ESA Genesis Science Workshop 2026

ESA WG3:
Scheduling and End-to-End Simulations

Matthias Schartner, Helene Wolf, Lisa Kern, Rimsky Wolfs,
David Schunck, Lucia McCallum, Hakan Sert, Johannes Böhm

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Scheduling

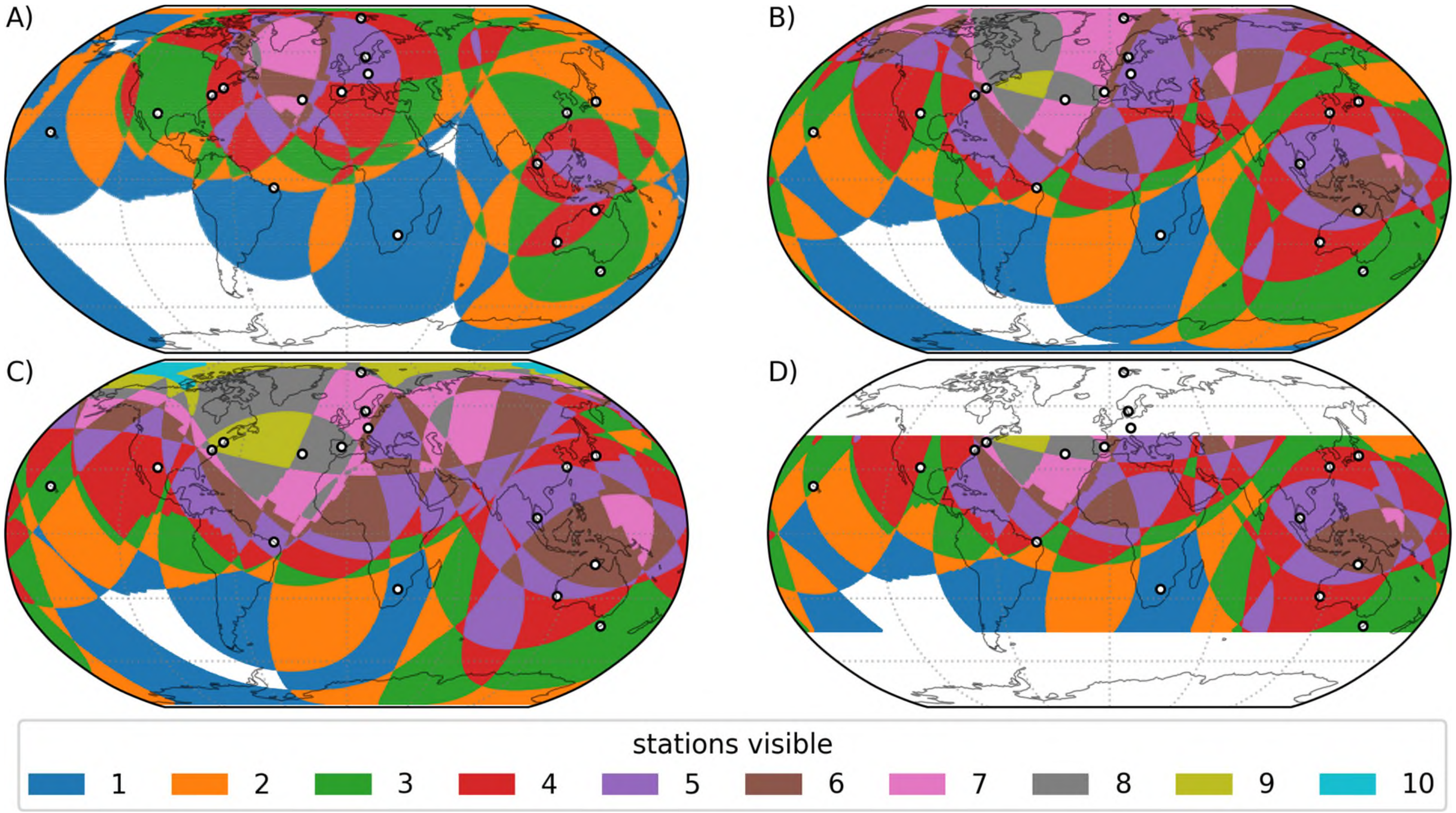
- VieSched++ (Schartner, 2019) playing the important role
  - software development done at ETH Zürich
- Fine-tuning of parameters
  - done at ETH Zürich, TU Wien, Chalmers, U Tasmania, ROB
  - minimum repeat time of Genesis scans
  - cut-off angle of Genesis observations
  - weight factors and optimization
    - (remote) stations, sky coverage, number of observations, idle time

Scheduling

- Geometry: high satellite orbit most important

h = **3000** km
$i = 95°$

h = **6000** km
$i = 95°$



h = **9000** km
$i = 95°$

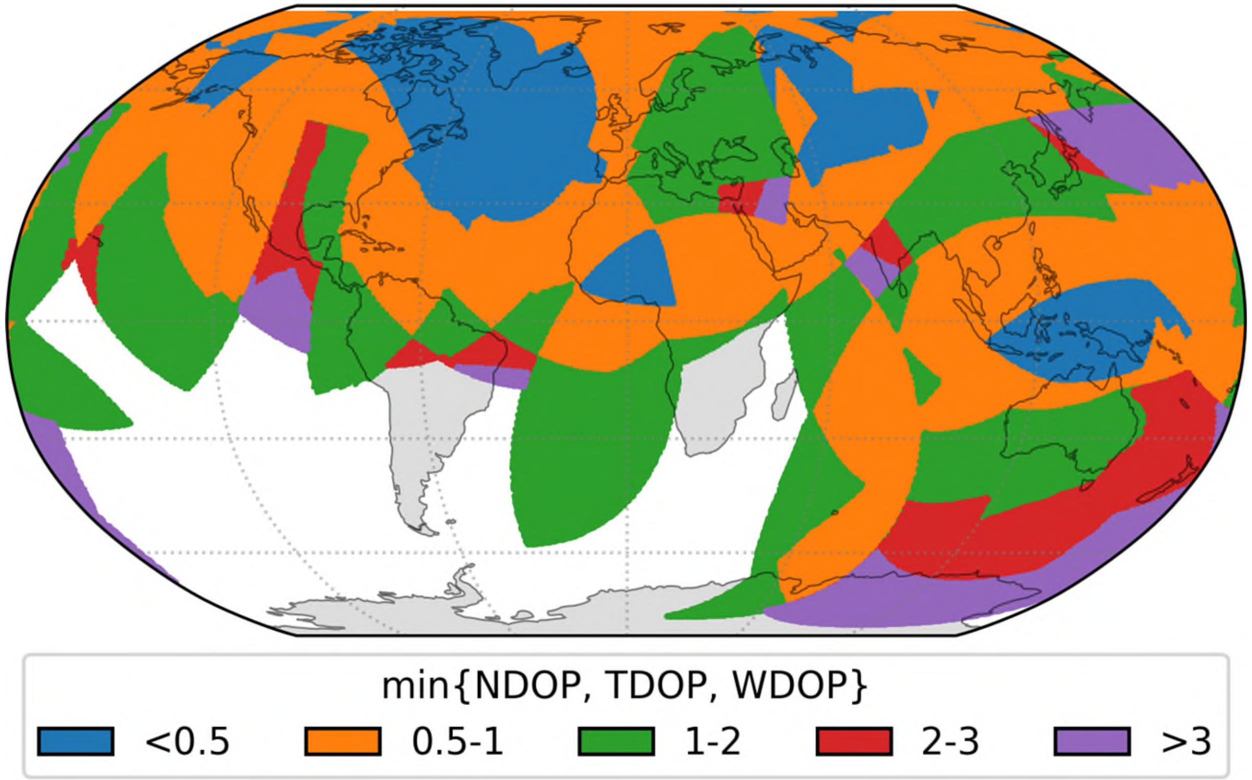
$h = 6000$ km
i = **45°**

Scheduling

- Geometry: Dilution of Precision (DOP)
  - quantifies how geometry amplifies group delay errors
  - lower values refer to better results
  - Four types:
    - WDOP (cross track)
    - TDOP (along track)
    - NDOP (normal $\approx$ radial, typically worse)
    - UDOP (UT1-UTC)

