Full-scale Monte-Carlo Data Simulation and Evaluation in the ELT Data Center

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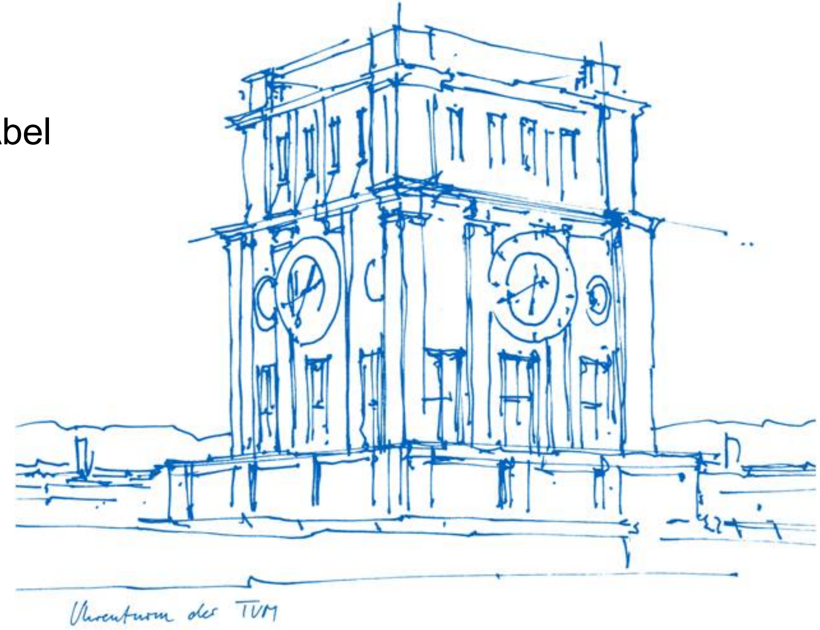
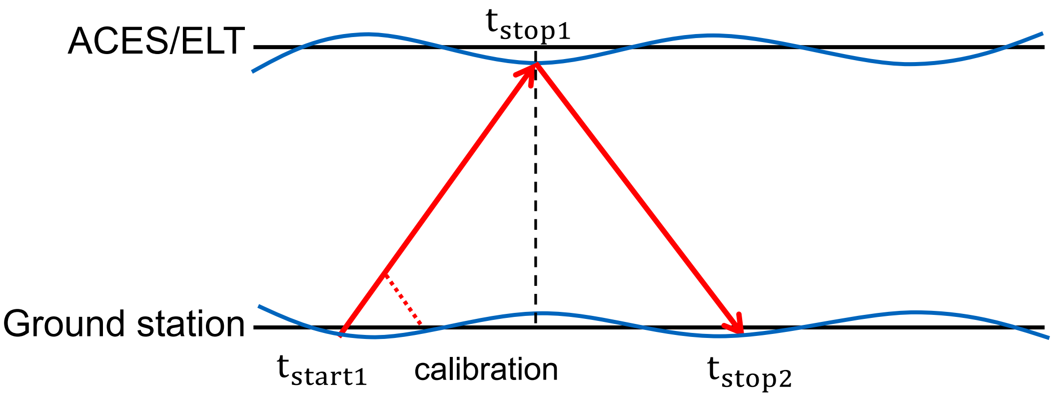
Chair of Satellite Geodesy



ACES Workshop, Munich, 22-23 October, 2018

ELT principle

Optical link, pulsed



Short introduction to ELT (continued)

Principle of ELT (optical link, pulsed)

- One way:

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

- Two way:

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

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

- Time transfer:

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

Capabilities of the simulation environment

Geometric components

- Earth orientation (IERS 2010 Conventions)
- ISS attitude simulation
  (3 axes, constant offsets and oscillations
- Detector and reflector position
- Intra-reflector delay (function of incidence angle)
- Visibility constraints (minimum elevation

Signal delays

- Troposphere (including cloud cover)
- Sagnac effect (processing in ITRF)
- Shapiro delay

