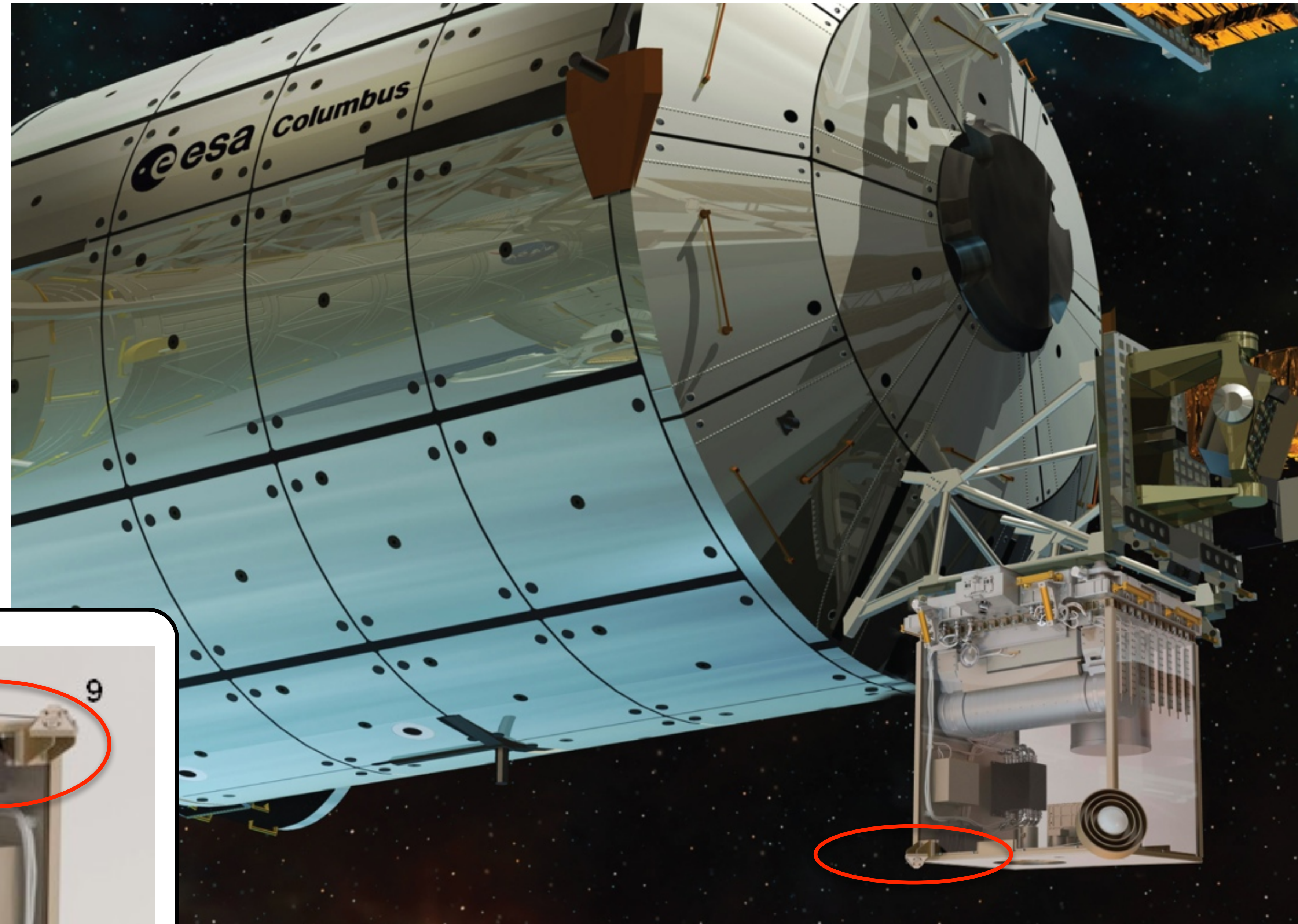
e_2
e
e_3
e_1
e_4
T_2
T_1
T_4
T_3
e_2
e
e_3
e_1
e_4
T_2
T_1
T_4
T_3