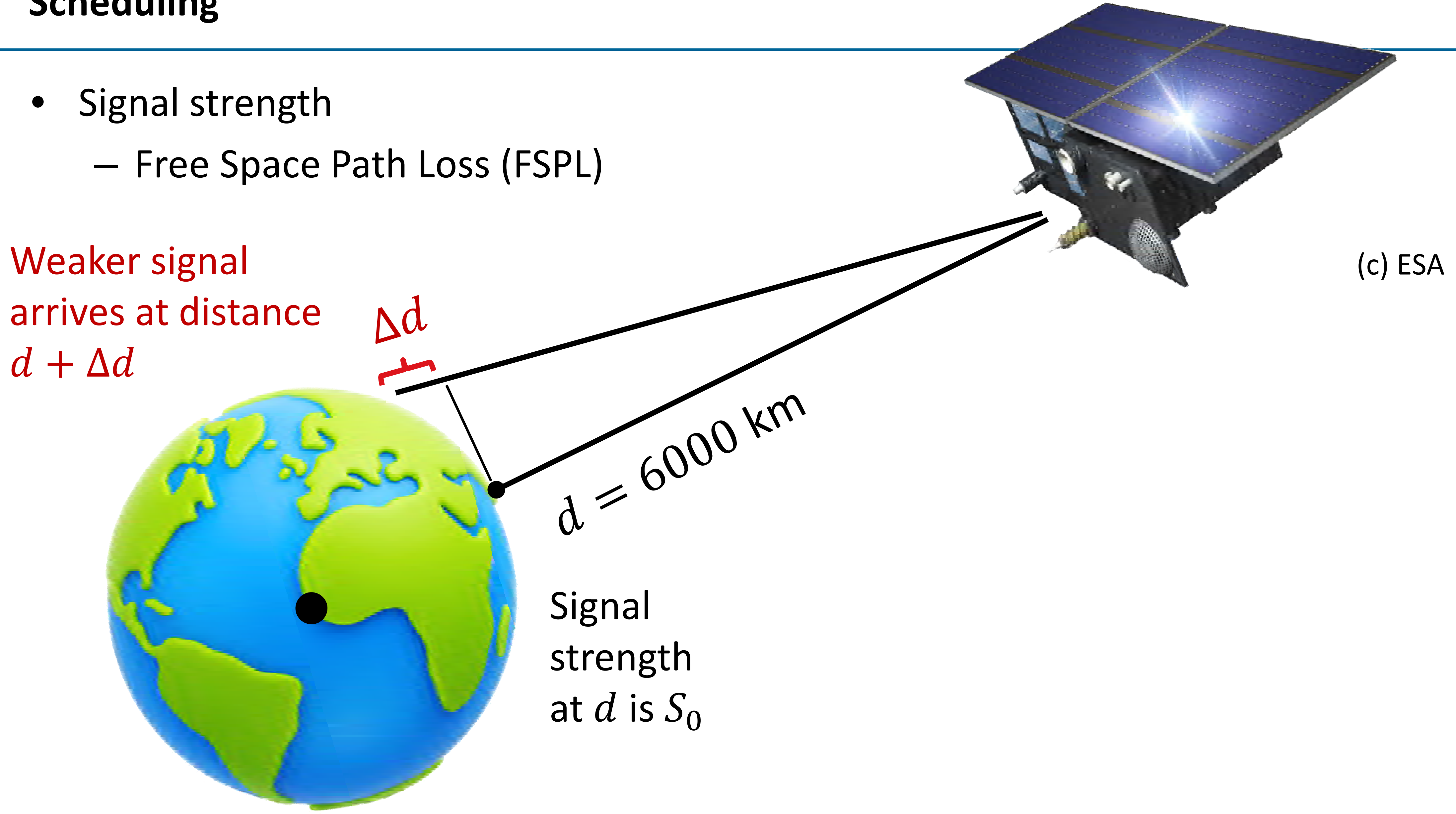
Scheduling

- DOP values can be used for scheduling
  - low values indicate good quality of orbit determination but also accurate estimation of station coordinates



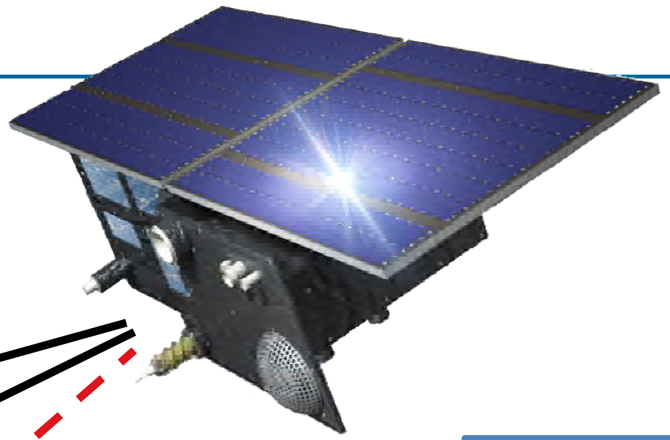
Scheduling

- Signal strength
  - Free Space Path Loss (FSPL)