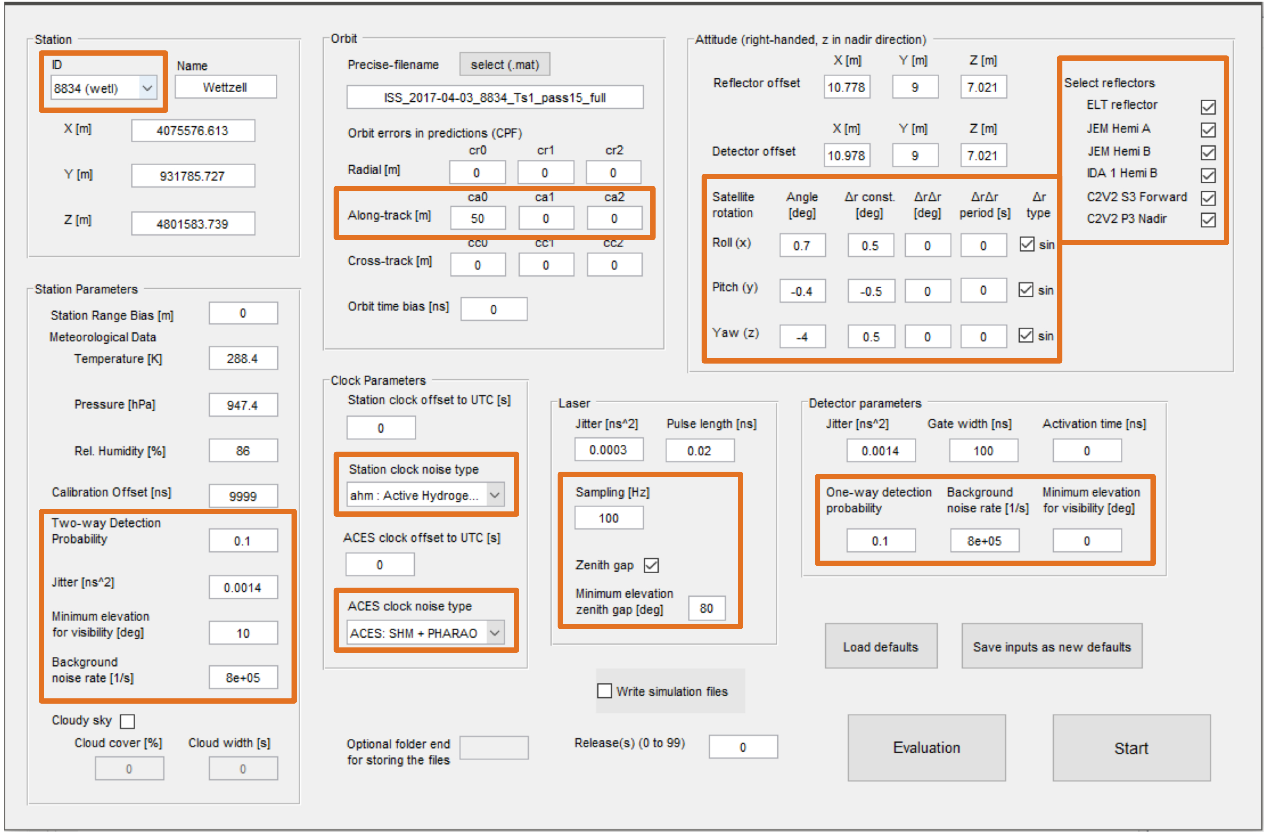
Relativistic effects on clocks

- Drift of clocks w.r.t. to UTC
  - … due to special relativity (relative velocity)
  - … due to different gravitational potential

Stochastic components

- Background noise
- Laser Jitter
- Pulse width
- Noise of ground- and space-based clocks

Capabilities of the simulation environment (continued)



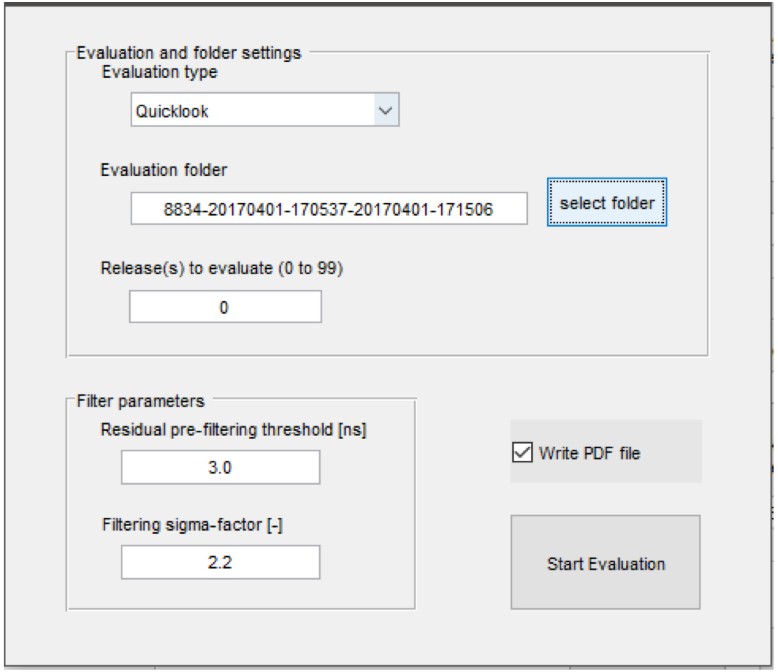
ELT data processing

ELT reflector identification and coarse 2-way filtering

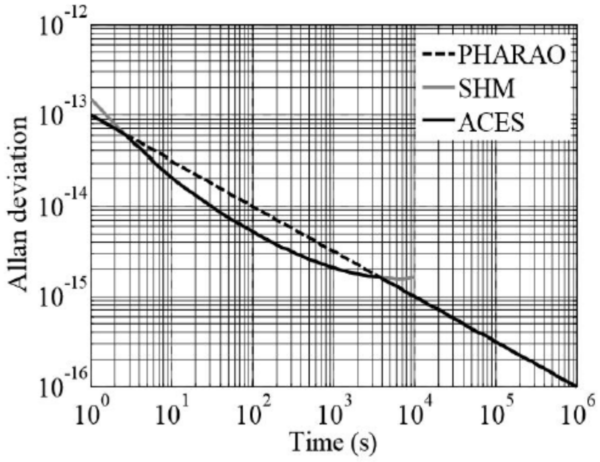
Final 2-way filtering and orbit (attitude) improvement

