Full SSR-Based Frequency Transfer for Compact Reference Frequencies

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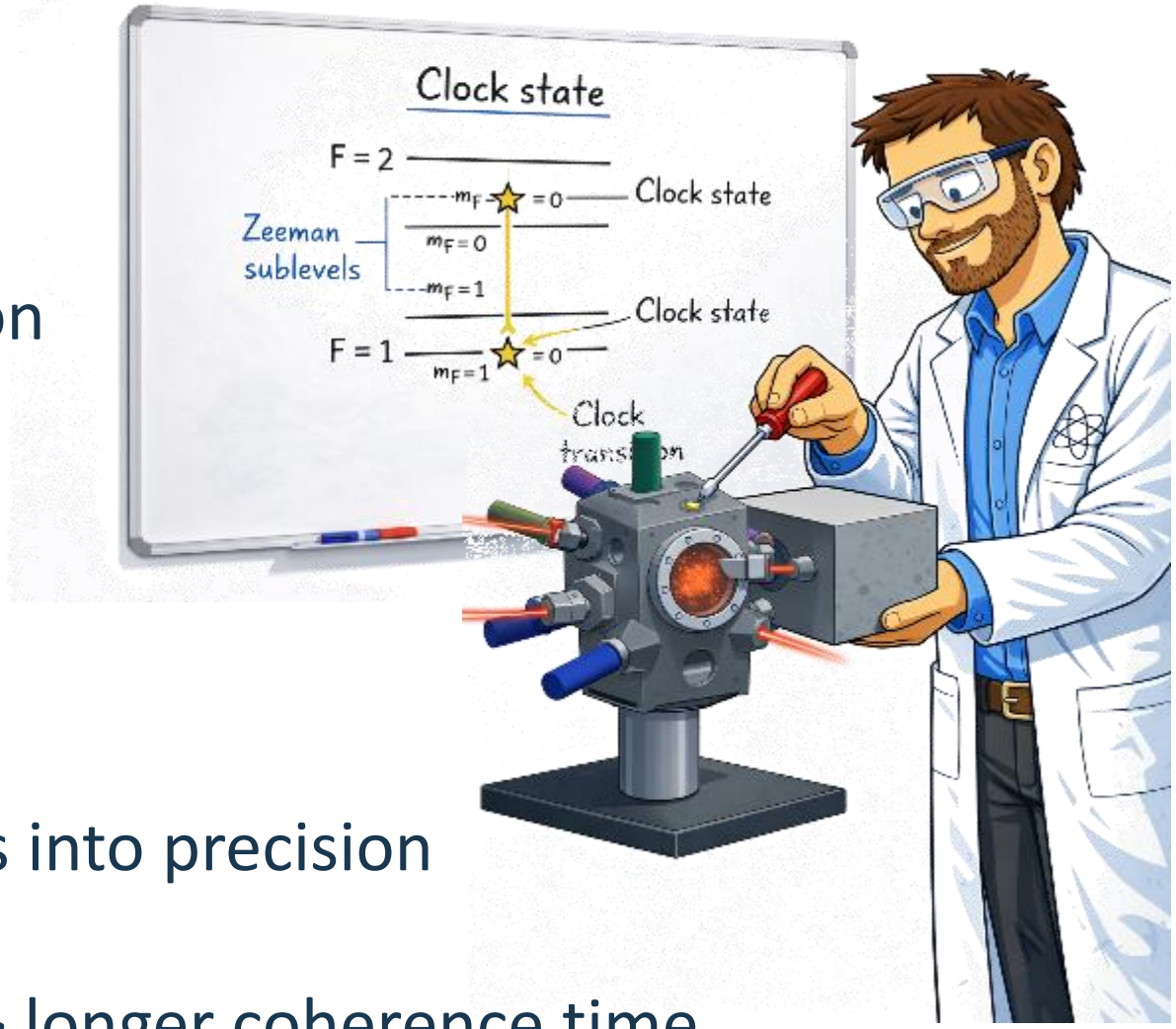
Motivation

- GNSS Time&Frequency Synchronization
  - Communication
  - Power Grid operation

- **Quantum Technologies**
  - Research Facilities
  - Frequency stability directly couples into precision of measurements
  - Atomic states: smaller linewidth => longer coherence time
    - Quantum Computer, Atomic Clocks etc.



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Motivation

- Dark Fiber Link
  - High performance
    - ~5e-16 @ 1s [2]
  - High costs
  - High maintenance