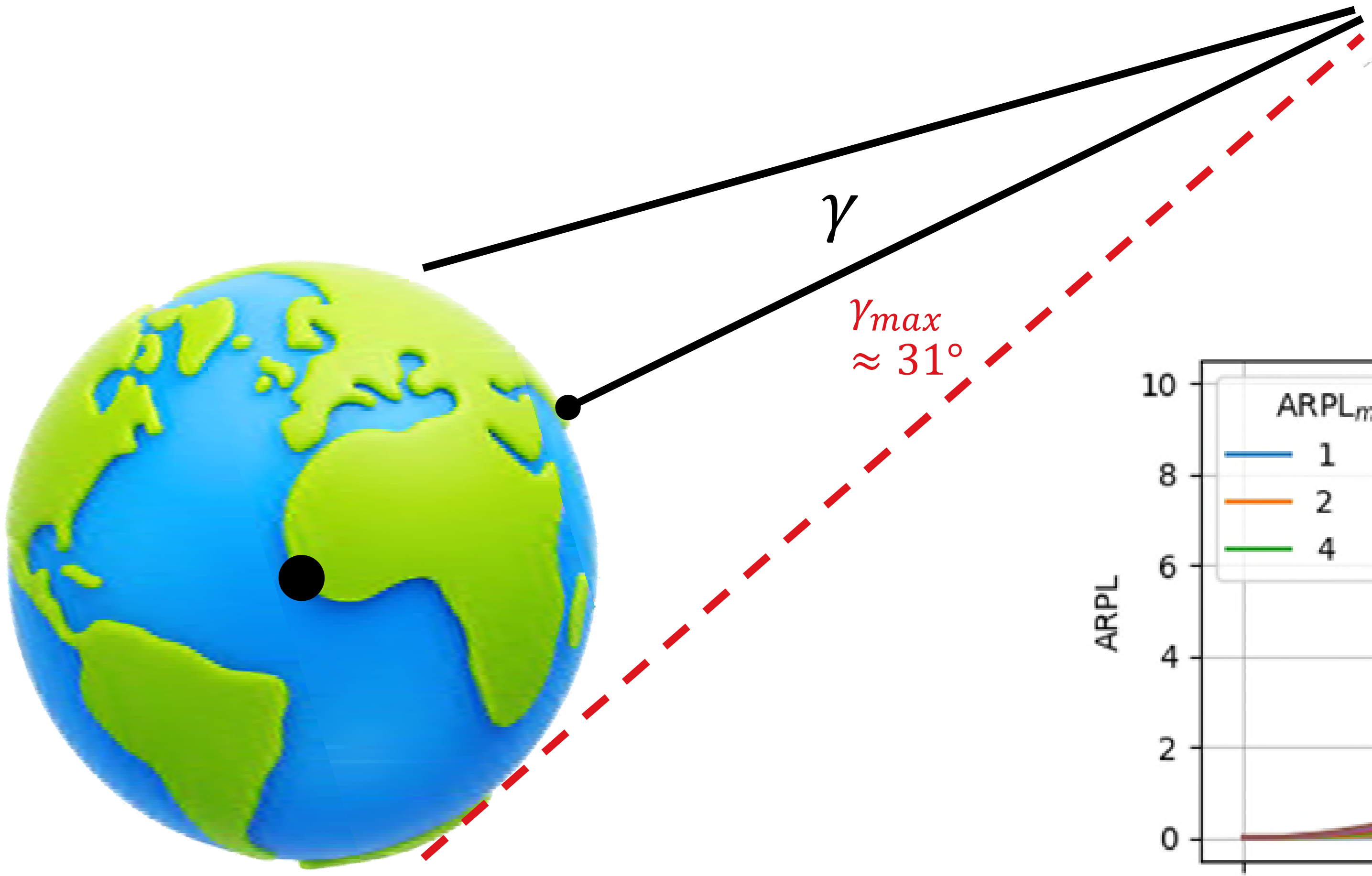


Scheduling

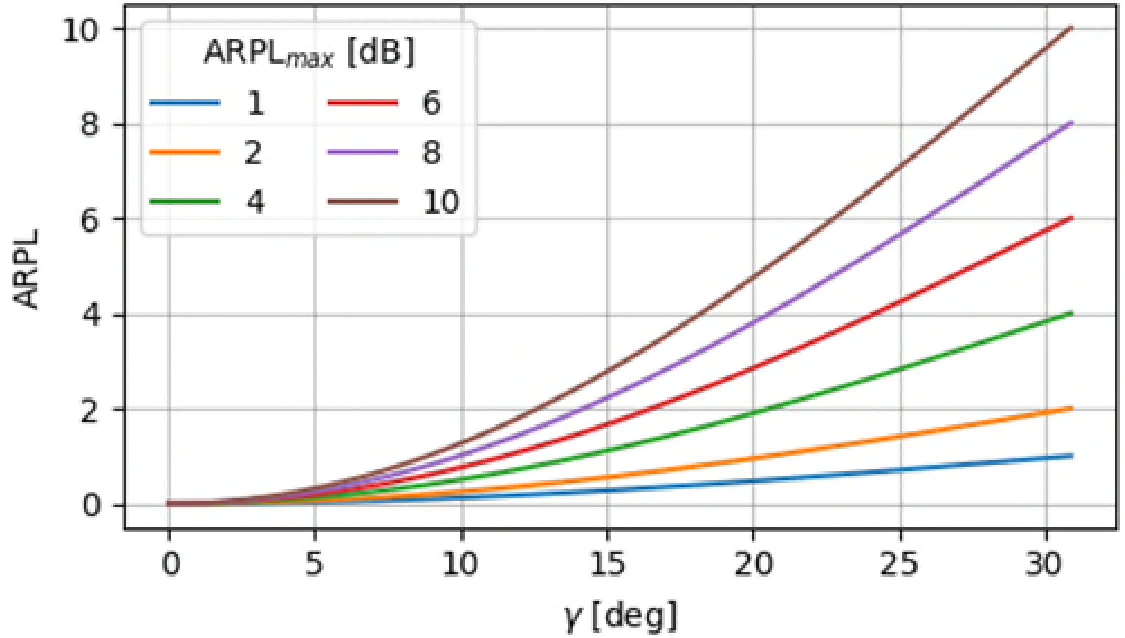
- Signal strength
  - Antenna Radiation Pattern Loss (ARPL)



(c) ESA



Next slide:
Testing different $\boldsymbol{S_0}$
and $\mathbf{ARPL}_{\boldsymbol{max}}$



Scheduling

Required Observing Duration

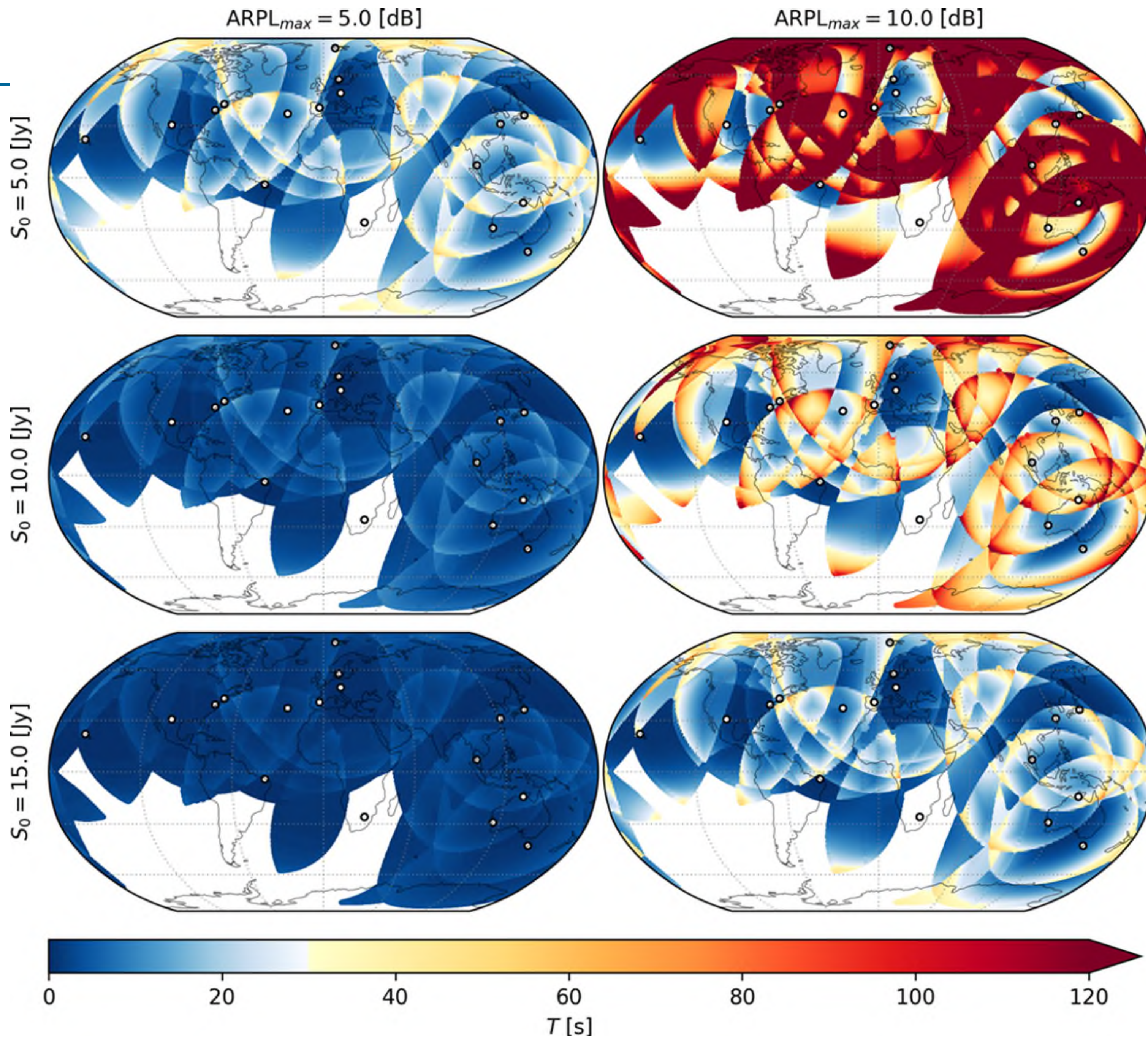
$$T = \frac{1}{\eta^2} \cdot \frac{SNR^2}{S_1 \cdot S_2} \cdot \frac{\mathrm{SEFD}_1 \cdot \mathrm{SEFD}_2}{rec}$$