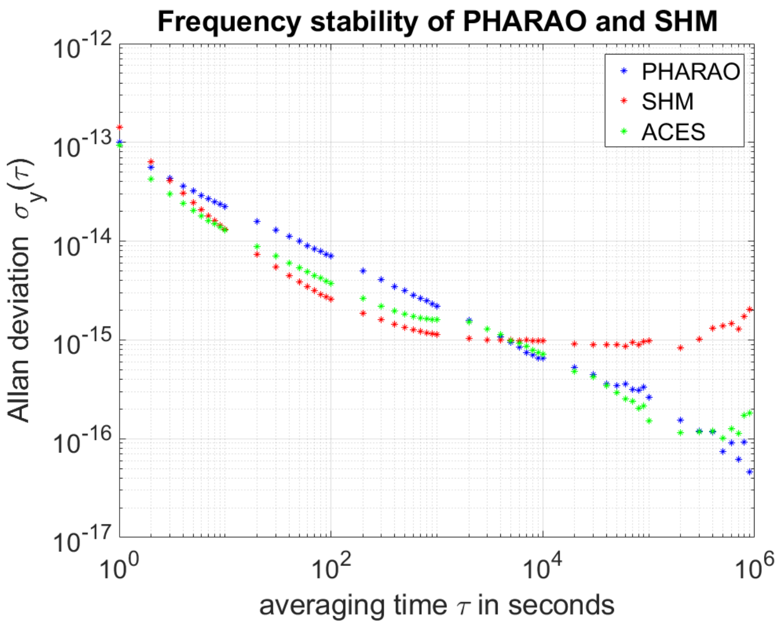
1-way filtering based on orbit (attitude) corrections

- Preliminary noise reduction
- Build histogram
- Exponential noise reduction
- Signal peak localization
- Iterative sigma screening

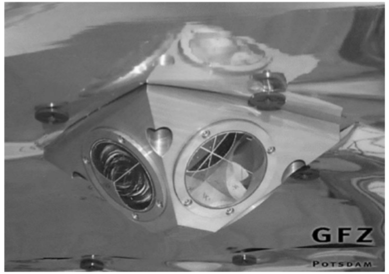


Simulation of the ACES clock





Signal delay in the ELT reflector



Description of ELT CCR Configuration

To extract ranges from SLR measurements and to consider geometrical corrections the configuration of the CCR has to be known. This implies <u>knowledge of the location of the CCR reference point</u> with respect to the ACES coordinate system, <u>the orientation of the CCR and the CCR correction table</u>.

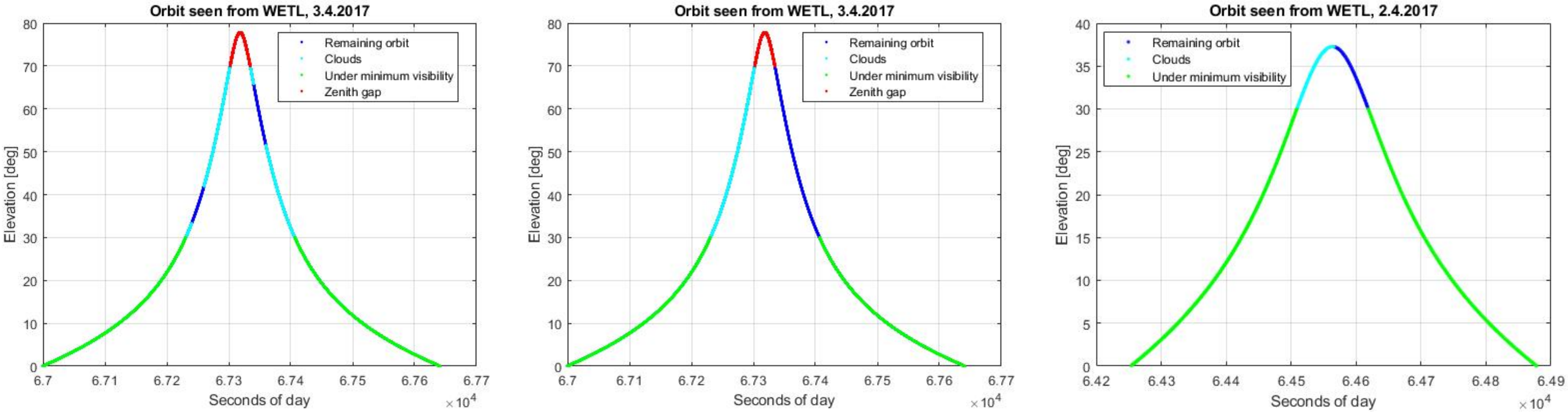
ELT CCR reference point and orientation

ASCII file containing list of start time and ELT CCR reference point and orientation information. The ELT CCR <u>detector reference point is defined in relation to the ACES reference point</u> and the <u>orientation of the CCR is defined by quaternions</u>. The x-axis of CCR is in azimuth = 0, y-axis in azimuth = 90° and z-axis in boresight.