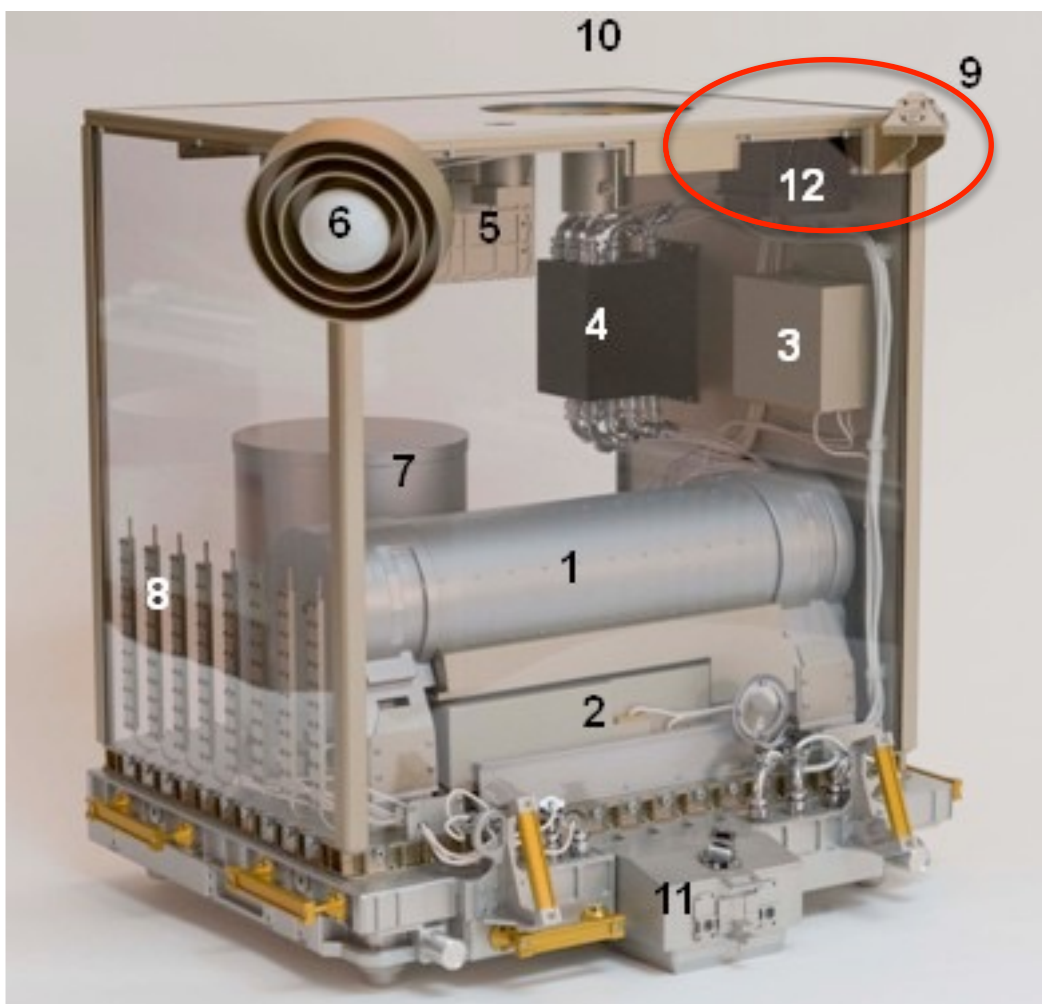


$\tau_0 + \tau_2$
2-way = τ_3
$\tau_0 + \tau_1$
1-way
bias
$\tau_0 + \tau_1 = \tau_0 + \tau_2 - \tau_3$
τ_1
τ_2
Closure via the clock
$\tau_0 = 0$
clk

ACES

2WSTFT und ELT laufen gemeinsam





1. PHARAO Cesium Tube
2. PHARAO Laser Source
3. PHARAO computer
4. XPLC
5. MWL
6. GNSS Antenna
7. Space hydrogen Maser
8. Heat pipes
9. Laser corner cube reflector
10. MWL antennae
11. CEPA
12. ELT

The payload has a volume of about $1 m^3$ and a mass of ~362 kg.