Required observing duration T

- Rows: S_0
- Columns: ARPL_{max}
- Target SNR: 20 per band

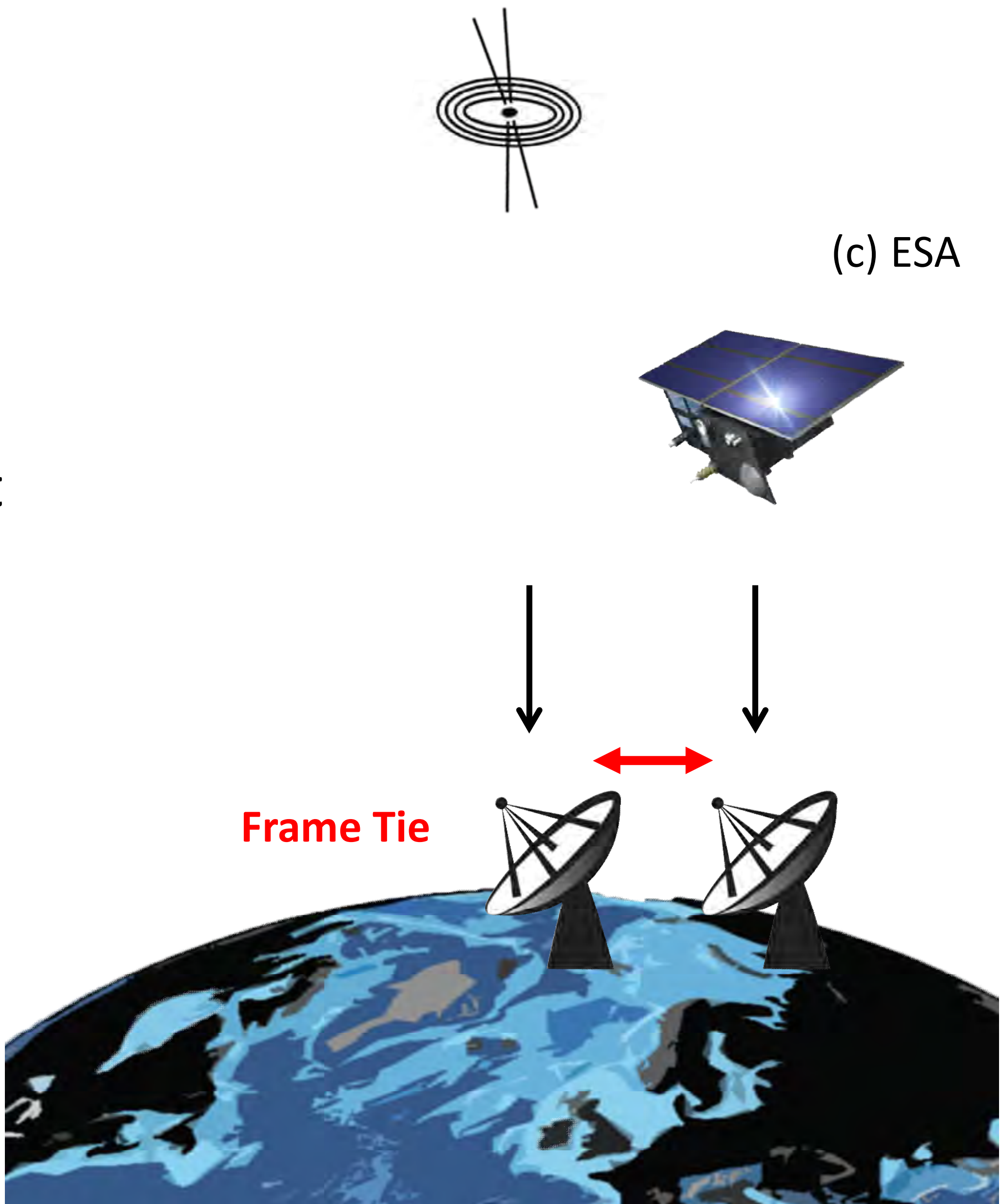
Blue areas: $T < 30$ sec

Yellow to **red**: $T \geq 30$ sec



End-to-end simulations

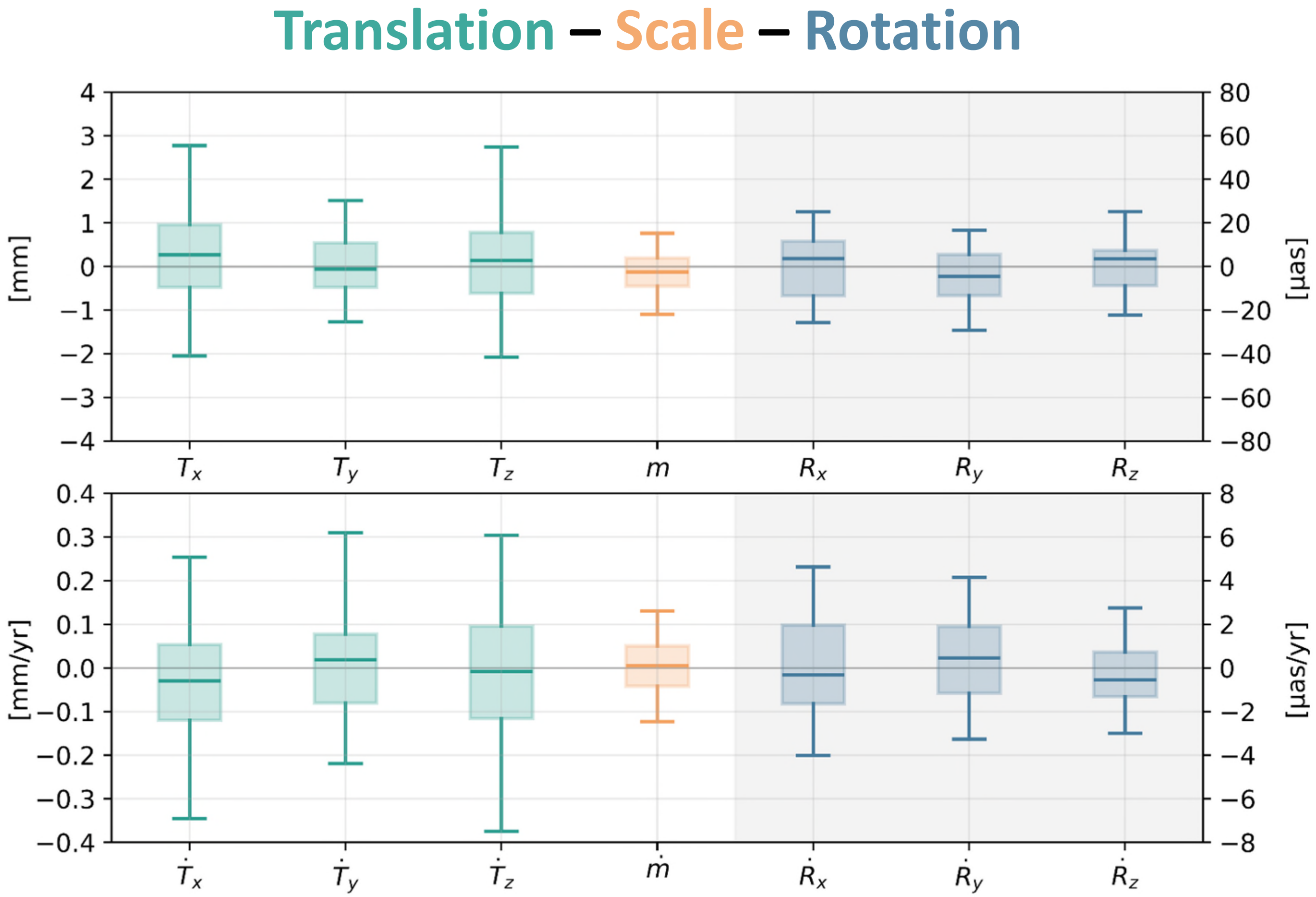
- Scheduling
  - Different networks, optimization criteria, etc.
  - Genesis next to quasars
- Monte Carlo simulations
  - Tropospheric turbulence, etc.
  - Possible systematic errors, e.g., due to different phase centres are not modelled yet
- Analysis
  - Station coordinates, orbits, etc.
- Purpose
  - Software must be ready and mature in time