CCR Correction

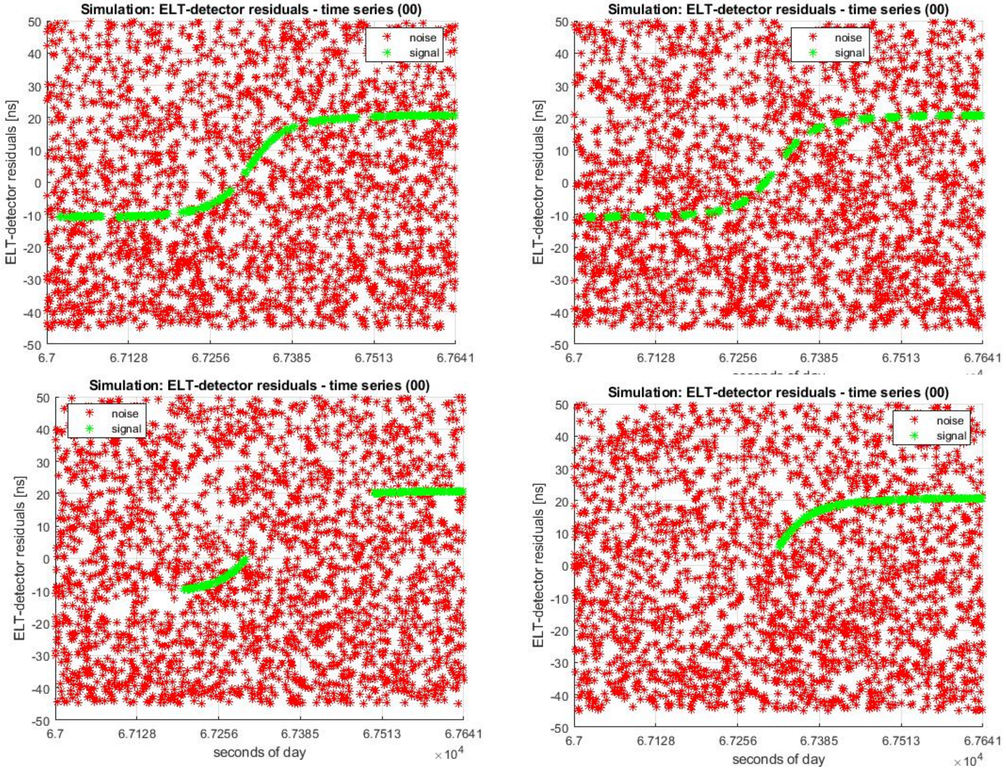
<u>Azimuth and elevation-dependent range corrections relative to the mechanical reference point</u> of CCR have to be taken into account. These corrections <u>imply the optical and mechanical parameters of the reflector array</u>. The corrections are <u>provided in the nearest-prism approximation</u>.

Elevation cut-off, zenith gap, cloud coverage (continued)



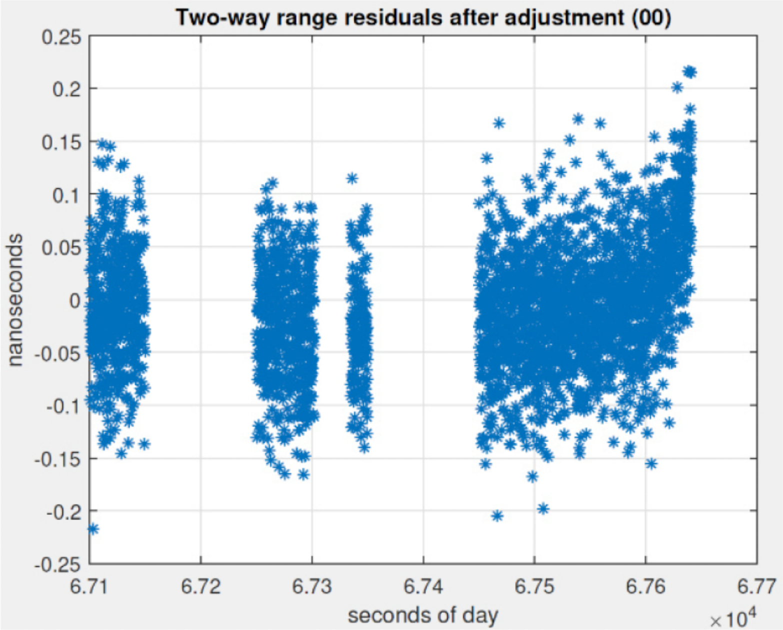
- Clouds of <u>equal "duration"</u> and <u>regular distribution</u>
- <u>Parameters</u>: Total cloud coverage P_{clouds} [%/pass] and cloud frequency f_{clouds} [#/pass]