ELT Laser Energy and average Power Assessment

FILL OUT THE GREY FIELDS TO CHECK, IF YOUR LASER IS SUITABLE FOR ELT

Laser System			
Name	TBD		
Description	YAG		
Z136 Standard	Z136.1-2014		
Analysis Type	Single Wavelenth		
Laser			
Wavelength	1064 nm		
Pulse Mode	MultiPulse		
Pulse Width	12 ps		
Pulse Repetition Rate	100 Hz		
		average Power	**Energy**
Energy per pulse	mJ		1,00E+00
Average Power	mW	1,00E+02	
Divergence	**half-angle in µrad**	100	100
Divergence	half-angle in rad	0,0001	0,0001
Distance Laser - Observer	km	400	400
MPE limit to be used (12 ps to 13 µs pulse)			2,00E-06
MPE limit to be used (>10 sec)	W/cm^2	5,06E-03	
atmospheric attenuation (Transmission 60 to 80%)	per ANSI-Z136.6 C4.1.3. Upward directed Beam	0,8	0,8
Radiant exposure at ISS distance **(crew unaided eye)**	energy (in J) * transmission / ((tan half-angle * distance (in cm))^2 * pi) [J/cm²]		**1,59155E-11**
Radiant exposure at ISS distance **(crew unaided eye)**	power (in W) * transmission / ((tan half-angle * distance (in cm))^2 * pi) [W/cm²]	**1,59155E-09**	
Required ELT detector energy level @ ISS	[J/cm²]	**N.A.**	**2,30E-13**
Impact of crew using Telescope			
Objective Diameter	mm	400	400
Objective Entry Surface	cm²	1256,637061	1256,637061

