

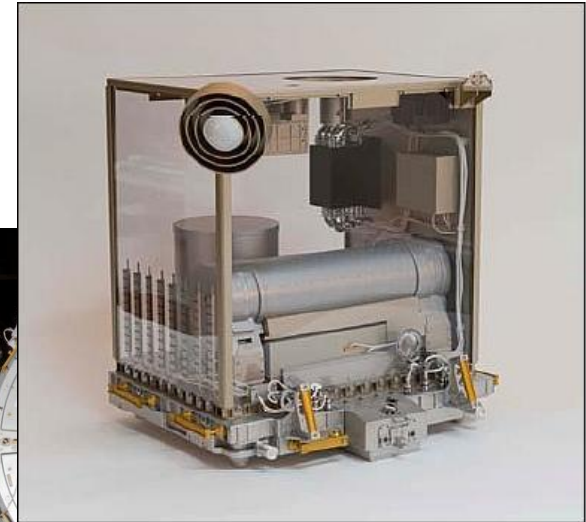
# Verification of ELT performance by Monte Carlo Simulations

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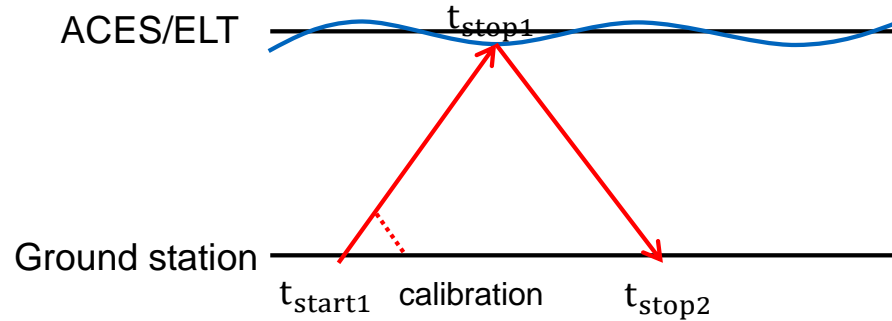
Technical University Munich



# The ELT experiment



# Optical time transfer



- One way:  $tof_{1W} = R_{CoM} + \tau_{troposphere} + \tau_{Sagnac} + \tau_{Shapiro} + \tau_{attitudeDetector}$
- Two way:  $tof_{2W} = 2 * (R_{CoM} + \tau_{troposphere} + \tau_{Shapiro} + \tau_{attitudeReflector}) + \tau_{Reflector}$
- Time transfer:  $\tau = \frac{t_{return} + t_{start}}{2} - t_{detector} + \tau_{corr} = \frac{tof_{2W}}{2} + t_{start} - t_{detector} + \tau_{corr}$

# Simulation tool

## 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
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- 
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## Stochastic components

- Background noise
- Laser Jitter
- Pulse width
- Noise of ground- and space-based clocks
- Cloud coverage (frequency and duration)

Station

ID: 8834 (wett) Name: Wetzell

X [m]: 4075576.613  
Y [m]: 931785.727  
Z [m]: 4801583.739

Station Parameters

Station Range Bias [m]: 0  
Meteorological Data  
Temperature [K]: 288.4  
Pressure [hPa]: 947.4  
Rel. Humidity [%]: 86  
Calibration Offset [ns]: 9999

Two-way Detection Probability: 0.1  
Jitter [ns<sup>2</sup>]: 0.0014  
Minimum elevation for visibility [deg]: 10  
Background noise rate [1/s]: 8e+05

Cloudy sky   
Cloud cover [%]: 0 Cloud width [s]: 0

Orbit

Precise-filename: select (.mat)  
ISS\_2017-04-03\_8834\_Ts1\_pass15\_full

Orbit errors in predictions (CPF)

	cr0	cr1	cr2
Radial [m]	0	0	0
Along-track [m]	50	0	0
	ca0	ca1	ca2
Cross-track [m]	0	0	0
	cc0	cc1	cc2

Orbit time bias [ns]: 0

Clock Parameters

Station clock offset to UTC [s]: 0  
Station clock noise type: ahm : Active Hydroge...  
ACES clock offset to UTC [s]: 0  
ACES clock noise type: ACES: SHM + PHARAO