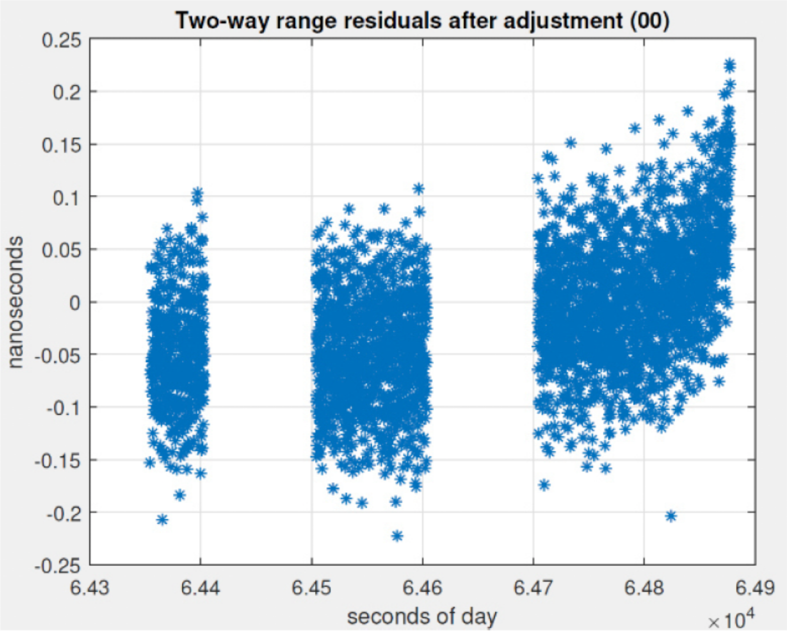
Elevation cut-off, zenith gap, cloud coverage (continued)



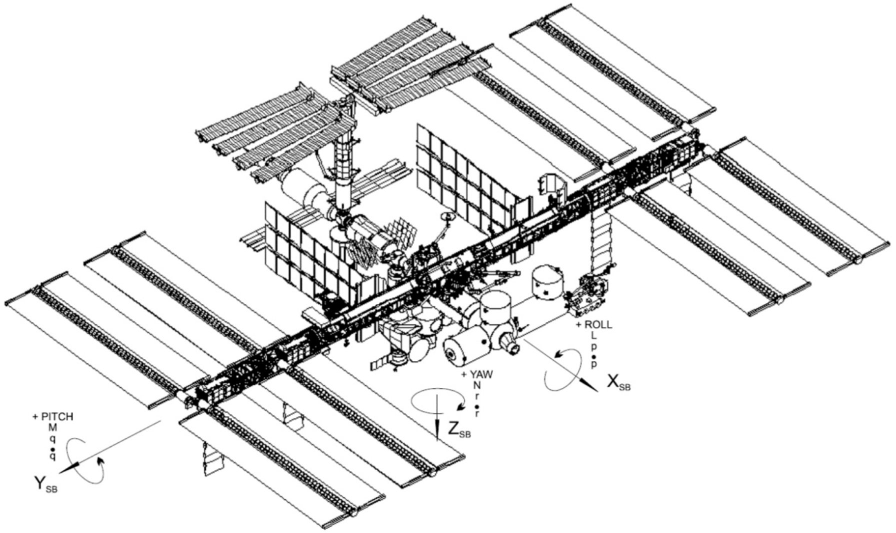
Simulated 2-way range residuals for different cloud coverage parameters

Cloud coverage and periodic attitude error





Multiple reflectors on the ISS



Name	$\boldsymbol{X}$ [m]	$\boldsymbol{Y}$ [m]	$\boldsymbol{Z}$ [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

Multiple reflectors on the ISS (continued)

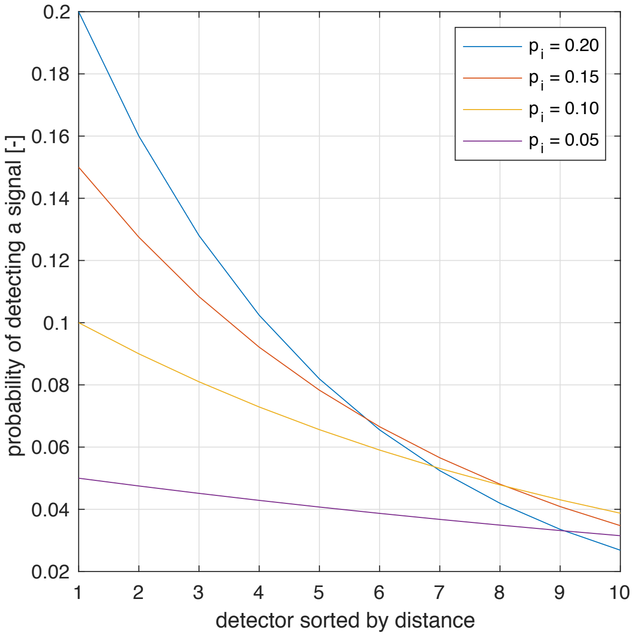
For reflectors $i = 0 \dots N$ with distances $d_i \leq d_{i+1}$ with respect to the observer the probability of detecting a signal is:

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

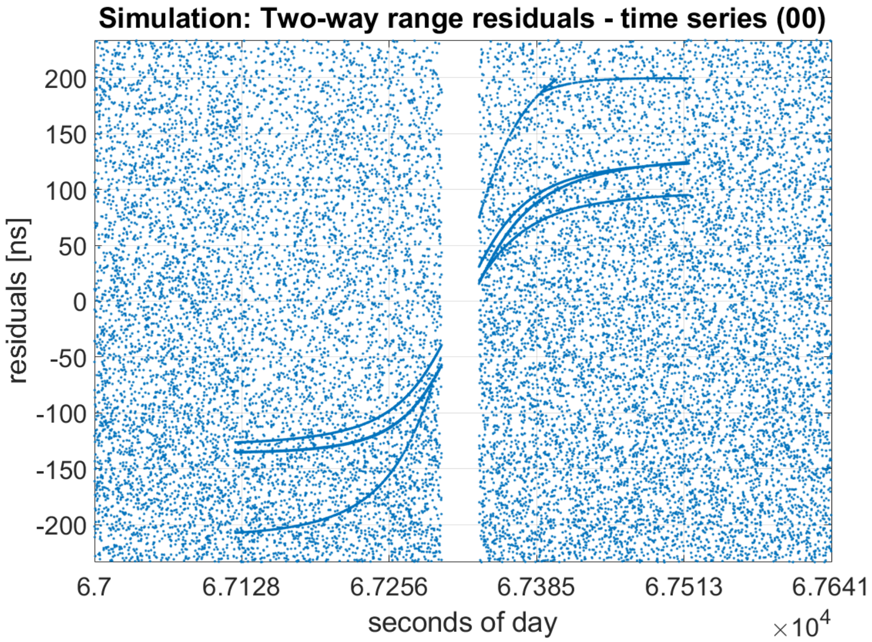
The single-reflector probabilities p_i may account for differences in the effective cross section among the reflectors.

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

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



Multiple reflectors on the ISS (continued)



New noise reduction algorithm

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

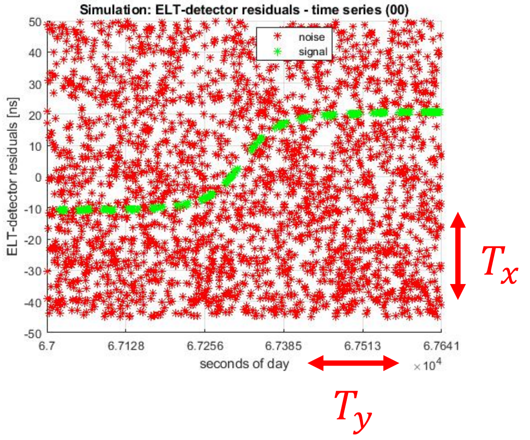
$$P_{n+s}(T_x) = 1 - \exp\left[-(n_n T_x + N_s)\right]$$

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

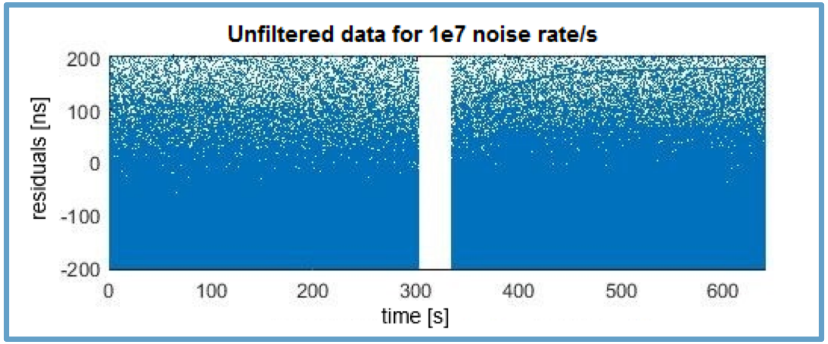
$$P_{n>thr} = \sum_{m=N_t}^{\infty} p_{binomial,n}(m)$$