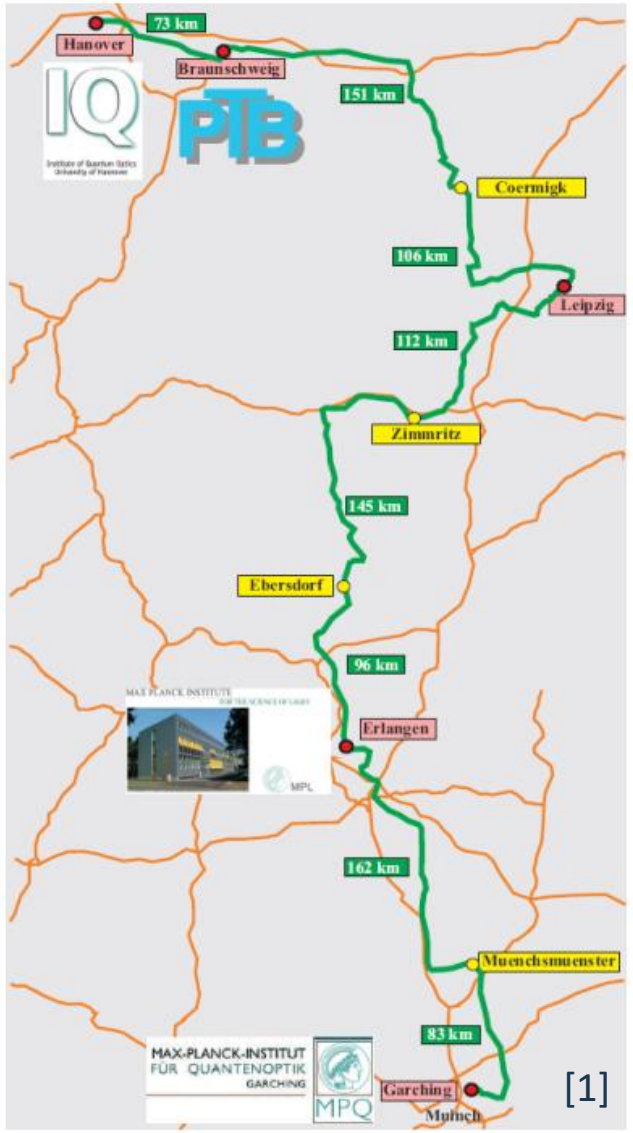

Fig. 1: Fiber link from PTB in Braunschweig to the IQ at LUH, Hanover and to the MPQ, Garching via Leipzig and MPL, Erlangen. Intermediate containers for signal conditioning are marked as yellow dots.

[1] H. Schnatz *et al.*, *IEEE* (2009), [2] F. Guillou-Camargo et al., Applied Optics (2028)

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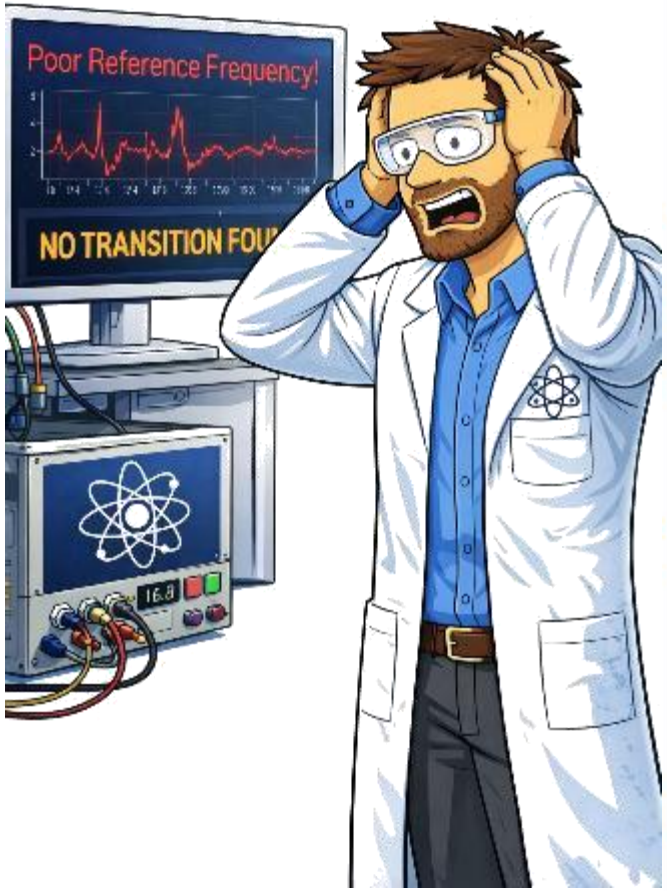

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- What if you are not part of the fiber network?

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Motivation

GNSS based frequency transfer

- GNSS Disciplined Oscillator
  - Steered to carrier frequency
  - Longterm stable but affected by atmosphere

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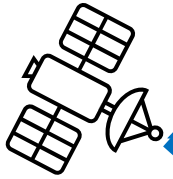
- **SSR-based frequency transfer**
  - **S**tate **S**pace **R**epresentation
  - Similar to PPP-AR
  - Utilizes a regional reference network