Laser

Jitter [ns<sup>2</sup>]: 0.0003 Pulse length [ns]: 0.02  
Sampling [Hz]: 100  
Zenith gap   
Minimum elevation zenith gap [deg]: 80

Attitude (right-handed, z in nadir direction)

	X [m]	Y [m]	Z [m]
Reflector offset	10.778	9	7.021
Detector offset	10.978	9	7.021

Select reflectors

- ELT reflector
- JEM Hemi A
- JEM Hemi B
- IDA 1 Hemi B
- C2V2 S3 Forward
- C2V2 P3 Nadir

	X [m]	Y [m]	Z [m]	$\Delta r$ type
Satellite rotation				
Roll (x)	0.7	0.5	0	<input checked="" type="checkbox"/> sin
Pitch (y)	-0.4	-0.5	0	<input checked="" type="checkbox"/> sin
Yaw (z)	-4	0.5	0	<input checked="" type="checkbox"/> sin

Detector parameters

Jitter [ns<sup>2</sup>]: 0.0014 Gate width [ns]: 100 Activation time [ns]: 0  
One-way detection probability: 0.1 Background noise rate [1/s]: 8e+05 Minimum elevation for visibility [deg]: 0

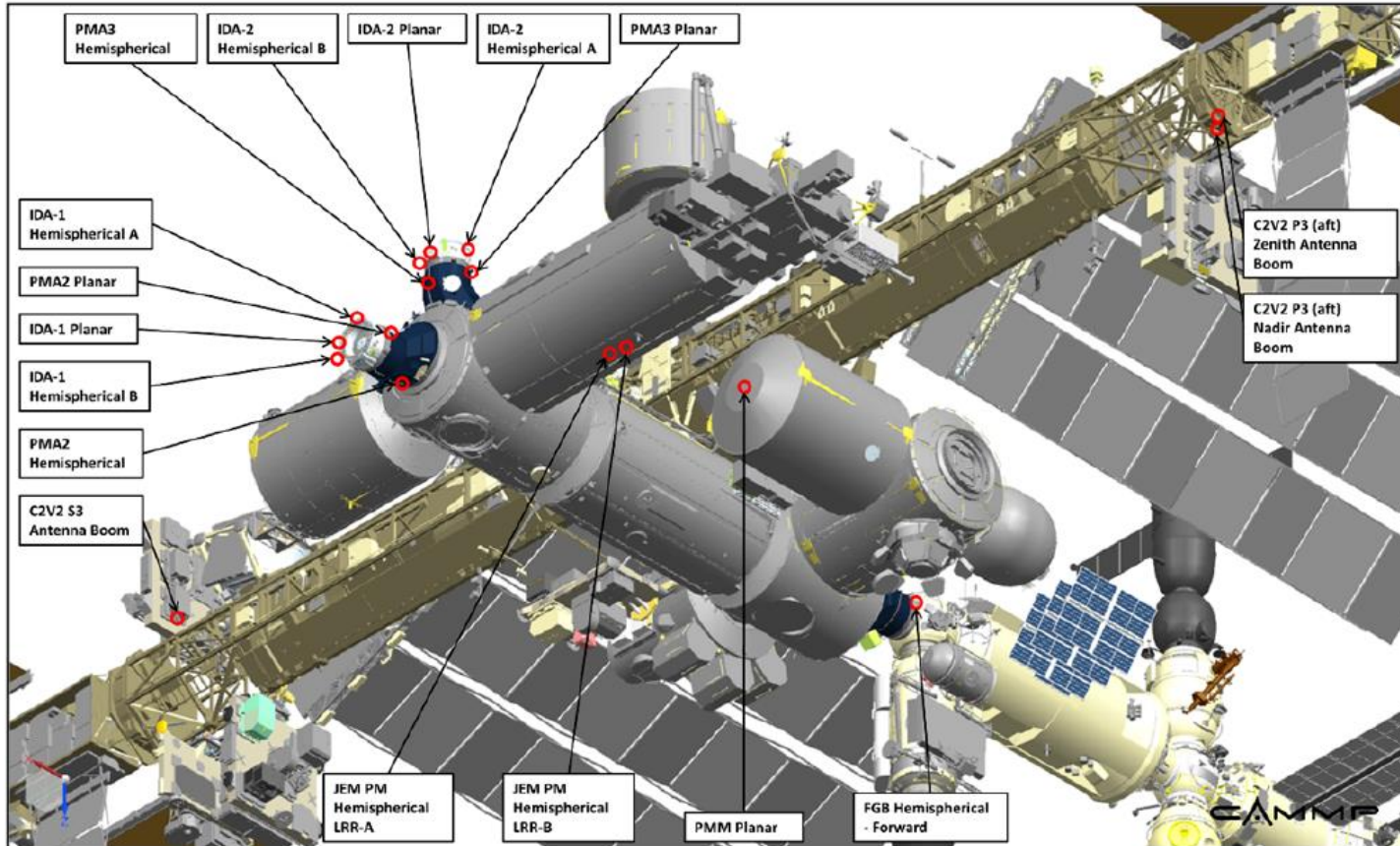
Write simulation files

Optional folder end for storing the files:  Release(s) (0 to 99): 0

Load defaults Save inputs as new defaults

