ELT Data Processing –
about Noise, Calibration Capability and Synergies

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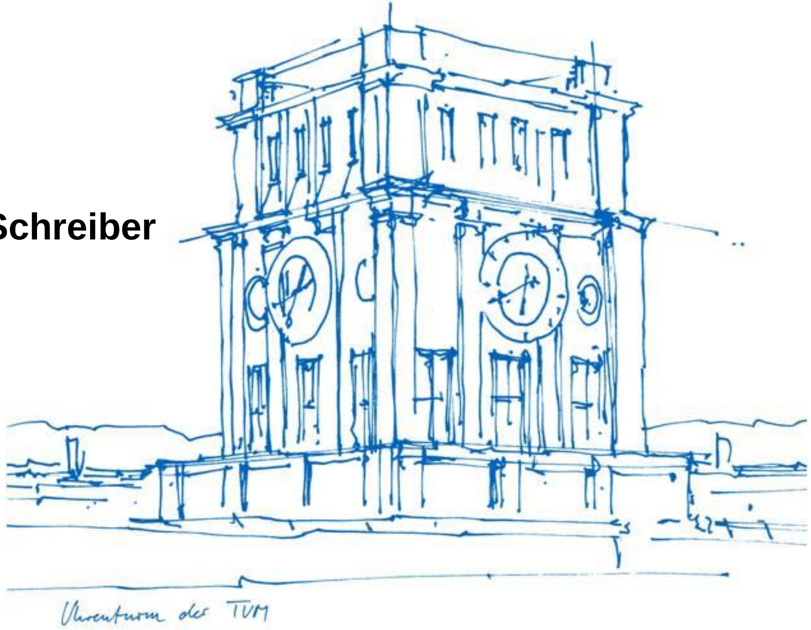
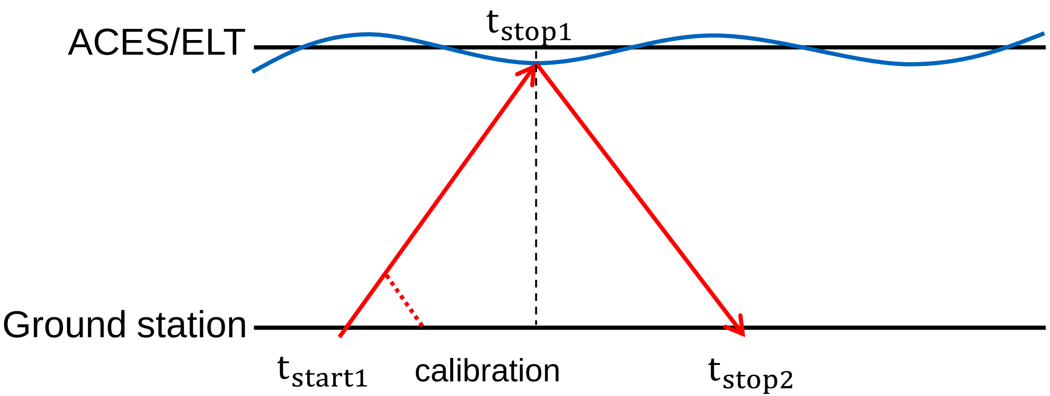


ELT Data Processing – about Noise, Calibration Capability and Synergies

1. European Laser Timing: Measurement principle and data analysis
2. Complications I: due to ISS
3. Complications II: Complexity of the measurement on ground
4. Comparison: ELT versus MWL
5. Synergies: ELT and microwave techniques

Measurement principle

Optical link, pulsed



Measurement principle

Principle of ELT (optical link, pulsed)

- One way:

$$tof_{1W} = R_{CoM} + \tau_{troposphere} + \tau_{Sagnac} + \tau_{Shapiro} + \tau_{attitudeDetector}$$

- Round trip:

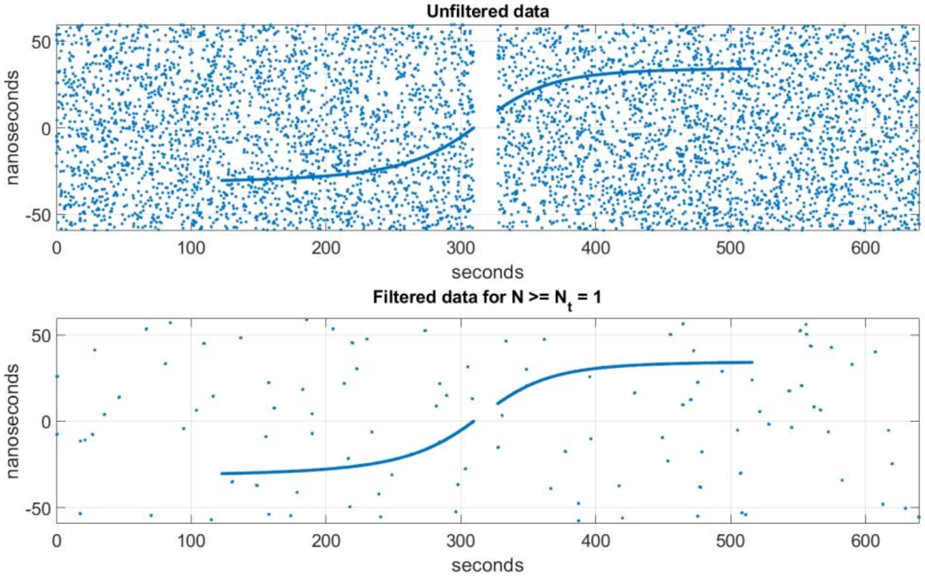
$$tof_{2W} = 2 * \left(R_{CoM} + \tau_{troposphere} + \tau_{Shapiro} + \tau_{attitudeReflector}\right) + \tau_{Reflector}$$