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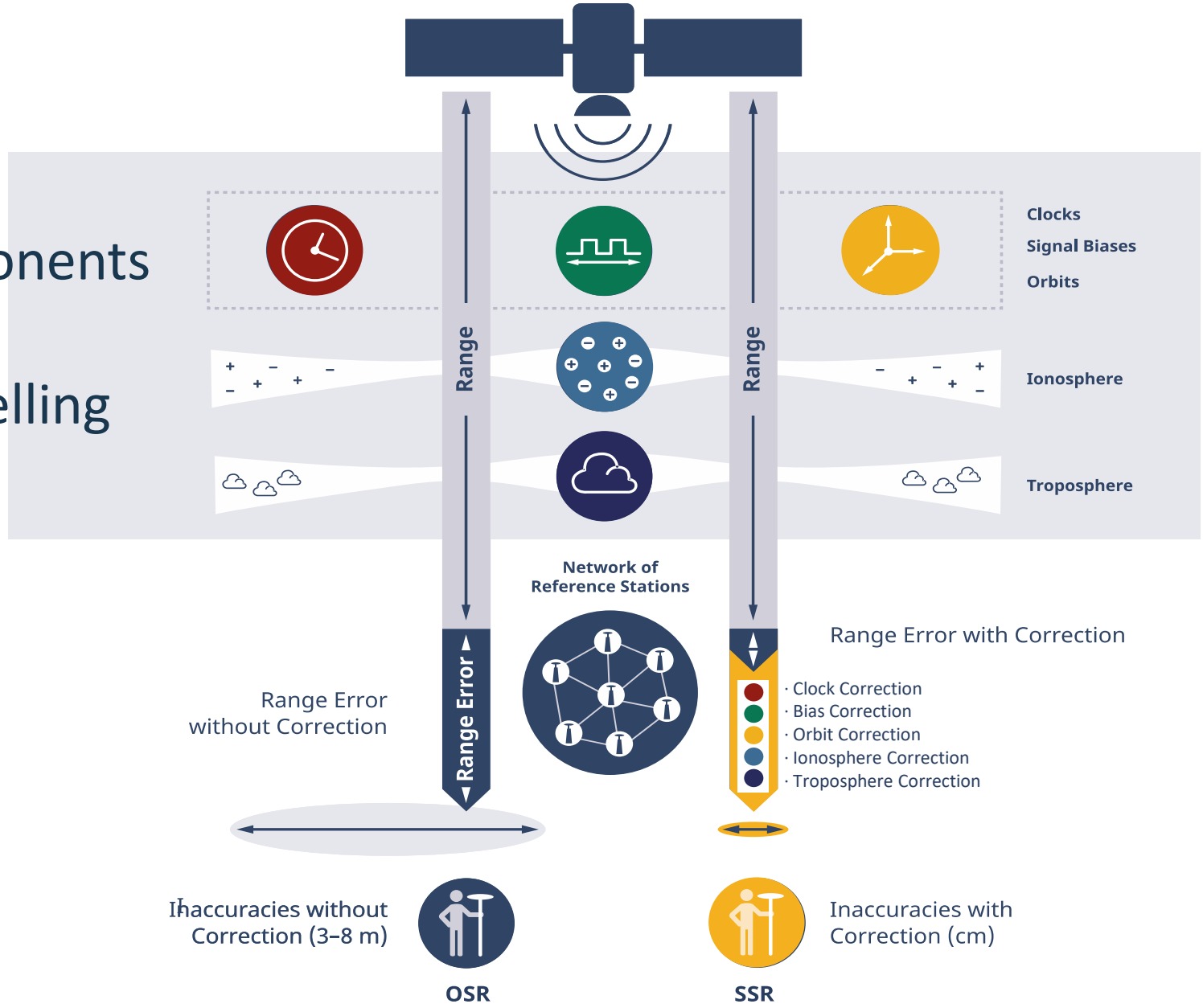
SSR

What are the benefits?

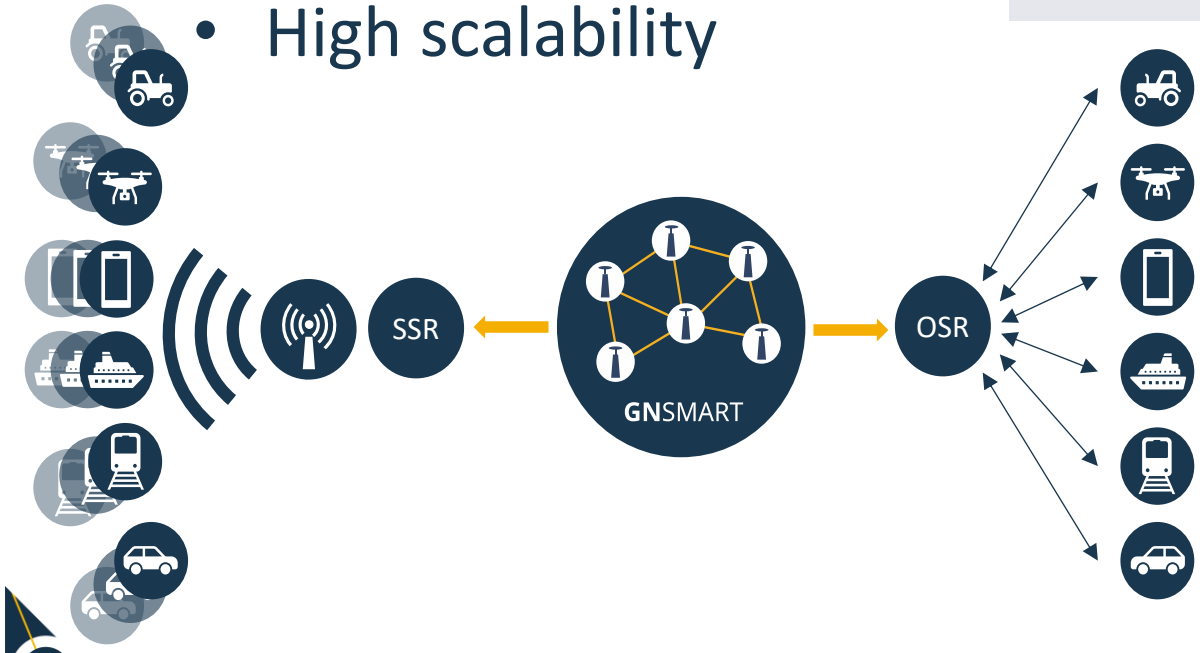
- Separates correction components
- Used for positioning
- Regional troposphere modelling