End-to-end simulations

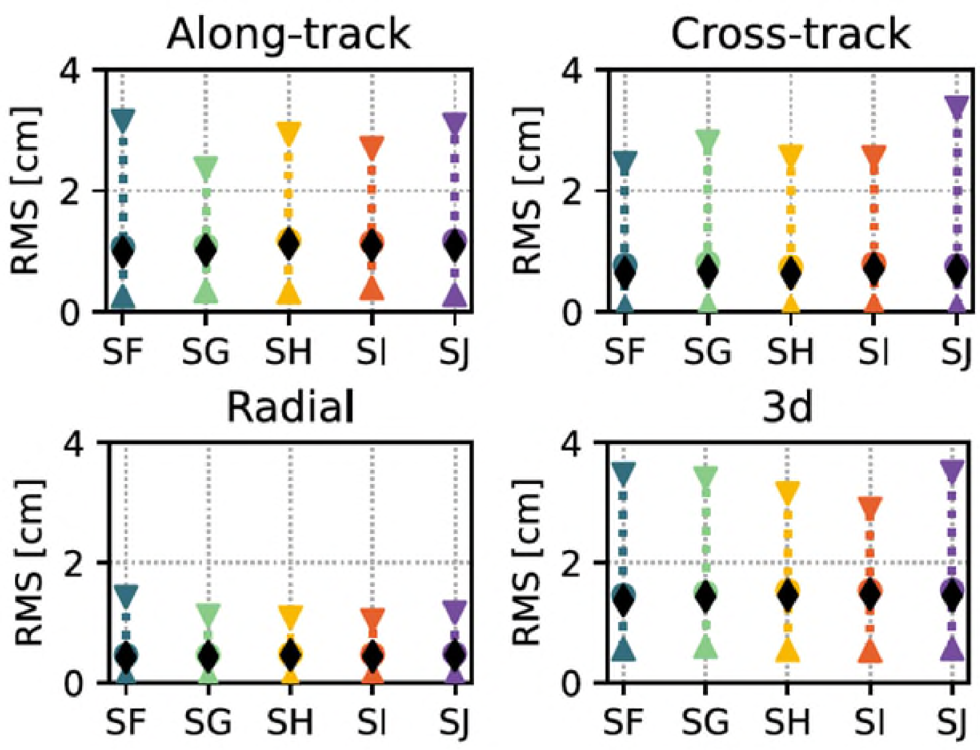
- Helmert parameters between Genesis and quasars TRFs
  - based on 30 sets of weekly 24-hour sessions over 5 years
  - 12-14% of satellite scans, 30s scan length
  - simulation of main error sources (troposphere, clock, white noise)
  - Orbits fixed
  - Loading errors not simulated

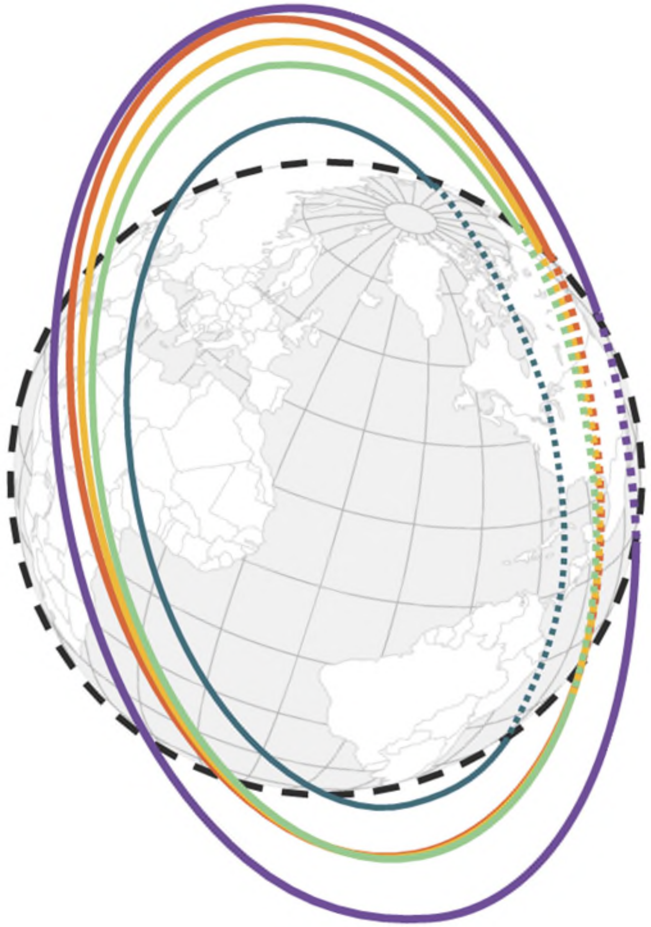
We can detect frame inconsistencies at that level



End-to-end simulations

- Orbit estimation (next to station coordinates and ERP)
  - Different semi-major axis, eccentricities, and RAAN
  - 24 VGOS network observing for 24 hours (30 sets)
  - Simulation of troposphere, clock, and white noise



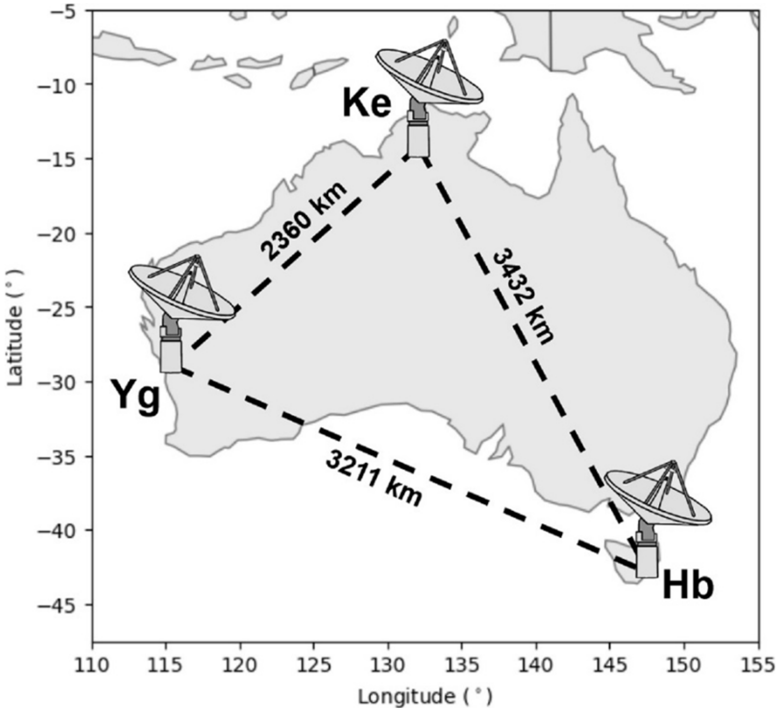


More simulations ongoing

- Orbit estimation
  - for combination with other techniques at normal equation level
  - VLBI should be part of combined orbit determination

- Impact of calibration errors on terrestrial reference frame and handling

- Real observations of GNSS satellites
  - e.g., McCallum et al., 2025



Single Station Delay Measurements (PRN-Option)