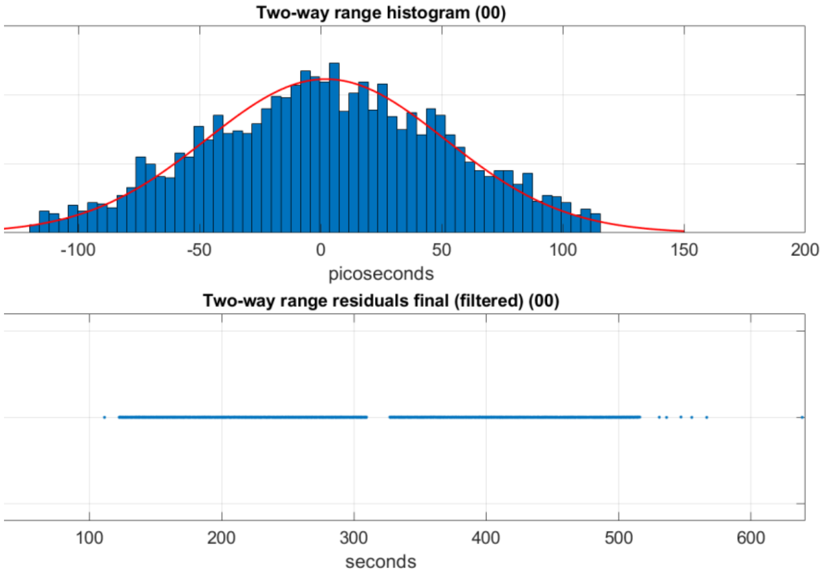
with R_{CoM}: Distance between spacecraft CoM and station reference point

- Time transfer:

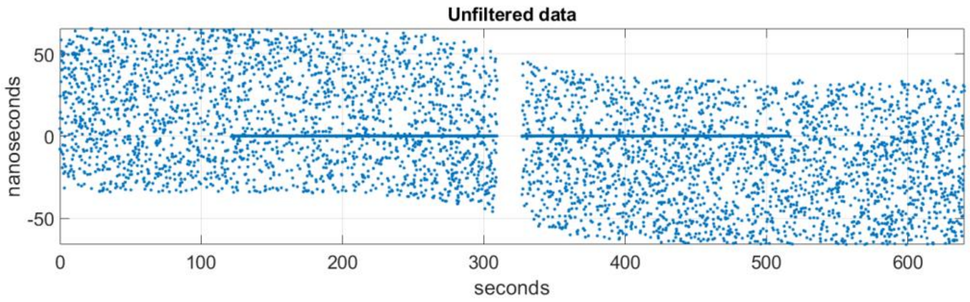
$$\tau = \frac{t_{return}+t_{start}}{2} - t_{detector} + \tau_{corr} = \frac{tof_{2W}}{2} + t_{start} - t_{detector} + \tau_{corr}$$