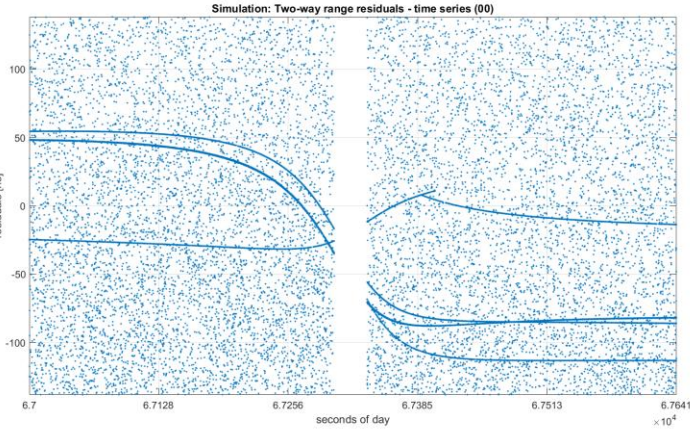
Evaluation Start

# Multi-reflector problem

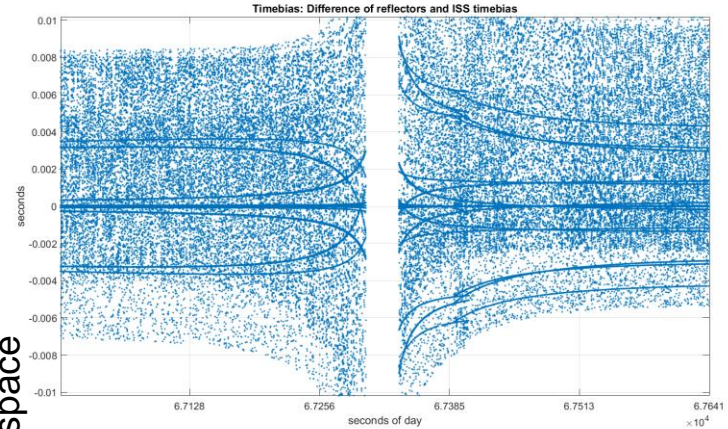


# Reflector identification

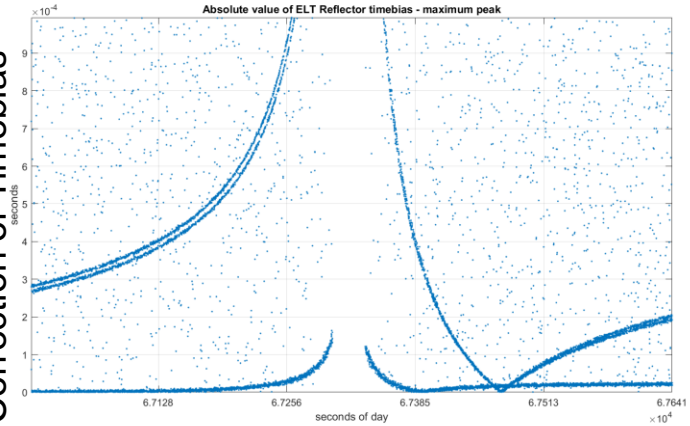
1  
Simulation



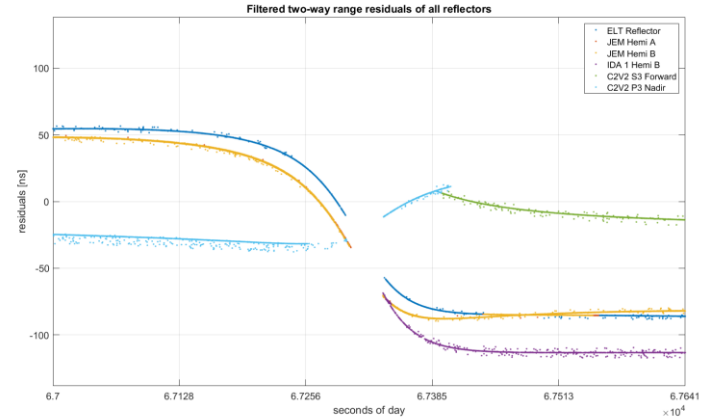
2  
Transformation in Timebias space



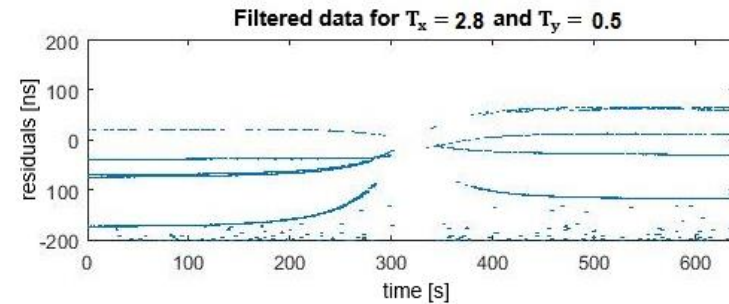
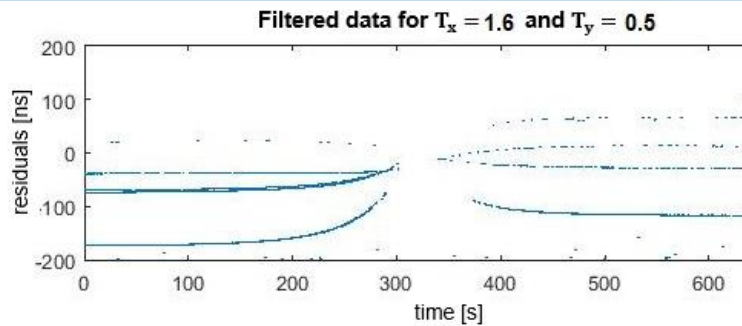
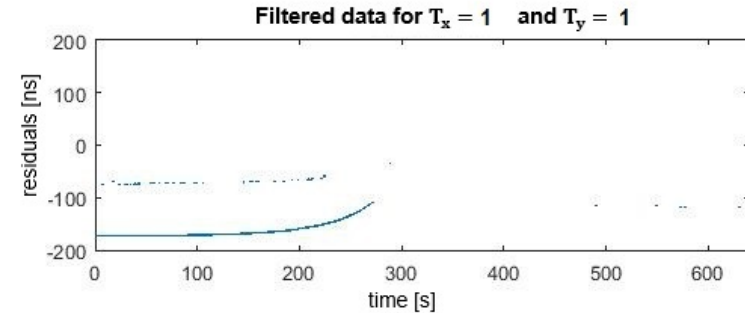
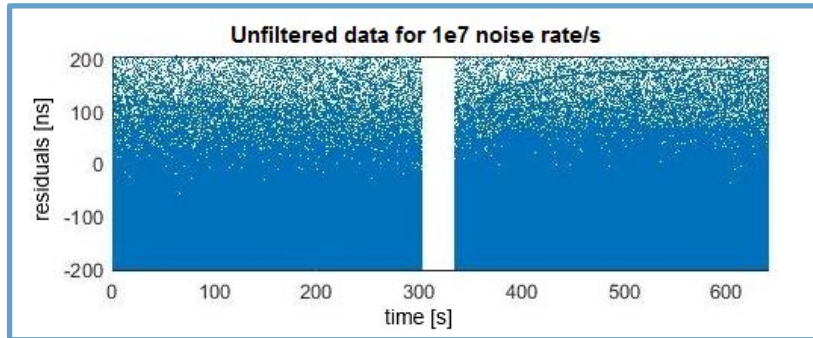
3  
Correction of Timebias