Transponder SC - Local Time Distribution

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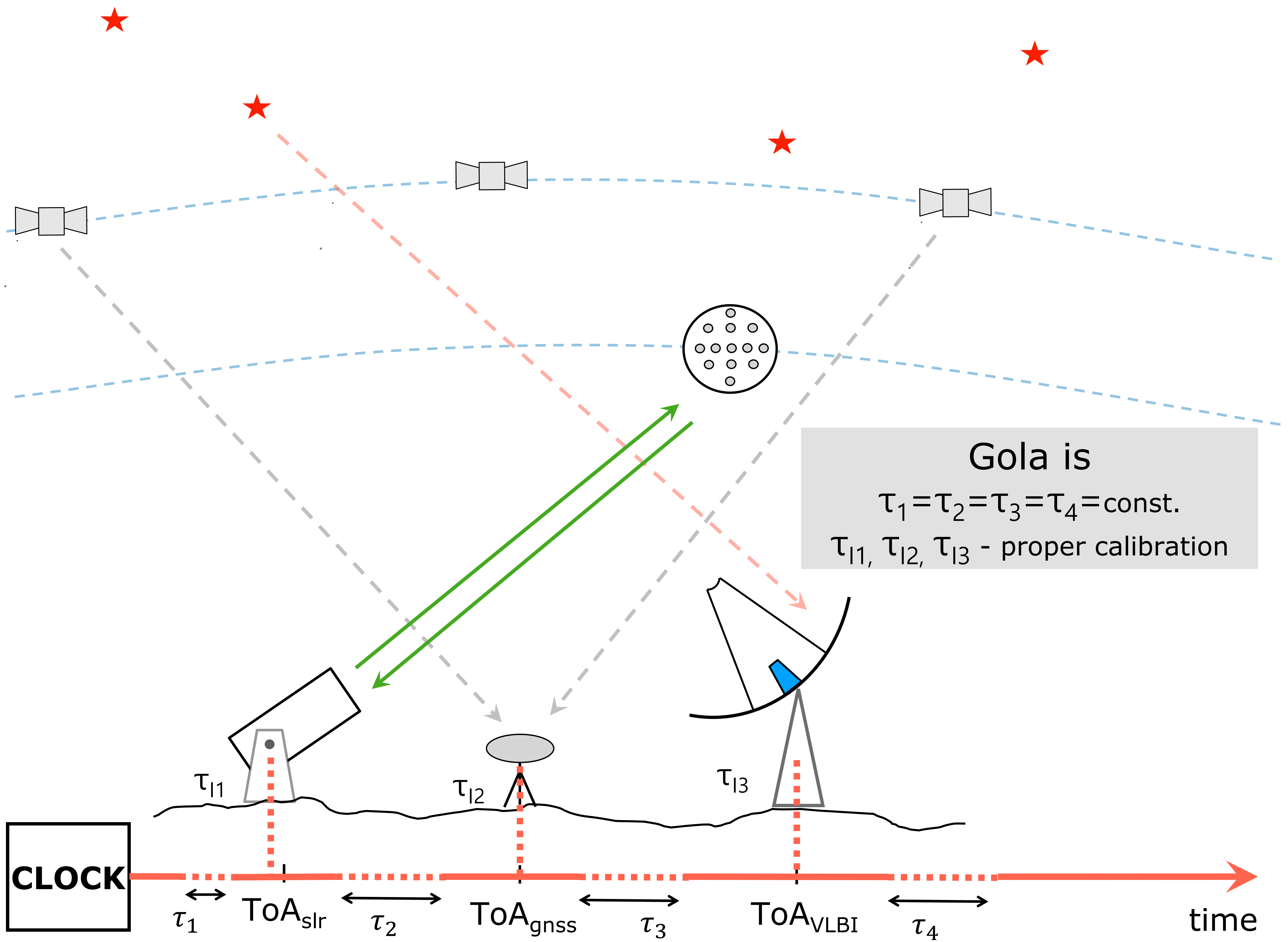
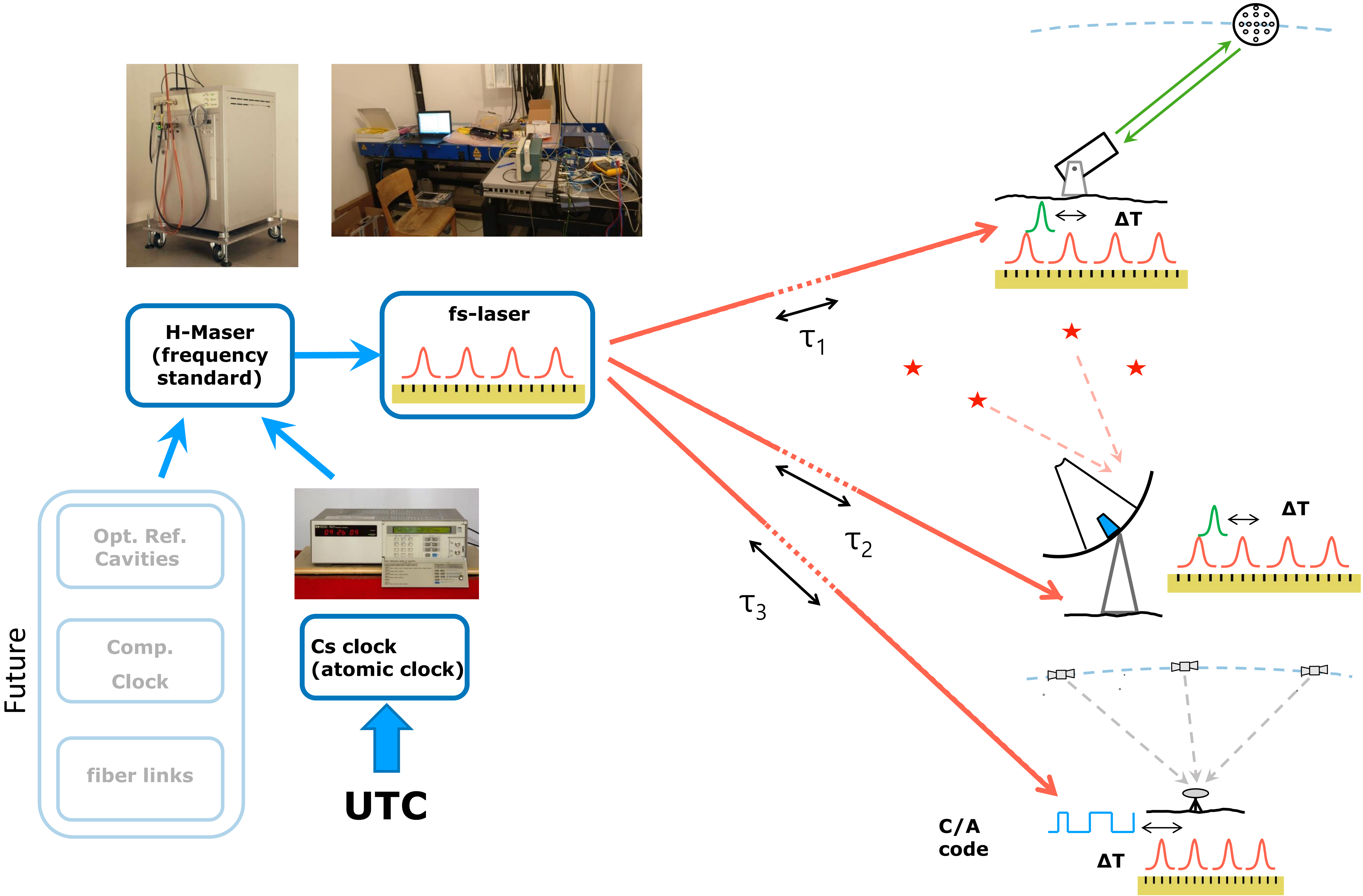
TECHNISCHE UNIVERSITÄT MÜNCHEN