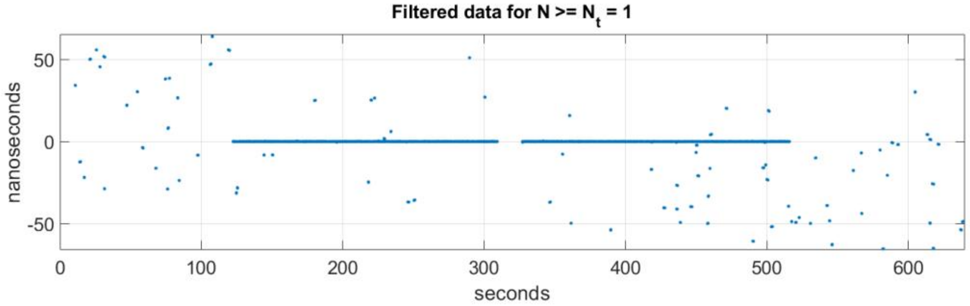
Round-trip measurements

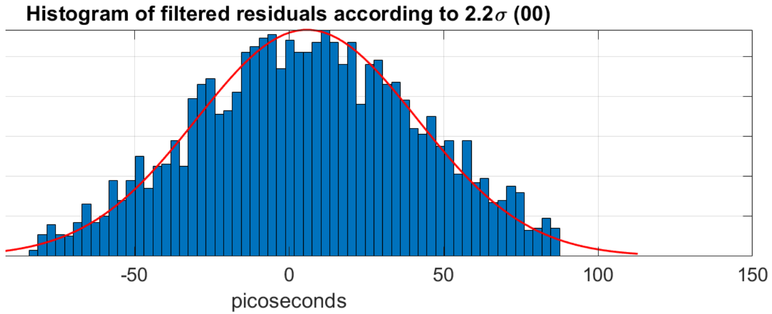


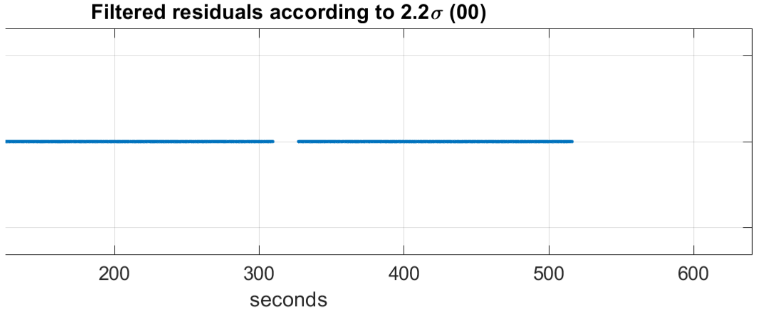


One-way measurements

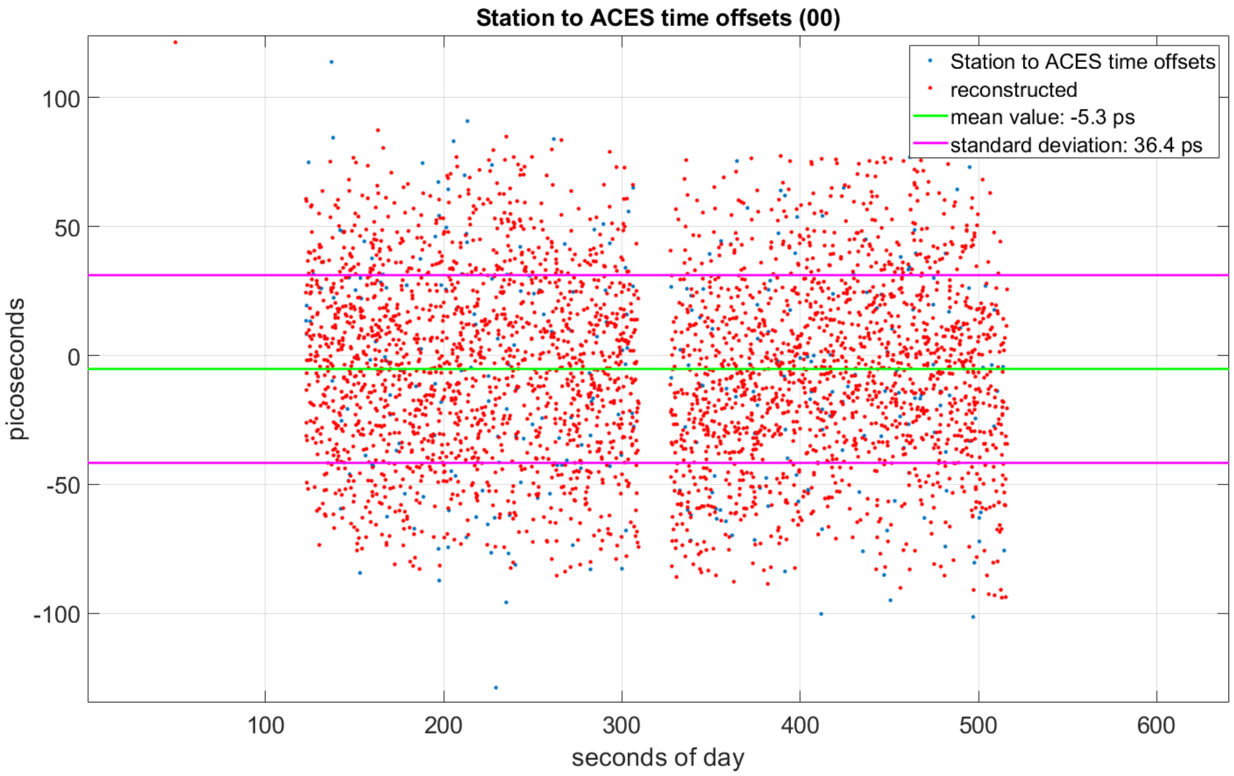




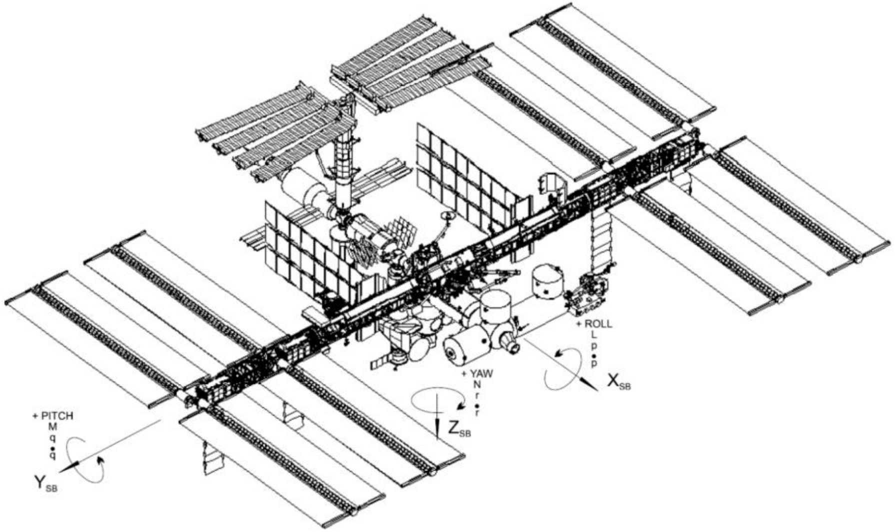




Time transfer



Multireflector problem



$Name$	X [m]	Y [m]	Z [m]
JEM LRR Hemi A	10.878	−5.448	7.021
JEM LRR Hemi B	10.876	−6.092	7.017
IDA 1 Hemi B (a)	15.789	0.891	6.239
C2V2 S3 Forward Antenna Boom Hemi (c)	1.524	22.887	−1.417
C2V2 P3 Nadir Antenna Boom Hemi (c)	−2.621	−22.887	−0.978

Multireflector problem

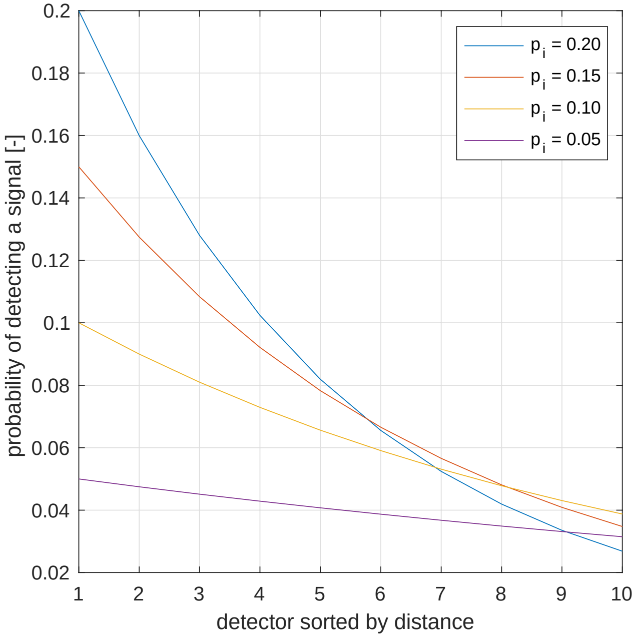
For reflectors $i = 0 \dots N$ with distances $d_i \leq d_{i+1}$ with respect to the observer the probability of detecting a signal is:

$$p_{i,eff} = p_i \prod_{j=0}^{i-1} (1 - p_j)$$

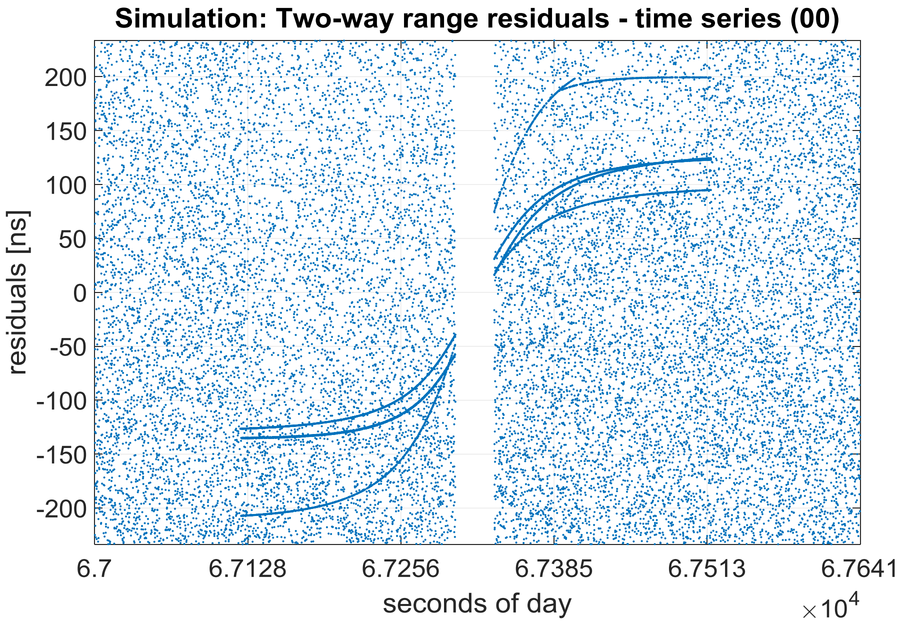
The single-reflector probabilities p_i may account for differences in the effective cross section among the reflectors.

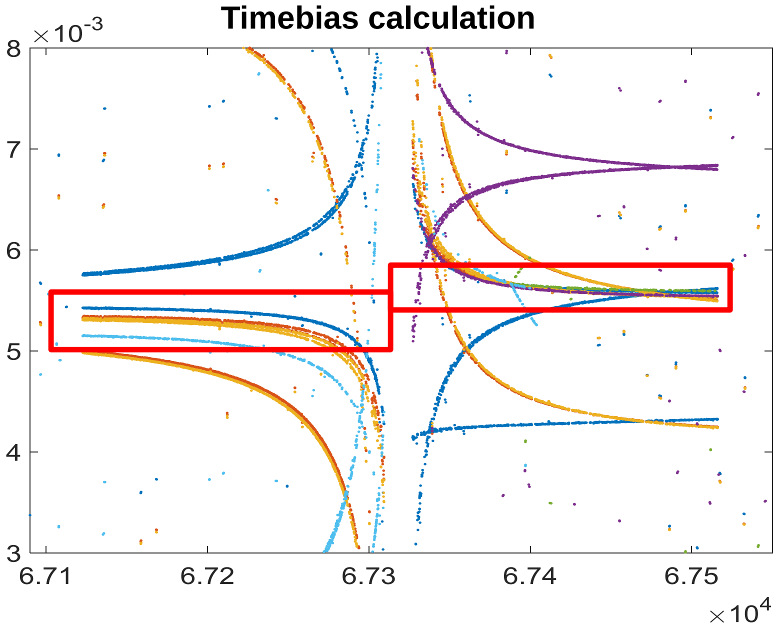
With a constant background noise rate, the noise statistics follows an exponential distribution in single photon mode:

$$p_{signal.i} = p_{eff,i} e^{-n_{noise} \Delta t_i}$$

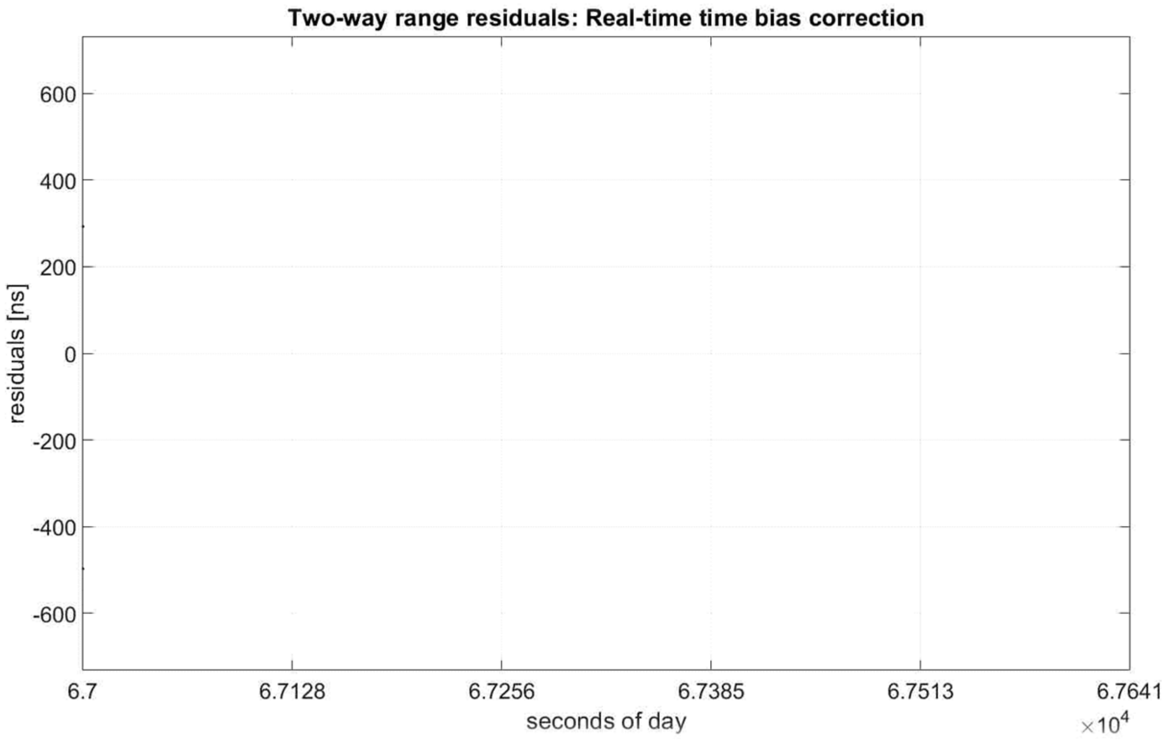


Detector identification

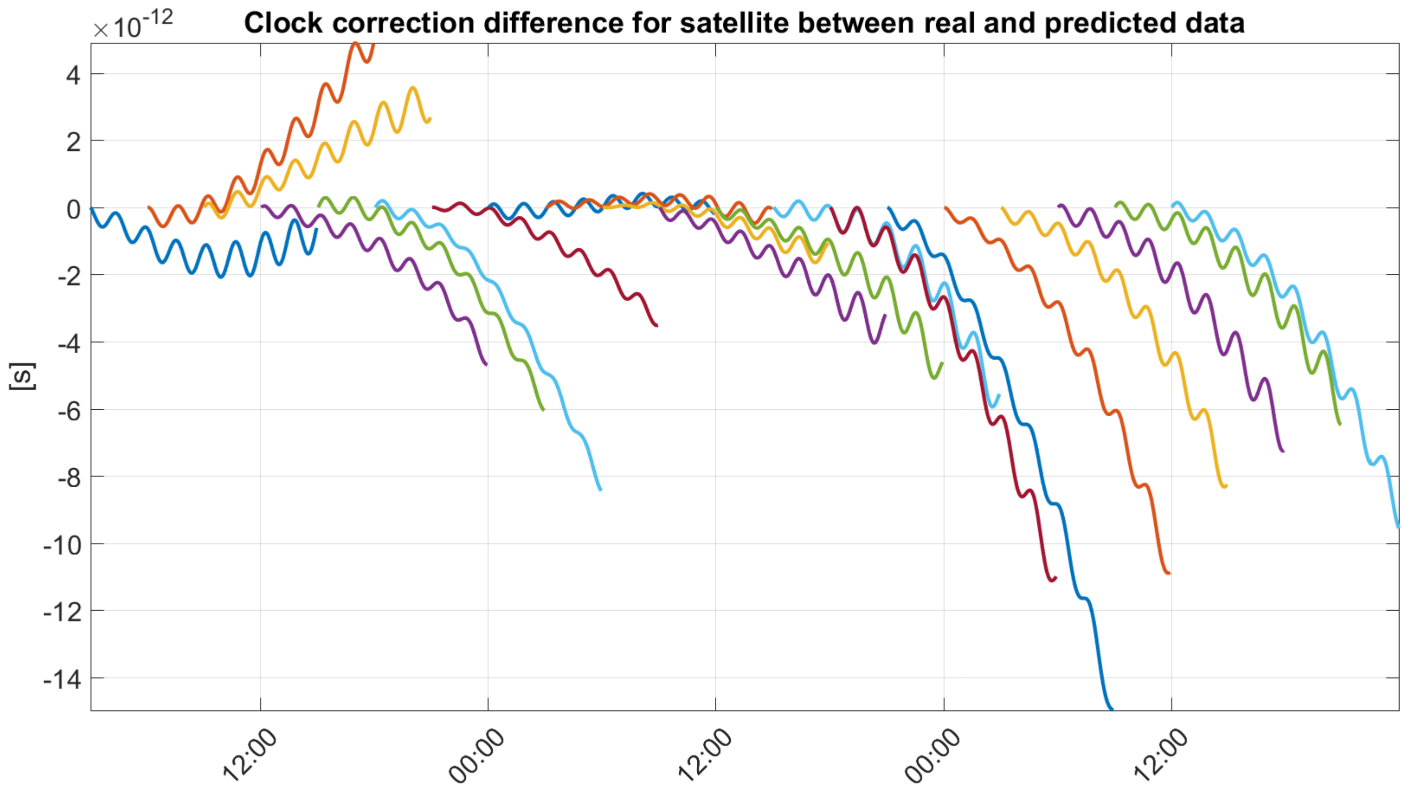




Complexity of ELT for ground stations



ACES clock prediction



New noise reduction algorithm

$$P_{s>thr} = \sum_{m=N_t}^{\infty} p_{binomial,n+s}(m)$$

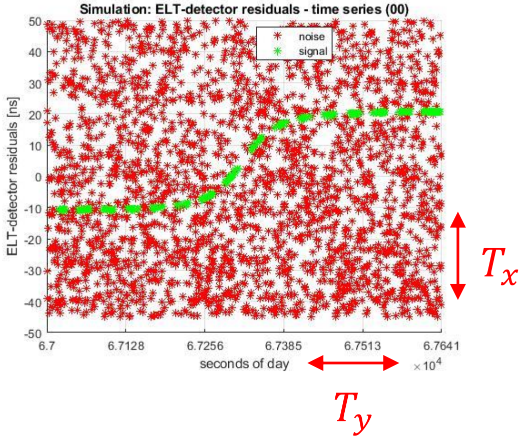
$$P_{n+s}(T_x) = 1 - \exp\left[-(n_n T_x + N_s)\right]$$

$$p_{binomial,n+s}(m) = \frac{y!}{m!(y-m)!} P_{n+s}(T_x)^m (1 - P_{n+s}(T_x))^{y-m}$$

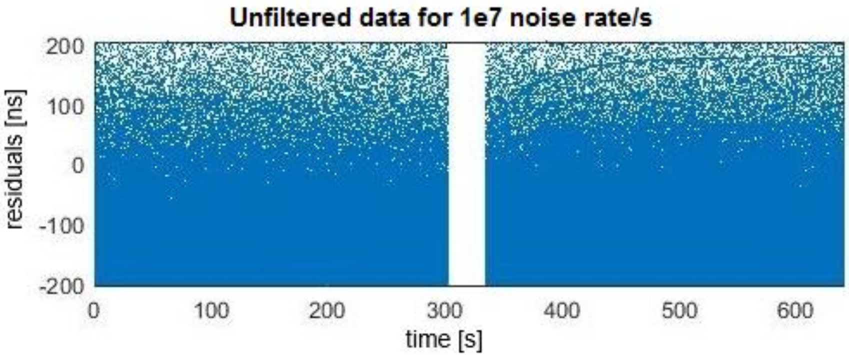
$$P_{n>thr} = \sum_{m=N_t}^{\infty} p_{binomial,n}(m)$$

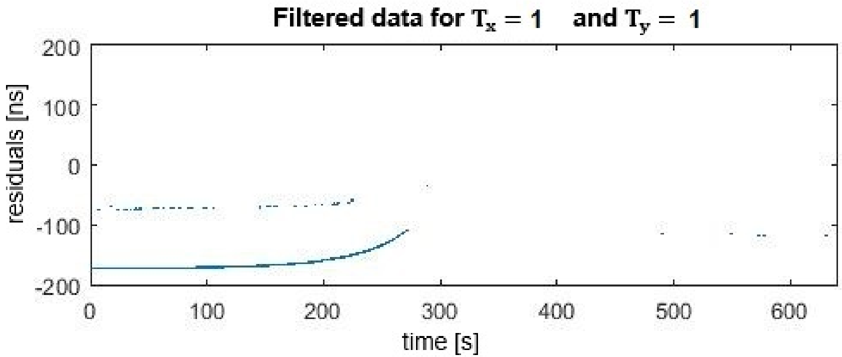
$$P_n(T_x) = 1 - \exp\left[-n_n T_x\right]$$