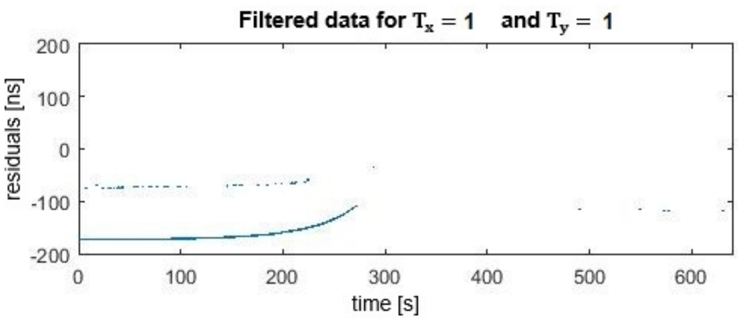
$$P_n(T_x) = 1 - \exp\left[-n_n T_x\right]$$

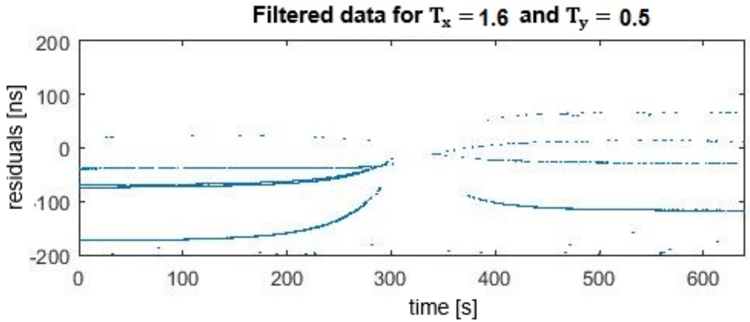
$$p_{binomial,n}(m) = \frac{y!}{m!(y-m)!} P_n(T_x)^m (1 - P_n(T_x))^{y-m}$$

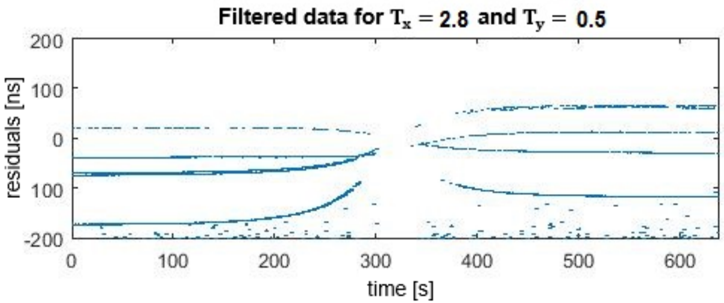


New noise reduction algorithm









Monte-Carlo simulations

- **Data simulation and processing for identical parameters**
  - Passes
  - Laser system characteristics
  - Signal propagation characteristics
  - … (neglecting multiple reflectors on the ISS)

- **Randomness introduced by the following sources**
  - <u>Background noise</u>
  - Laser jitter
  - Pulse width
  - Clock noise

- **Studies without systematic errors**
  - Expected to converge to “true” clock offset
  - … if filtering does not fail
  - … and yields unbiased time transfer triplets
  - How does <u>filtering</u> perform statistically?

- **Studies with systematic errors**
  - Unknown <u>attitude</u> and orbit errors will be present (particularly in quick-look processing)

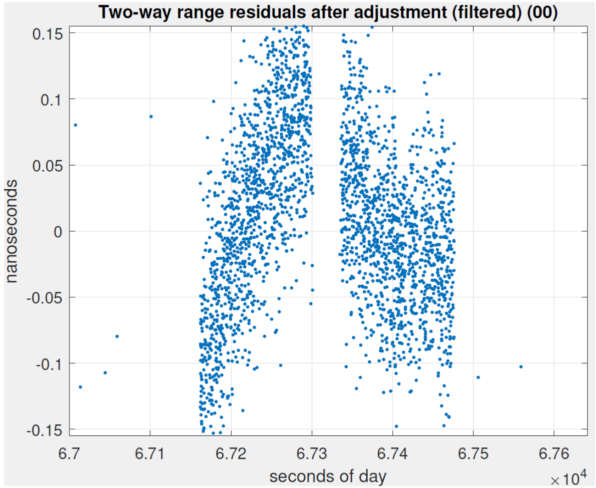
- Effects of <u>cloud coverage</u> and other constraints on performance

Monte-Carlo simulations (continued)

Background noise rate [1/s]	Noise reduction	Time transfer σ [ps]
5.00E+05	no	1.6979
5.00E+05	yes	0.4541
5.00E+06	no	4.7743
5.00E+06	yes	1.8626

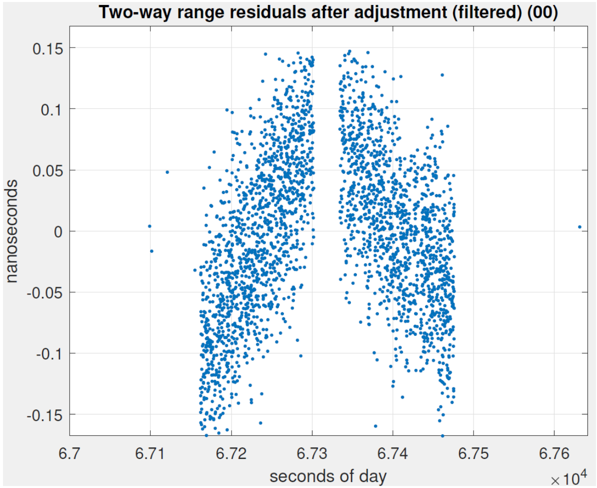
Monte-Carlo simulations (continued)