Presented by Thibault Deleu

On behalf of WG 3.7

March 2026

belspo

Royal Observatory
of Belgium

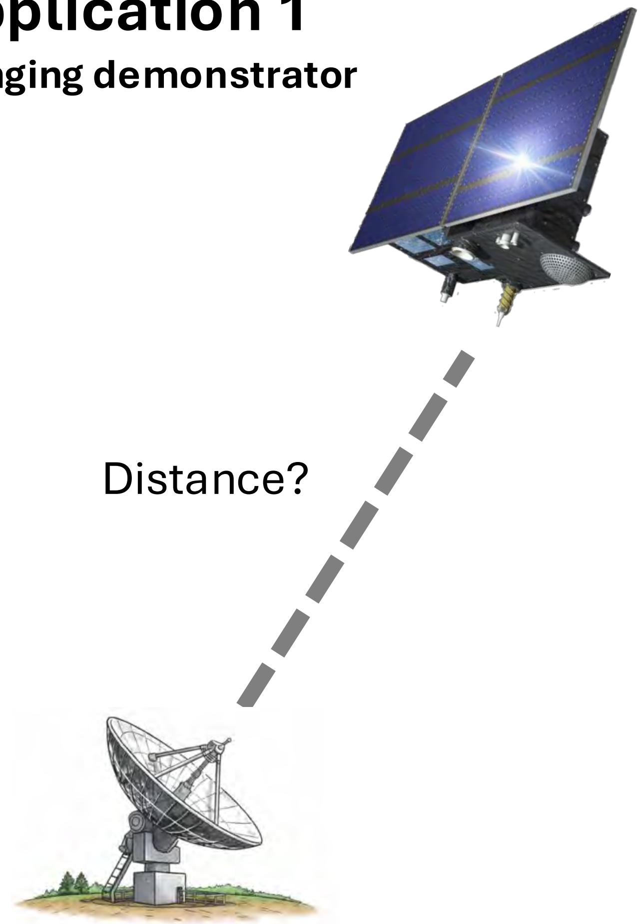
esa

Single station delay measurements

= Ranging process between the satellite and a ground station

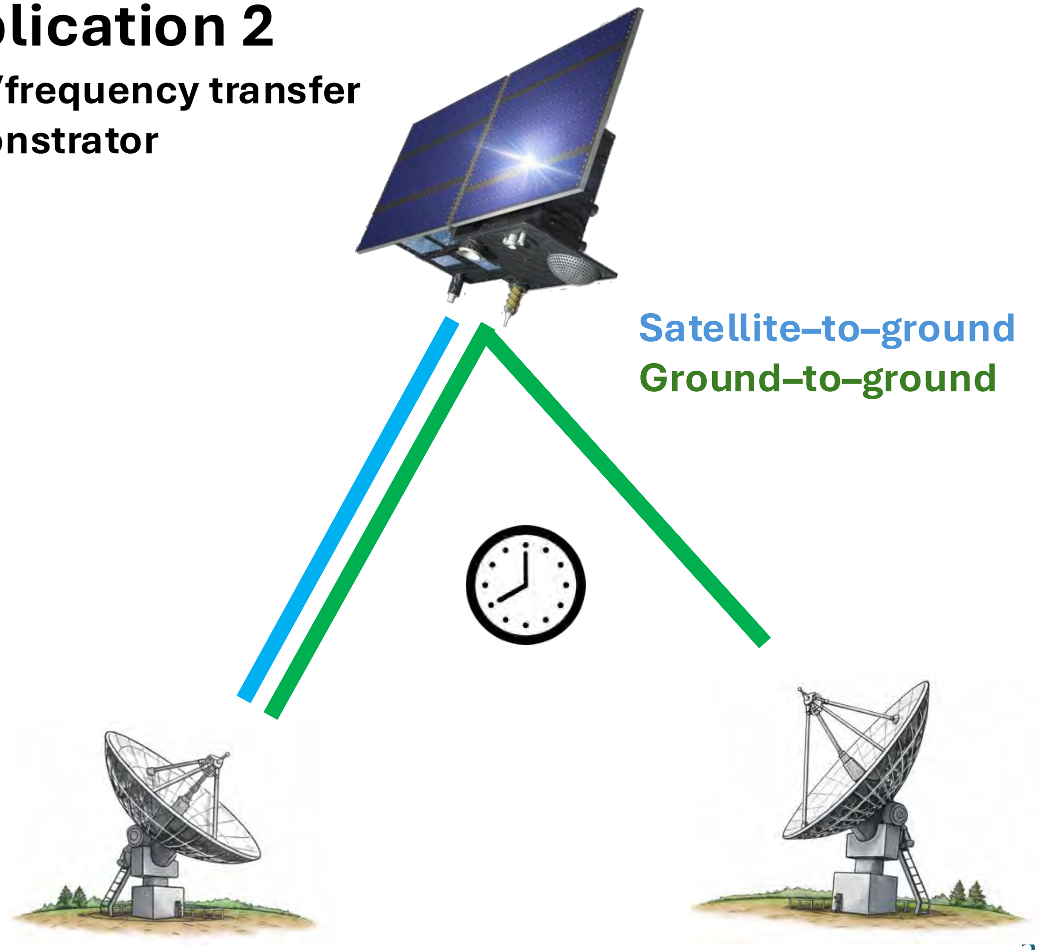
Application 1

Ranging demonstrator



Application 2

Time/frequency transfer demonstrator



Single station versus interferometric delay measurements

	Interferometric VLBI	Single Station	Key Insight
Waveform	Gaussian (white noise)	BOC signal (Galileo-like)	Genesis will not broadcast BOC and white noise together
SNR	$\sim \frac{\sqrt{S_1 S_2}}{\sqrt{N_1 N_2}}$	$\sim \frac{\sqrt{S_1}}{\sqrt{N_1}}$	15x to 50x SNR gain Scaling $\sqrt{t \cdot BW_{eff}}$
Sensitivity to e-box Group Delay	No	Yes	Need to characterize the group delay (variations)
Sensitivity to VT Amplitude Variations	Yes	Yes	Impacts SNR for both methods
Correlation Approach	DIFX	DIFX or GNSS-like (use of local replica)	GNSS-like requires equalization

Enablers and challenges

Satellite-to-Ground Frequency Transfer & Ranging

Current limitations
Satellite clock and radial delay component not visible from measurements

Work to perform
Update post-processing tools with single station measurements + remove group delay variation

Challenge
Uncertainty on group delay variations (with temperature, aging)

Time transfer

Current limitations
Clock offsets and instrumental delays cannot be distinguish

Work to perform
Remove instrumental delays (from VT and VLBI station)

Challenge
Uncertainty on absolute group delay

Ground-to-ground frequency transfer

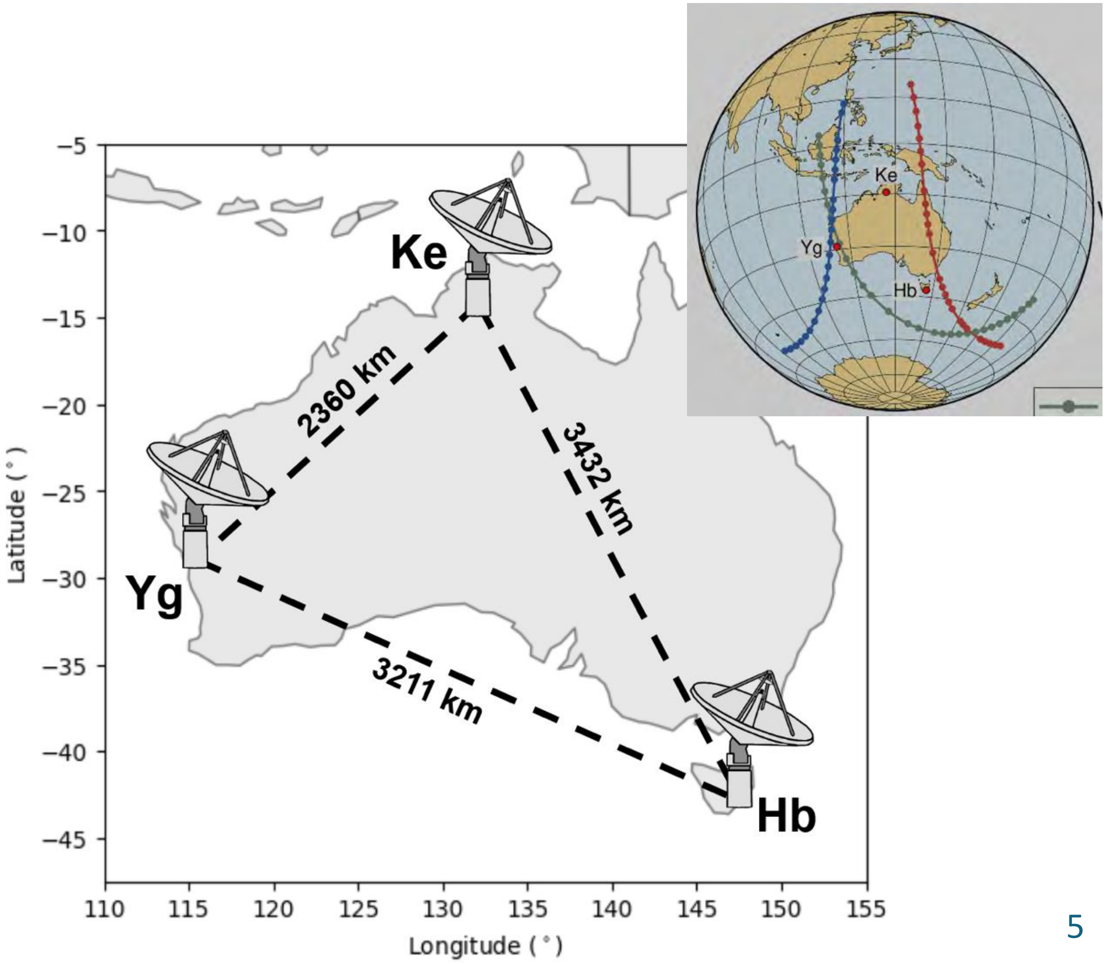
Current limitations
Long integration time needed to achieve good SNR