Federal Agency for Cartography and Geodesy



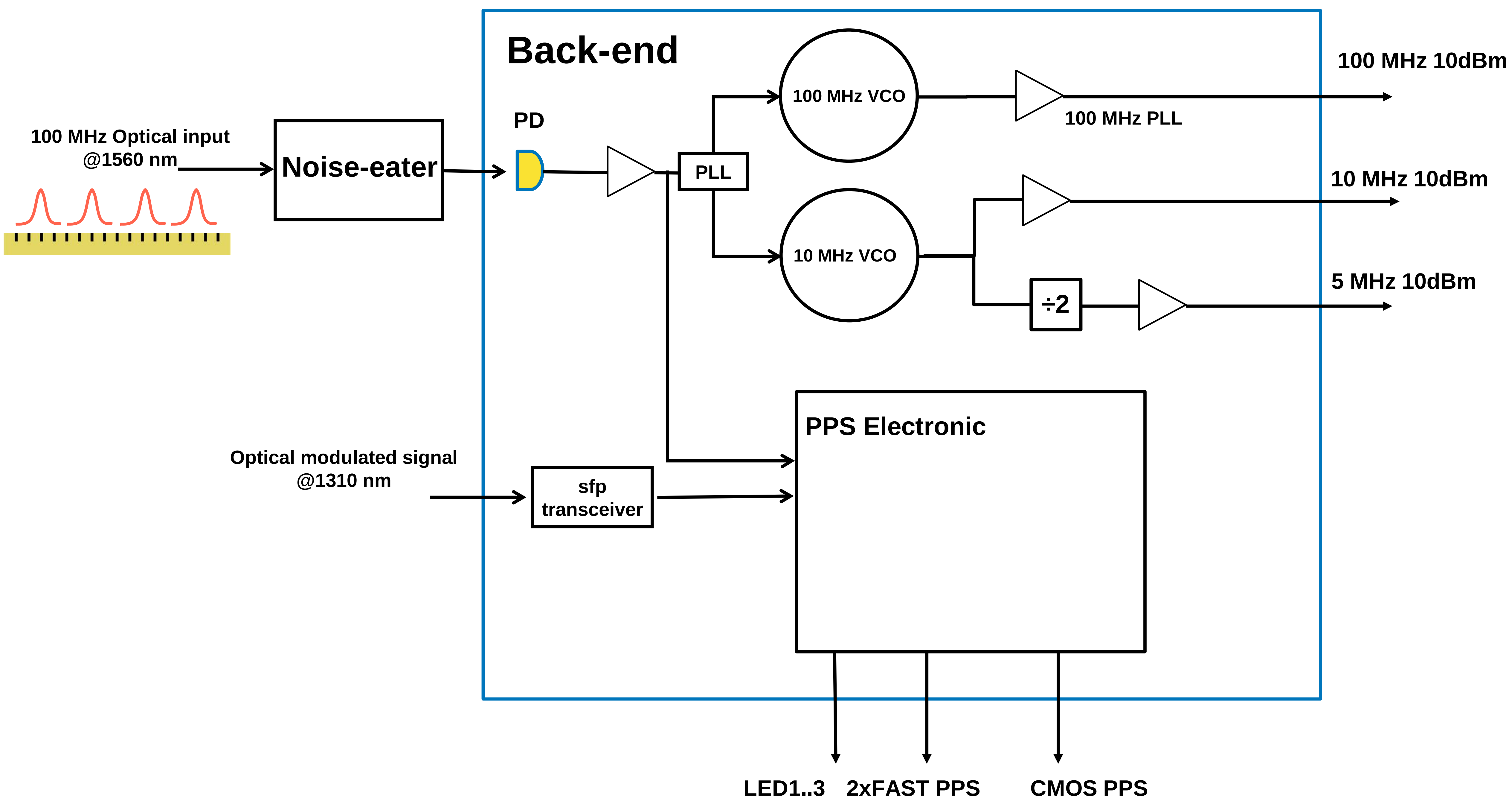
Gola is
τ1=τ2=τ3=τ4=const.
τl1, τl2, τl3 - proper calibration
τl1
τl2
τl3
CLOCK
τ1
ToAslr
τ2
ToAgnss
τ3
ToAVLBI
τ4
time