Attitude error (only pitch)



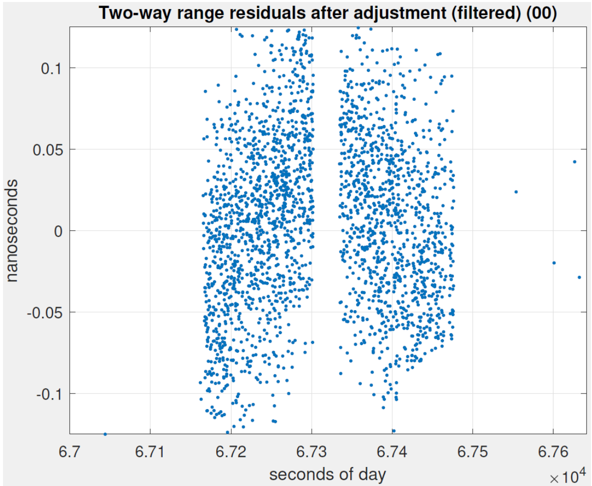
4rev/orbit

σ = 11.32ps



2rev/orbit

σ = 10.95ps

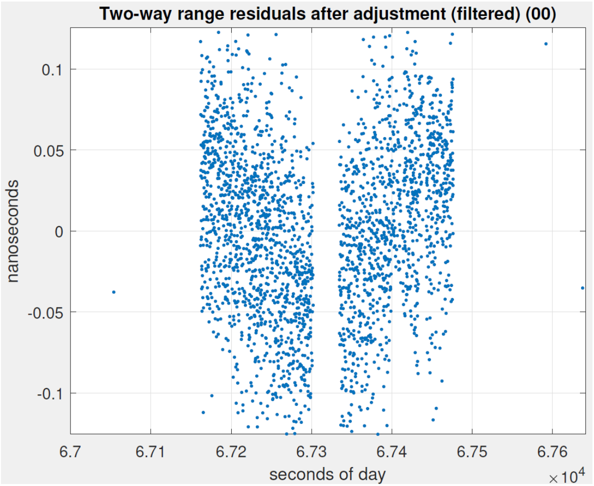


1rev/orbit

σ = 5.83ps

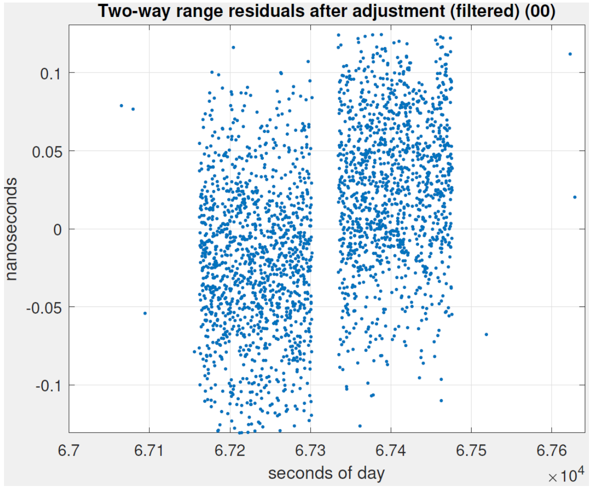
Monte-Carlo simulations (continued)

Attitude error (only roll)



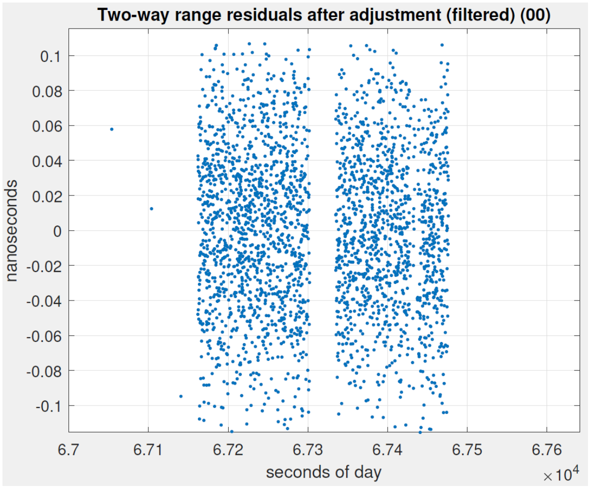
4rev/orbit

σ = 4.4ps



2rev/orbit

σ = 2.75ps



1rev/orbit

σ = 0.35ps

Outlook

- Further Monte-Carlo simulations will be performed (suggestions are welcome!)
- We identified the ISS attitude as a critical source of error

  (insights via ISS tracking campaign would be very helpful)
- Challenges due multiple reflectors (see next talk by Stefan Marz)