Work to perform
Replace interferometric correlation with differential single station correlations

Challenge
Accurate timestamping for data combination

Single station correlation test
ASO304 Experiment

- ASO304 experiment (Oct 30, 2024)
  - AuScope array, 5 GPS satellites
  - L1 & L2 frequencies
  - Single-station correlation (FGI-GSRx)
  - Geometric modeling
  - Systematic analysis



Signal properties

GPS signals

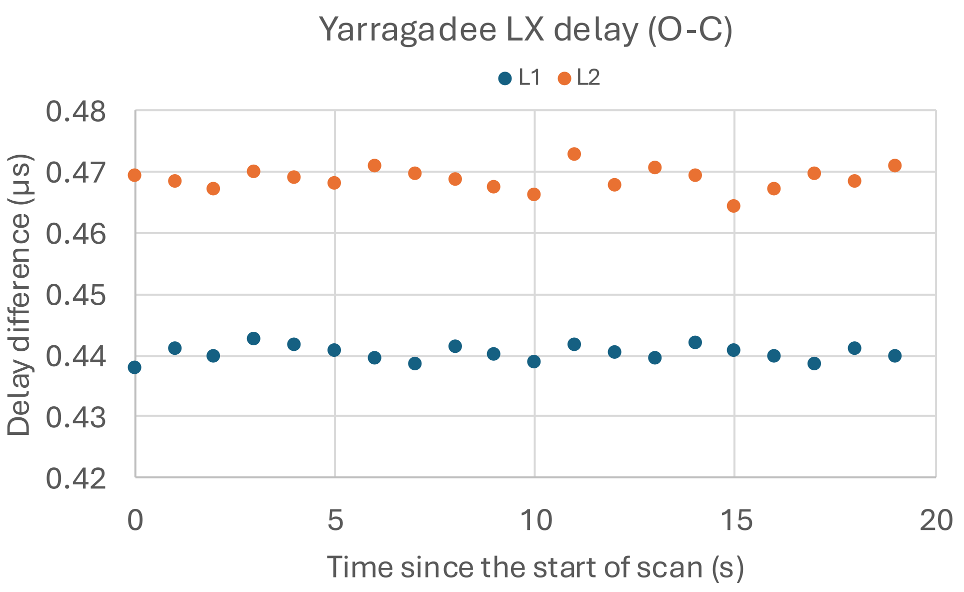
	GPS L1	GPS L2
Carrier frequency	1575.42 MHz	1227.6 MHz
Chip rate	1.023 Mbps	511.5 kbps
Code length (chips)	1023	10 230
Code length (time)	1 ms	20 ms

At VLBI station

	GPS L1 (X and Y pol.)	GPS L2 (X and Y pol.)
Sampling frequency	256 Msps (8 bits)	256 Msps (8 bits)
Sample duration	3.9 ns	3.9 ns
Number of code phases @ sampling rate	256 000	5 120 000
Scan length	~ 20 sec	~ 20 sec

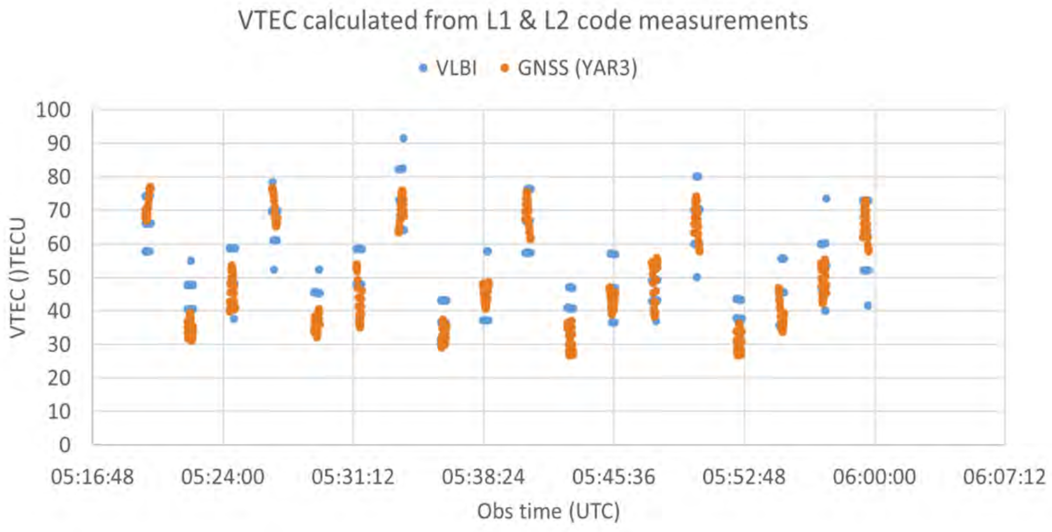
Correlation Precision: G10 @ Yarragadee

LX Code Delay (O-C) — L1 & L2



Constant bias < 1 μs; Precision in the order of 2 ns

VTEC from L1 & L2 — VLBI vs GNSS (YAR3)



TEC values consistent with GNSS receivers

Code delay measurement only, with cubic interpolation

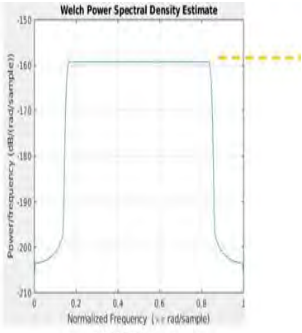
Amount of data: 30 min (Yg) + 40 s (Hb & Ke)

Waveform comparison

Objective	Tested	Method
Waveform for single-station operations (precision & side lobes)	AWGN + BOC with varied parameters	3 noise scenarios, same max. power spectral density

Signal Waveforms

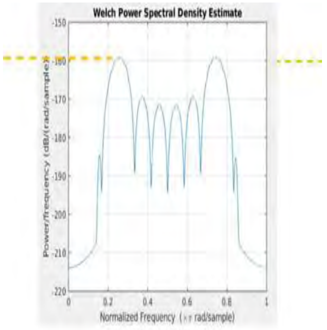
AWGN



AWGN signal

Gaussian / flat spectrum

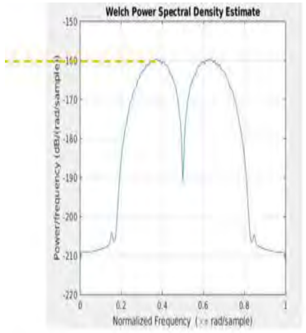
BOC(120,40)