Optical Time Distribution system at Geodetische Observatorium Wettzell



Geodetic Observatory Wettzell

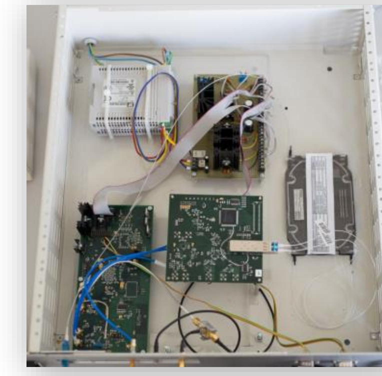
Back-end diagram



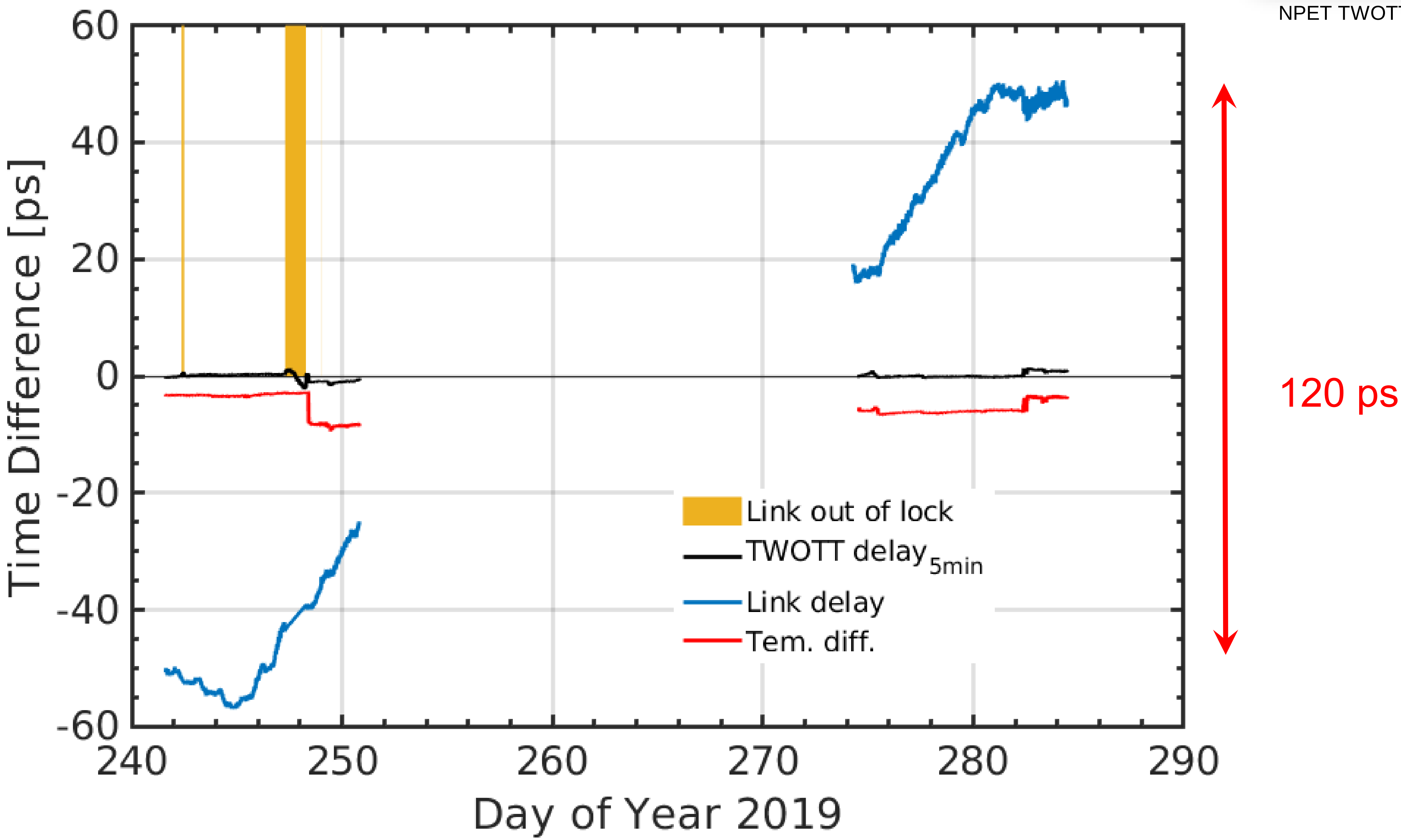
- FAST PPS1 - CML logic terminated by 50 Ohm
- FAST PPS2 - AC coupled PECL logic.
- 1 channel CMOS PPS terminated by 50 Ohm.