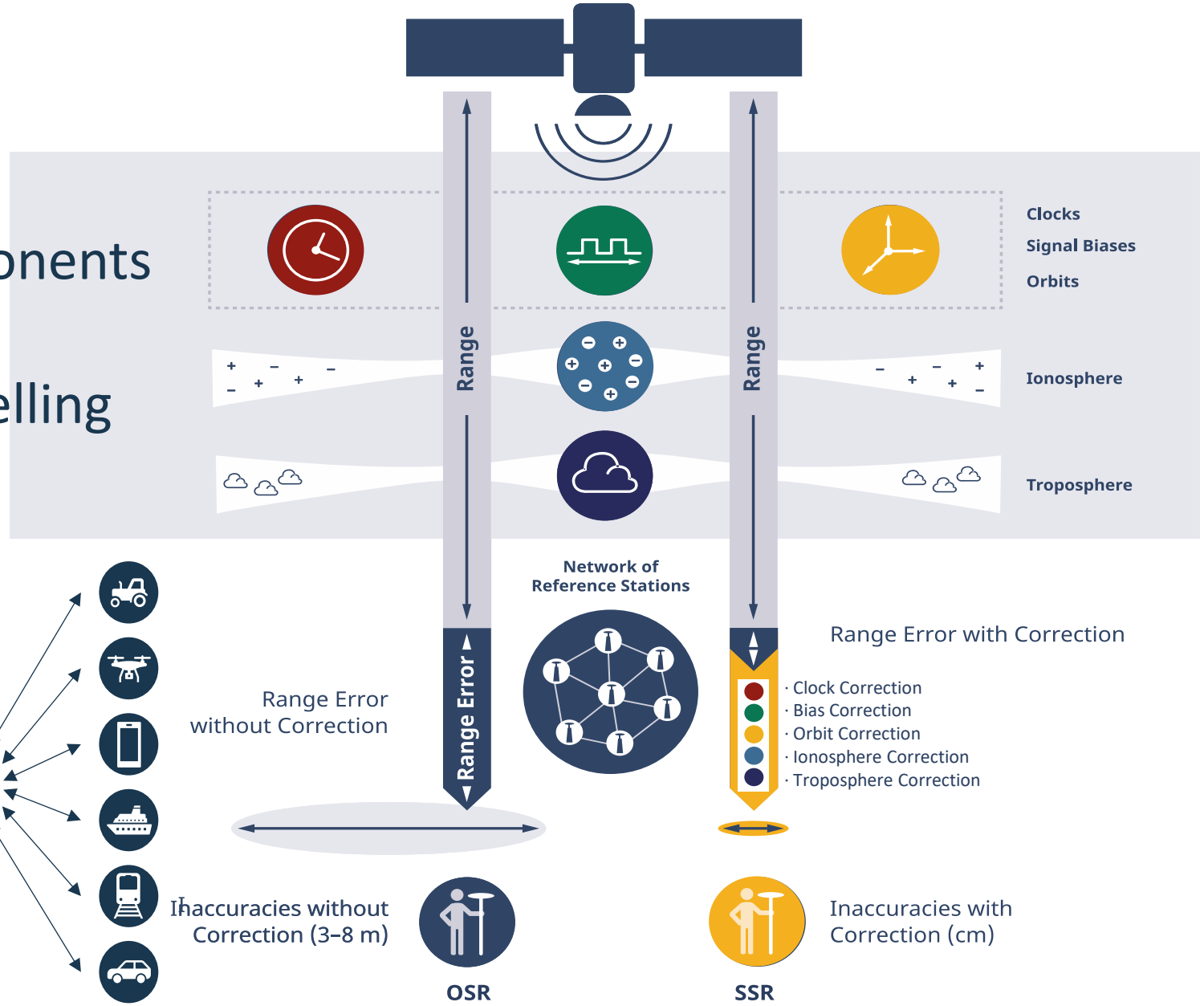


SSR

What are the benefits?

- Separates correction components
- Used for positioning
- Regional troposphere modelling
- Broadcast Corrections
  - High scalability