BOC(120,40)

Less power, more side lobes

BOC(80,80)



BOC(80,80)

More power, less side lobes

Same max. power spectral density

Simulation Setup

** VieRDS updated with new BOC signal capabilities*

Scenarios

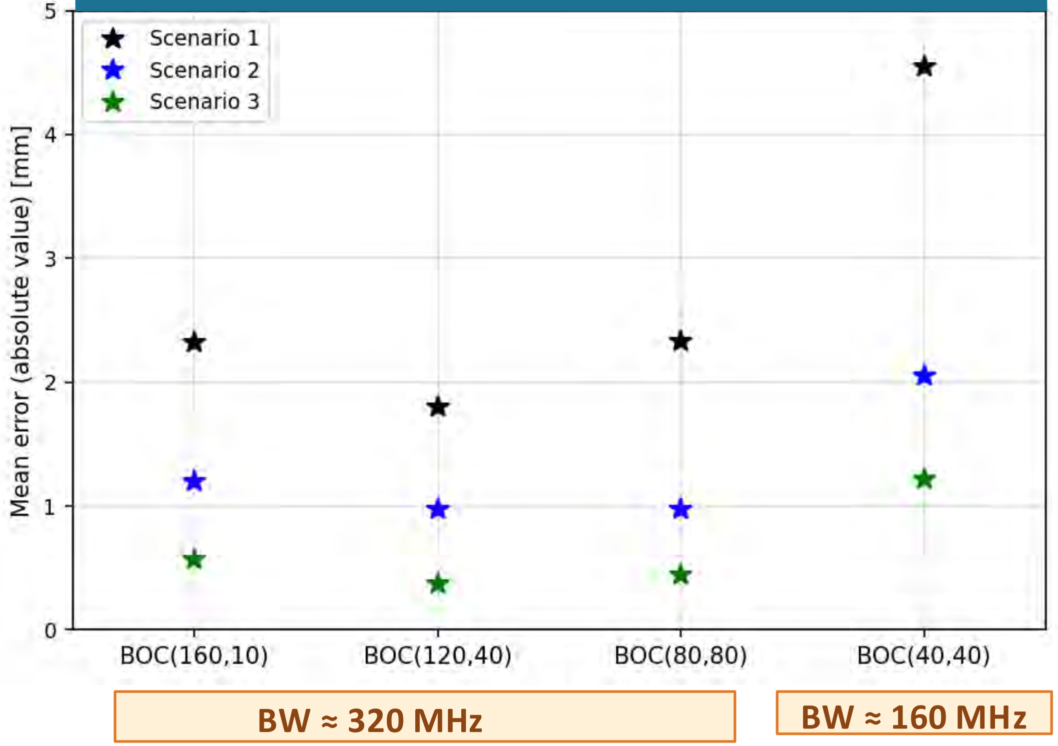
Scenario	System SEFD [Jy]	(Max) Source Flux [Jy]
1	5 000	1
2	2 500	3
3	2 500	10

Assumptions

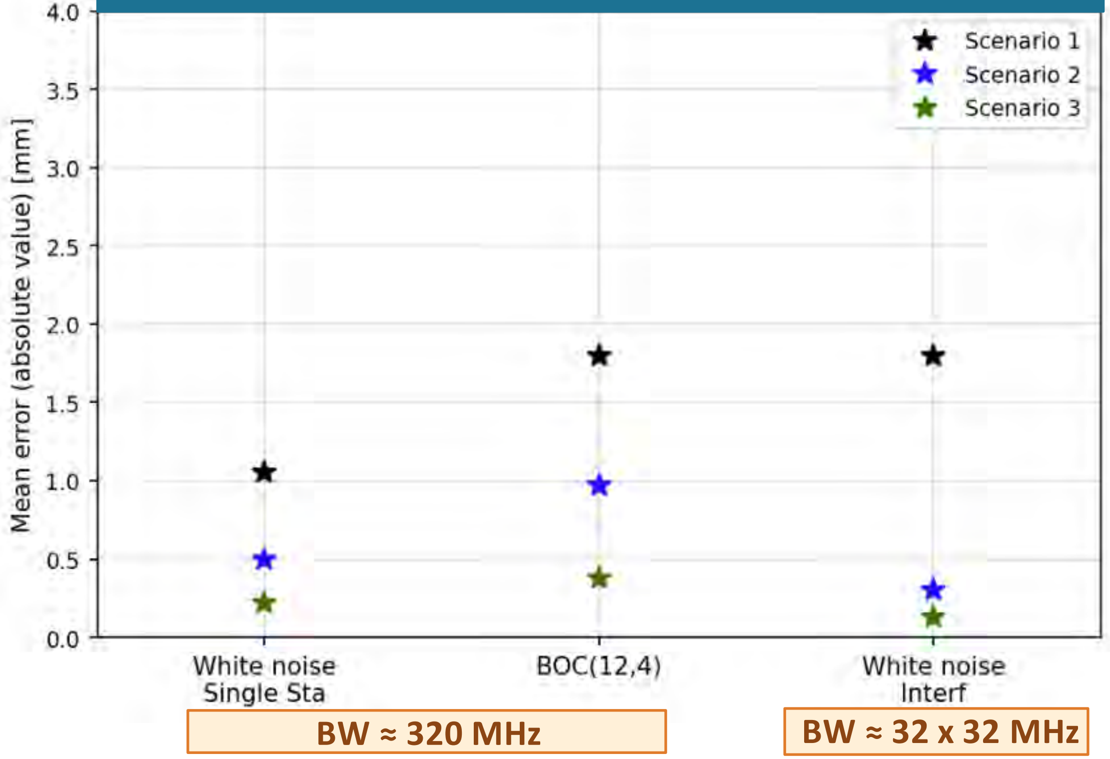
No delay between signals	Filter BW = 320 MHz
Same max. PSD between signals	FPGA clock = 512 MHz
Quantization: 2 bits	f_0 = 1.067 MHz
Integration time: 1 s	Code length: 4092

Results BOC versus AWGN

1. Precision for several BOC signals



2. Comparison with white noise



1. Signal bandwidth most important factor impacting precision
=> Side lobe level may be a second criterion

2. Precision slightly higher with white noise (single station)
+ Performance similar to interferometric case

Next steps

GNSS data

01 **Carrier Phase Tracking**
mm-level precision potential

02 **DIFX correlation**
Performance comparison with GNSS receiver

03 **Process Full ASO304 Dataset**
Including Galileo BOC signals

Genesis — Wideband

01 **Waveform simulations with impairments**
Include e-box, antenna, atmospheric delay, etc.

02 **E-box group delay (variations)**
In laboratory environment

03 **Multi-band single station**
and ionospheric correction strategy

04 **Frequency transfer and ranging performance assessment**
Space-to-ground and ground-to-ground performance

WG-3 questions

Genesis Science Workshop 2026

2026-02-13

Brussels

WG-3 mentimeter questions

- Is there anything that is missing in the work done so-far by WP-3?
- What VLBI aspects are most important for ESA and industry?
- What do the other WPs want WP-3 (VLBI) to focus on?

General questions to ESA and industry (1/2):

- Can the VLBI transmitter (e-box) be operated to achieve approximately constant power spectral density?
- Will the transmit antenna patterns include effects due to the satellite structure?
- When will preliminary antenna PCO and PCV be made available?
- How and when will the Genesis attitude be provided and to what accuracy?
- When will example attitude information be made available?

General questions to ESA and industry (2/2):

- VLBI transmitter (e-box): At what granularity will the group delay measurements of the instrument in terms of frequency and temperature be provided?
- Will it be possible to use the VLBI white noise signal for one-way-ranging correlation?
- What is the anticipated operation mode in terms of VLBI signal and PRN signal?

General questions to the other WGs:

- What information from the VLBI-side is needed for the future multi-technique combinations?

- How shall the Genesis orbit be represented for the multi-technique combination?