Error signal and time distribution of stationary link

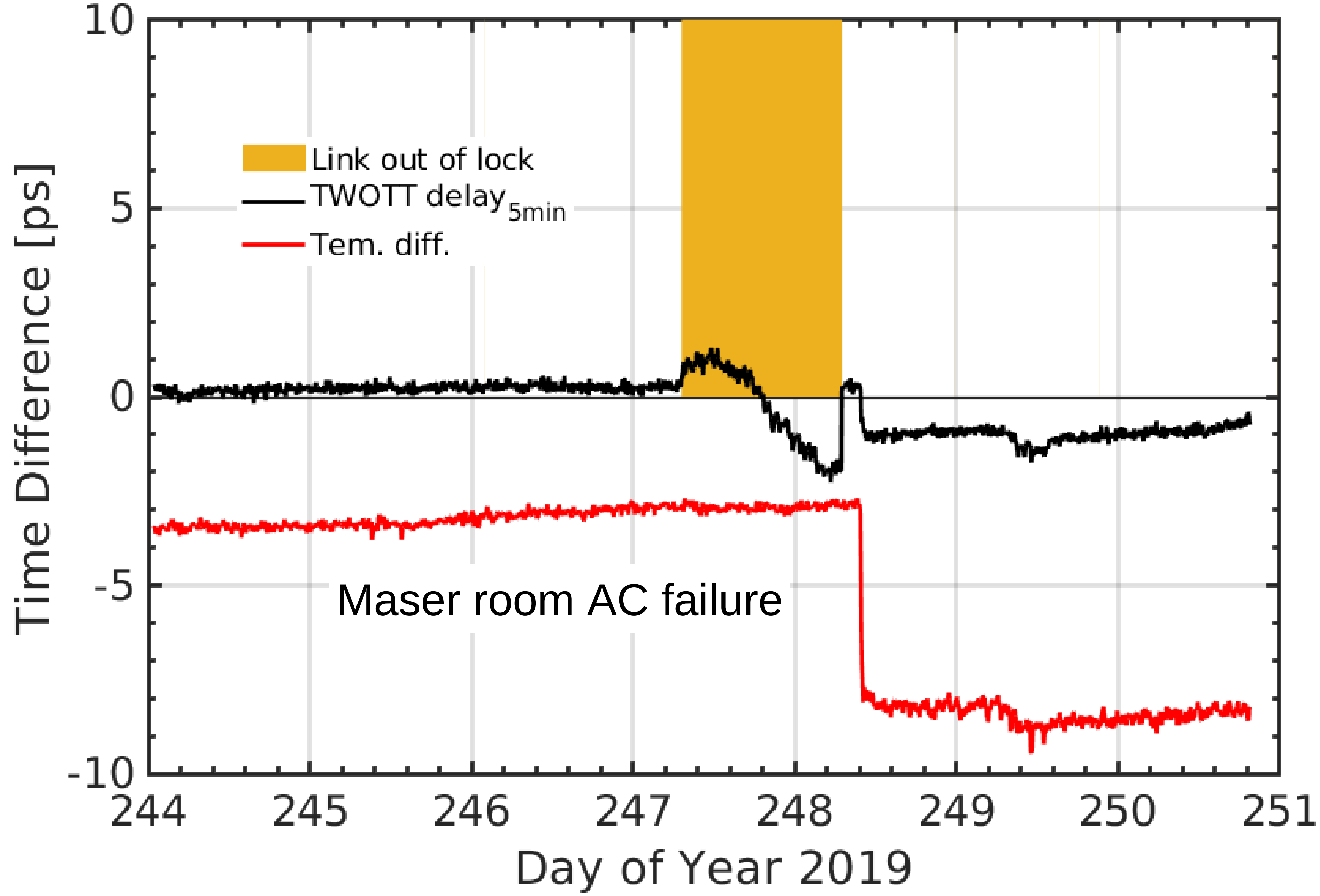
To validate new timing system in terms of stability and absolute delay we developed TWOTT system Event Timer **NPET.** J. Kodet et al., Metrologia, 2016.