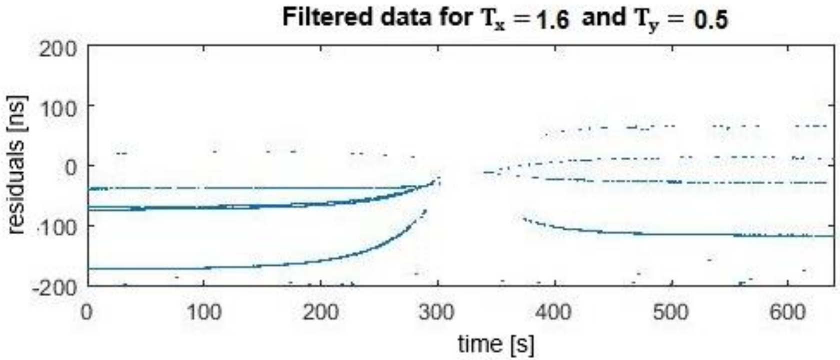
$$p_{binomial,n}(m) = \frac{y!}{m!(y-m)!} P_n(T_x)^m (1 - P_n(T_x))^{y-m}$$

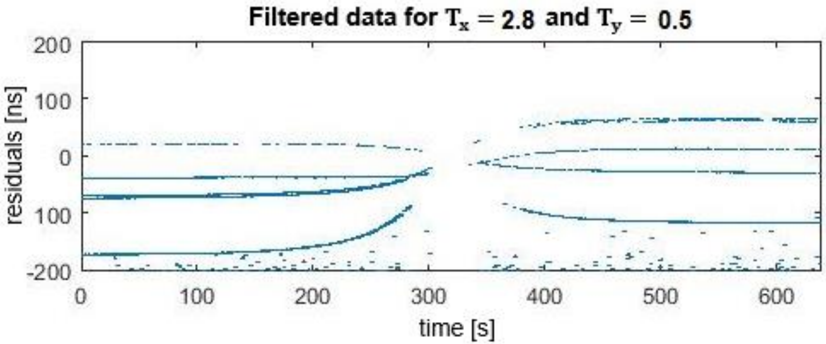


New noise reduction algorithm









Simulation capability

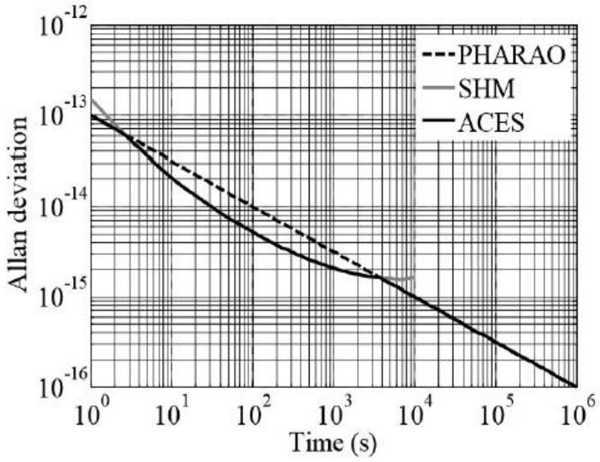
Geometric components

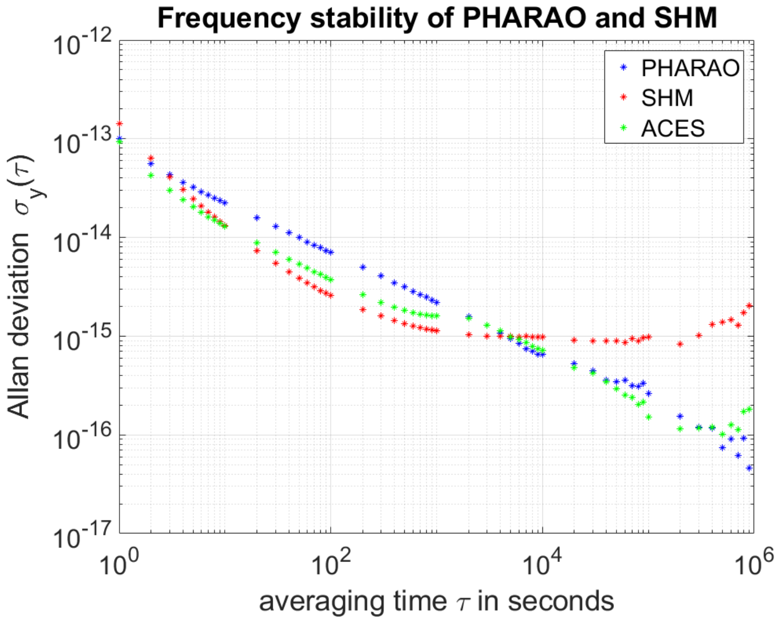
- ISS attitude simulation
  (3 axes, constant offsets and oscillations)
- Detector and multi reflector positions
- Intra-reflector delay (function of incidence angle)
- Visibility constraints (minimum elevation, clouds)
- Tidal motion and atmospheric loading