4  
Identification of Reflectors



# Binominal filtering





# Monte-Carlo simulations

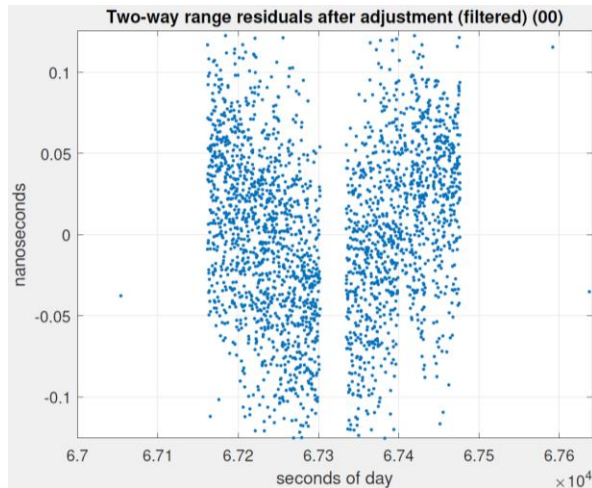
- **Data simulation and processing for identical parameters**
  - Passes
  - Laser system characteristics
  - Signal propagation characteristics
  - ... (neglecting multiple reflectors on the ISS)
- **Randomness introduced by the following sources**
  - Background noise
  - Laser jitter
  - Pulse width
  - 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 filtering perform statistically?
- **Studies with systematic errors**
  - Unknown attitude and orbit errors will be present (particularly in quick-look processing)
  - Effects of cloud coverage and other constraints on performance

# Results

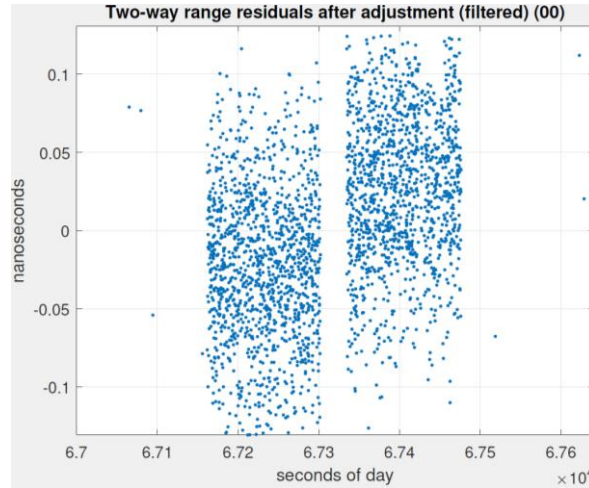
<b>Background noise rate [1/s]</b>	<b>Noise reduction</b>	<b>Time transfer <math>\sigma</math> [ps]</b>
5.00E+05	no	1.6979
5.00E+05	yes	0.4541
5.00E+06	no	4.7743
5.00E+06	yes	1.8626

# Monte-Carlo simulations

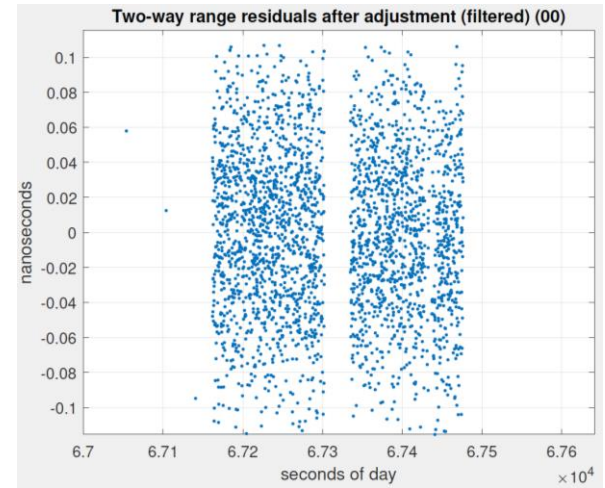
## Attitude error (only roll)



4rev/orbit  
 $\sigma = 4.4\text{ps}$



2rev/orbit  
 $\sigma = 2.75\text{ps}$



1rev/orbit  
 $\sigma = 0.35\text{ps}$

# Real-time TB correction

100 m along-track orbit error, 1 m radial orbit error, constant  $0.5^\circ$  attitude error