NPET TWOTT terminal



Time distribution of stationary link



Transponder standing committee

ILRS Technical Workshop
Stuttgart 21th – 25th October 2019

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ESA context

Call for tender
January 2019

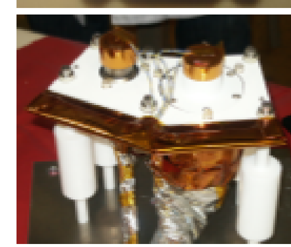
9.5 Advanced Laser Retro Reflector

Experimental Payload:	Advanced Laser Retro Reflector (Passive or Active)	TRL:	3-5

Description:

The LRR is a payload which allows the determination of the position and time (in case of active payload) by exploiting a global network of Laser Ranging Stations which very precisely measure the ranging from the satellite to the station. All existing Galileo satellites already embark Laser Retro-Reflectors. Novel passive reflectors (circular arrays or hollow cubes) may be considered for improved performance or accommodation.

Alternatively, an Active Laser Retro-Reflector (A-LRR) would allow the possibility to synchronize remote ground atomic clocks over inter-continental distance using standard Satellite Laser Ranging (SLR) techniques, as well as comparing ground clocks to the on-board atomic clocks directly, and may support the accurate independent orbit and clock determination. Such an idea has been demonstrated by SLR ground stations with the T2L2 instrument on board the Jason-2 satellite, and is expected for the ELT (European Laser Timing) instrument of the ACES experiment on board the ISS. Having an optical two-way time transfer on a Galileo satellite is unique because of the possibilities for common view of the satellite on the ground and the combination with a highly stable space atomic clock, providing the possibility of comparing ground clocks in non-common view (inter-continental comparisons) with high accuracy, offering the scientific community (time & frequency, metrology, fundamental physics, and geodesy) two-way range tracking, ground-to-space and ground-to-ground time transfers. Furthermore, two-way time transfers would be free (to the 1st-order) from errors coming from orbit models, which is one of the limitations of current GNSS systems. This would permit a unique characterization of the behaviour of the on-board atomic clocks, with respect to parameters such as temperature, radiation, magnetic field and aging. The availability of A-LRR in a Galileo satellite would be an opportunity to realize on-board co- locations between different space geodesy techniques (GNSS and SLR), in particular, if other scientific instruments such as a VLBI transmitter were co-located. It would allow relativity tests and ultimate time transfer capabilities and comparison between various techniques (e.g. PPP, TWSTFT, T2L2).



Time Transfer on Galileo satellites

- Ground-Space Time Transfer & Ground-Ground Time Transfer

- RF TT & optical TT comparison with improved accuracy

- Improved performance in non common view thanks to better space clocks (H-Maser compared to USO performances)

- Higher number of stations visibles for common view measurements and longer integration time thanks to the higher altitude of Galileo satellite (23320 m) compared to Jason-2 or the ISS

- 3D localization in space with synchronized SLR stations and by ranging simultaneously on a satellite equipped with an Active-LRR

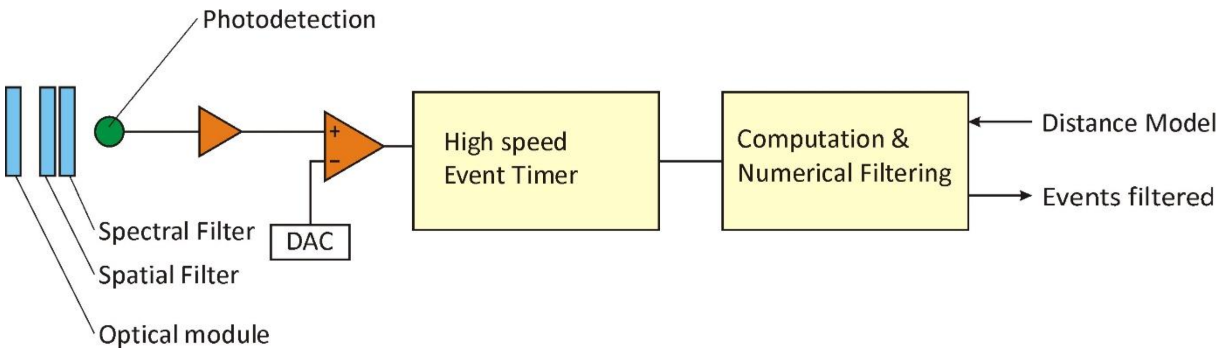
- Clock behaviour in the space environment

Conclusions & Perspectives

ESA interests to have optical time transfer instrument on Galileo as scientific payload.

=> New opportunity for optical Time Transfer
=> Coordinate Eurolas/ILRS answer ?

New T2L2 prototype in development at OCA :



based on a single non linear photo-detection with an auto-triggering and a numerical filtering done by an electronical system of laser event recognition and linked to a high speed event timer.