Stochastic components

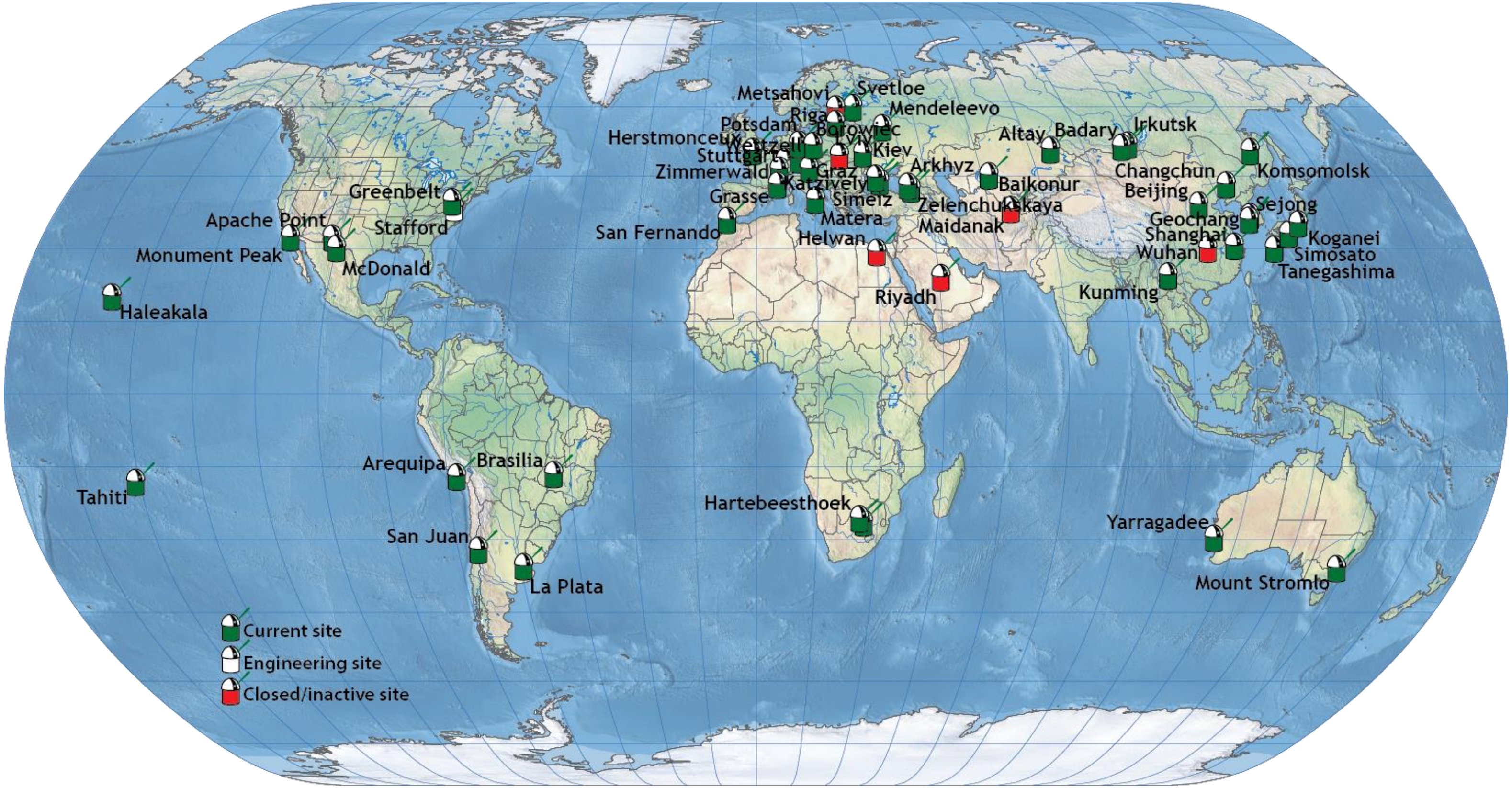
- Background noise
- Laser Jitter
- Pulse width
- Clock noise and offsets
- (Fluctuations in the troposphere)

Clock simulation





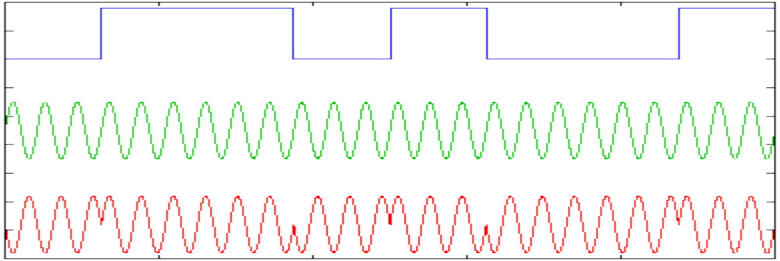
Ground segment



Comparison with MWL

ELT:

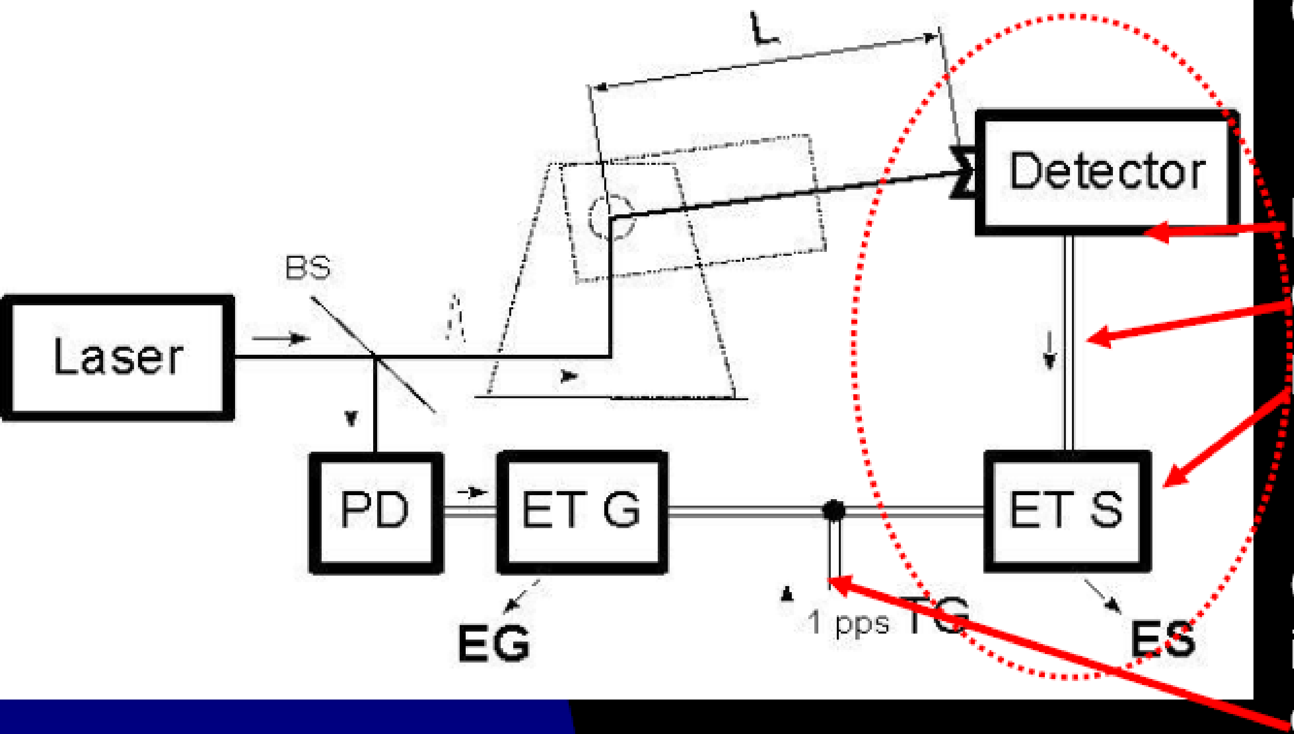
MWL:



Optical -> calibration -> 50 ps accuracy
no wet tropospheric delay
Time tagging of events -> jitter per detection
pulse length 10 ps / 1 kHz -> 4 ps @ 300s
7ps @ 1 d

Microwave -> no calibration -> 100 ps accuracy
wet tropospheric delay
Phase locked loop -> jitter per contact
100 Mchip/s / 14 GHz -> 230 fs @ 300s
8 ps @ 1 d

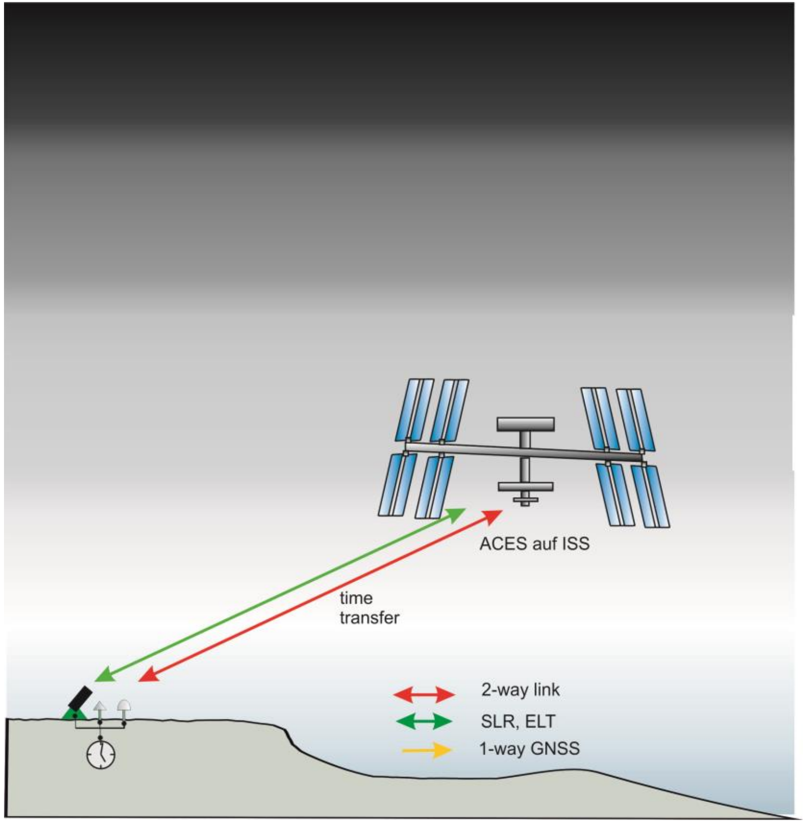
Calibration



Calibration Device

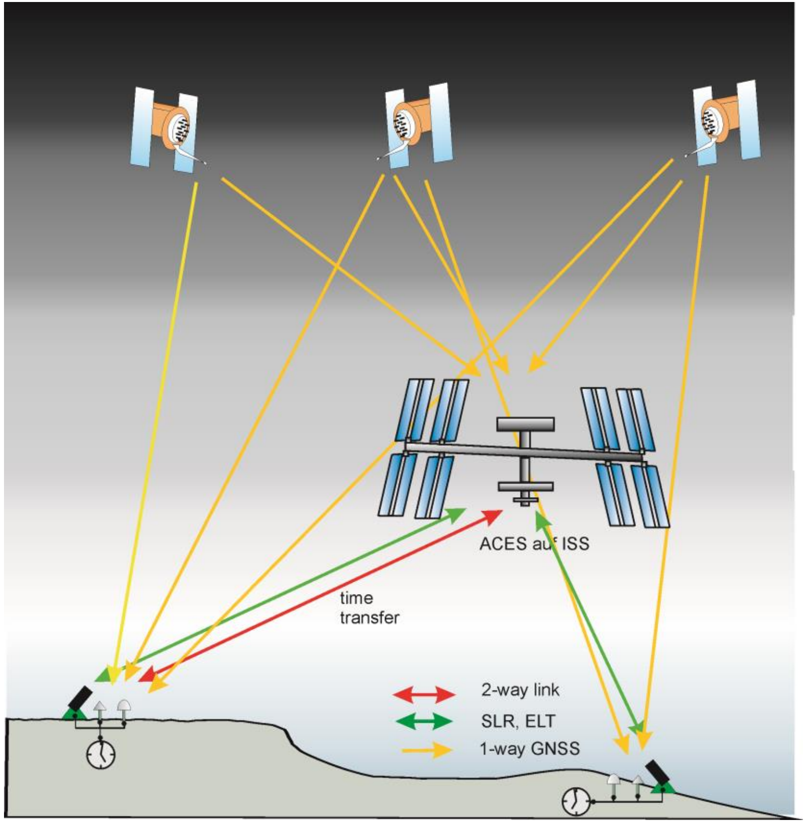
- Detector SPAD
- Cable
- NPET epoch timing
- Common epoch "1pps"; identical cable common clock frequency

Calibration of MWL



⇒ Calibration of MWL for time transfer and ranging
⇒ Troposphere
⇒ Short arc orbit adjustment
⇒ Systematic effects
⇒ Try a common parameter estimation and compare to time transfer in Lambda configuration

Calibration of GNSS links



⇒ Calibration of GNSS receiver
⇒ T2L2 only in common-view
⇒ ELT now also in non-common-view

Conclusions

ELT Data Center delivers the following products:

Space to ground clock comparison

Ground to ground clock comparison in common-view

Ground to ground clock comparison in non-common-view

MWL calibration