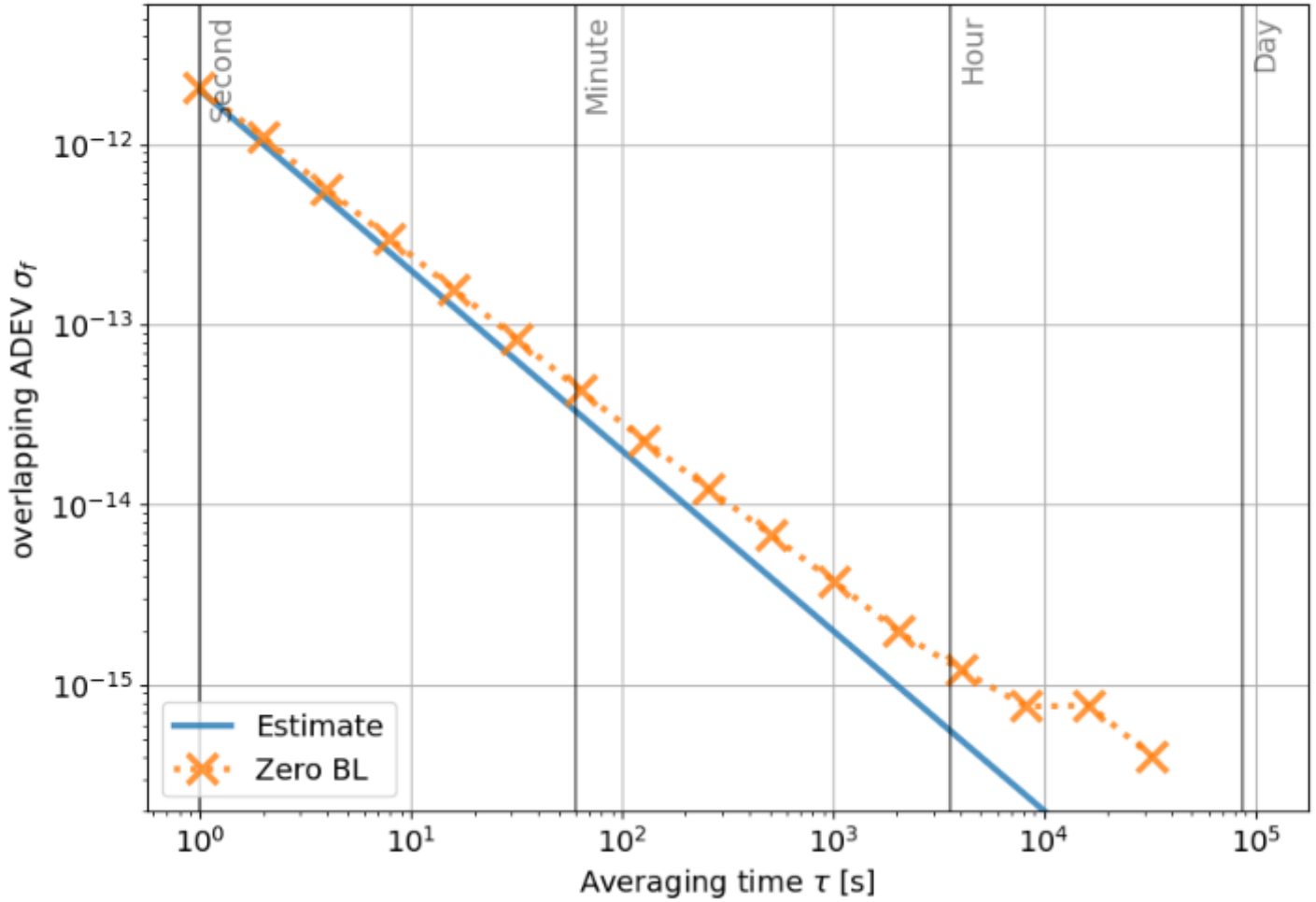


SSR-based frequency transfer

- Our estimated GOAL:

$$\sigma_f(\tau) = 2 \cdot 10^{-12} \cdot \tau^{-1}$$

- First Test: Zero-Baseline
  - Two RCVR
  - Same Antenna
  - Same OCXO

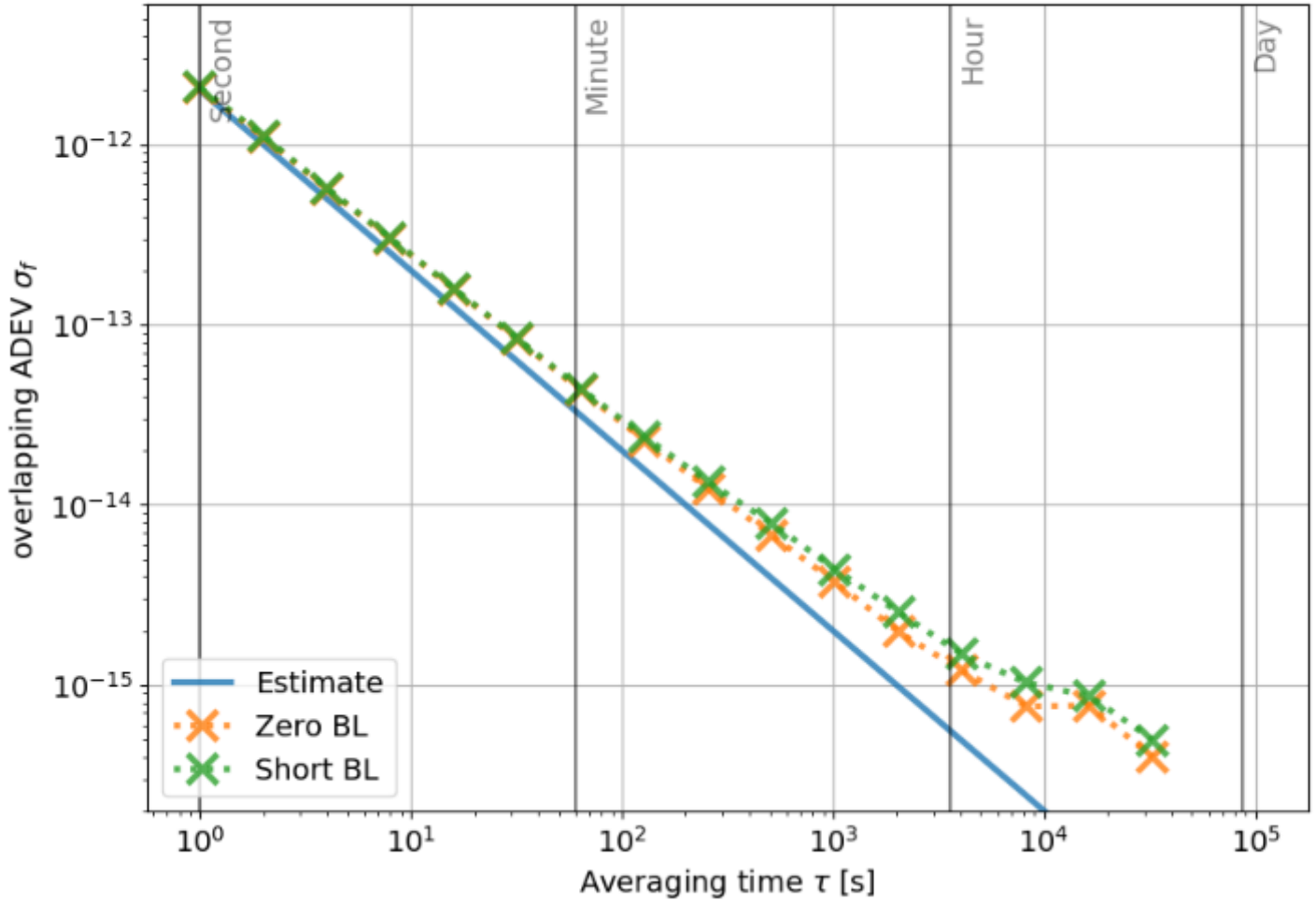


SSR-based frequency transfer

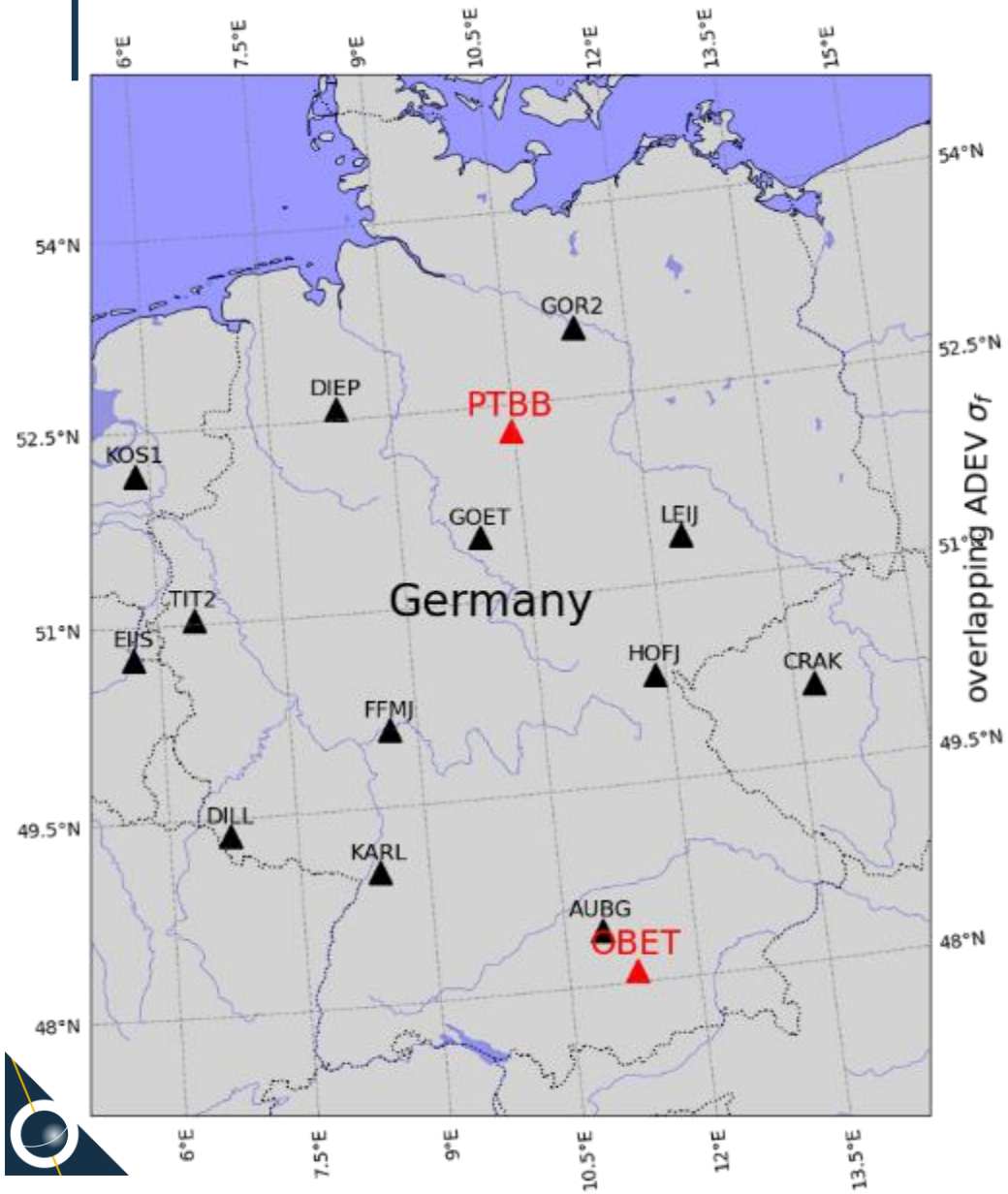
- Our estimated GOAL:

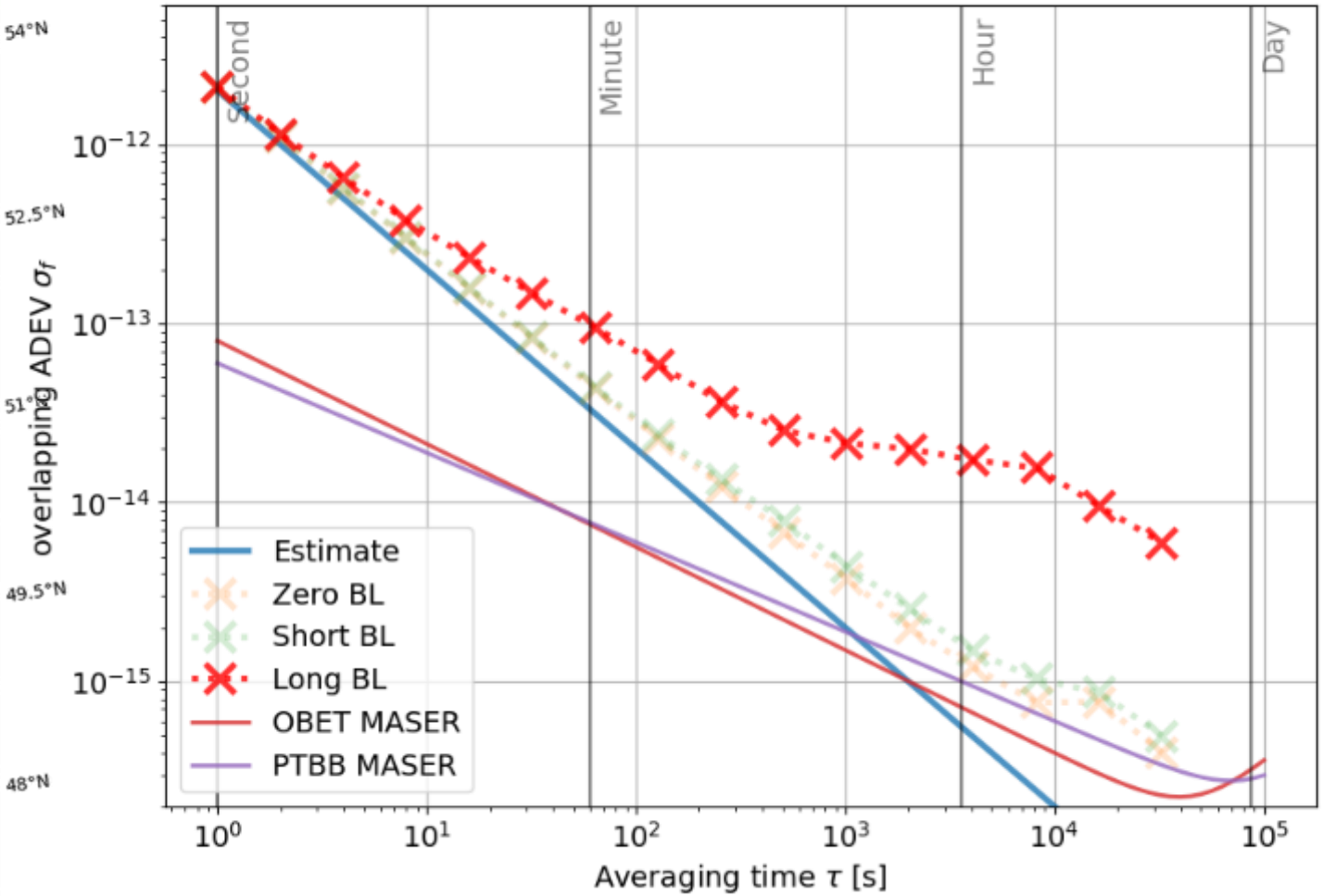
$$\sigma_f(\tau) = 2 \cdot 10^{-12} \cdot \tau^{-1}$$

- First Test: Zero-Baseline
  - Two RCVR
  - Same Antenna
  - Same OCXO
- Short-Baseline
  - Two Antennas
    - ~ 10 m apart



SSR-based frequency transfer





SSR-based frequency transfer

What do we get?

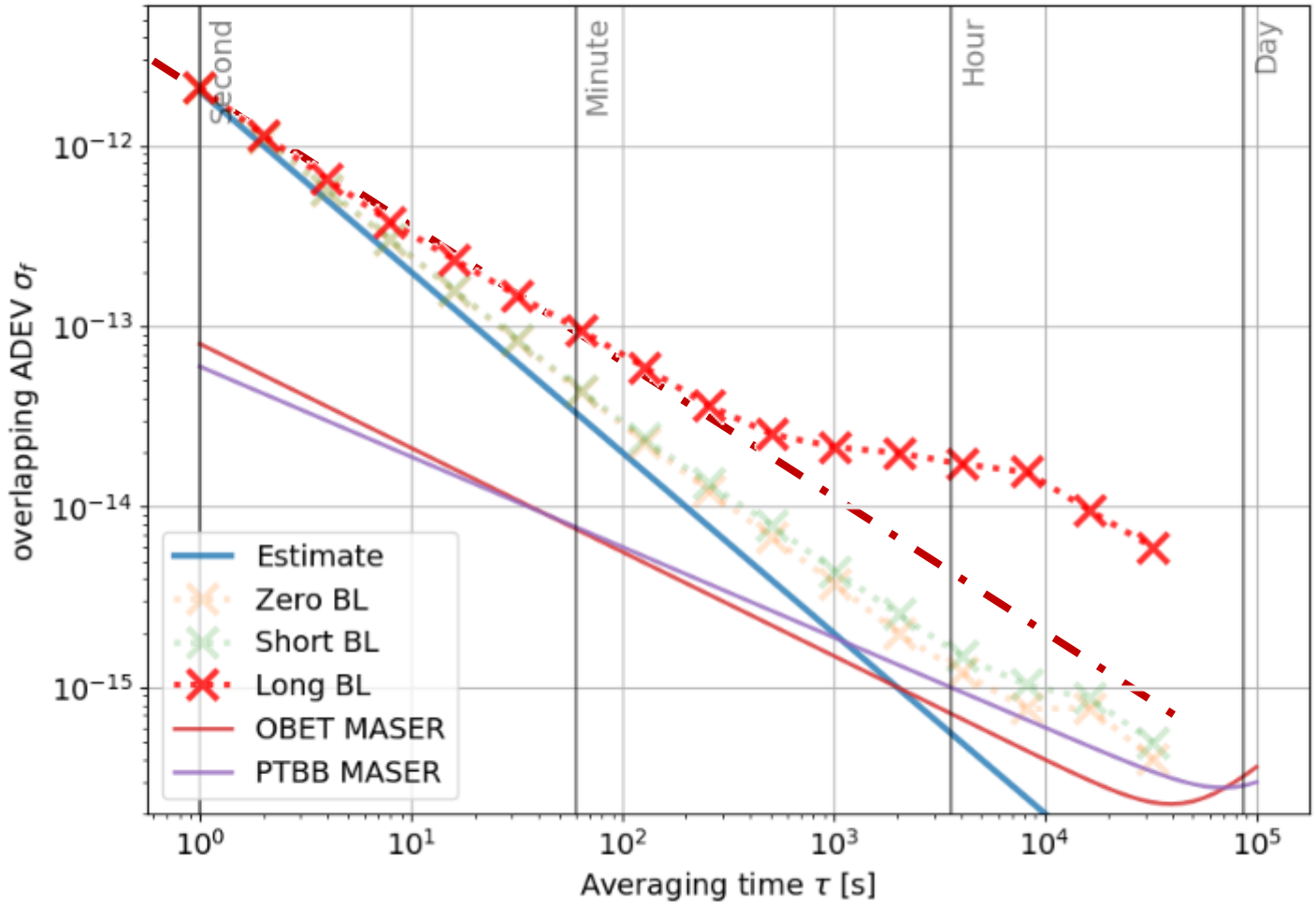
- Long-Baseline
- Our Goal:

$$\sigma_f(\tau) = 2 \cdot 10^{-12} \cdot \tau^{-1}$$

- Measured:

$$\sigma_f(\tau) = 2 \cdot 10^{-12} \cdot \tau^{-0.75}$$

- Drift at 1000 seconds



SSR-based frequency transfer

KOFREF (compact reference frequency)

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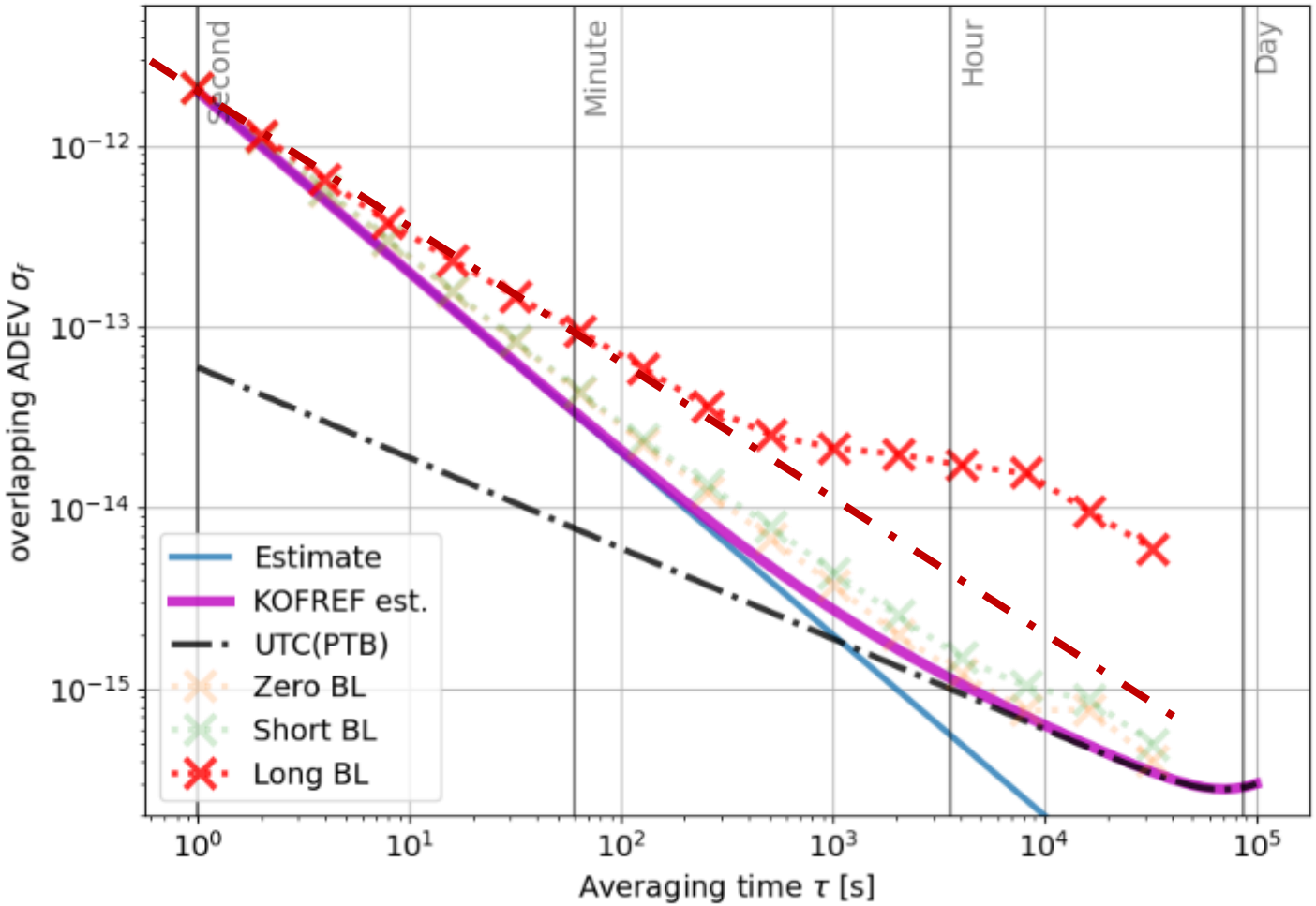

SSR-based frequency transfer

KOFREF (compact reference frequency)

- Frequency link through Germany

- Our Goal:

$$\sigma_f(\tau) = 2 \cdot 10^{-12} \cdot \tau^{-1}$$

- Measured:

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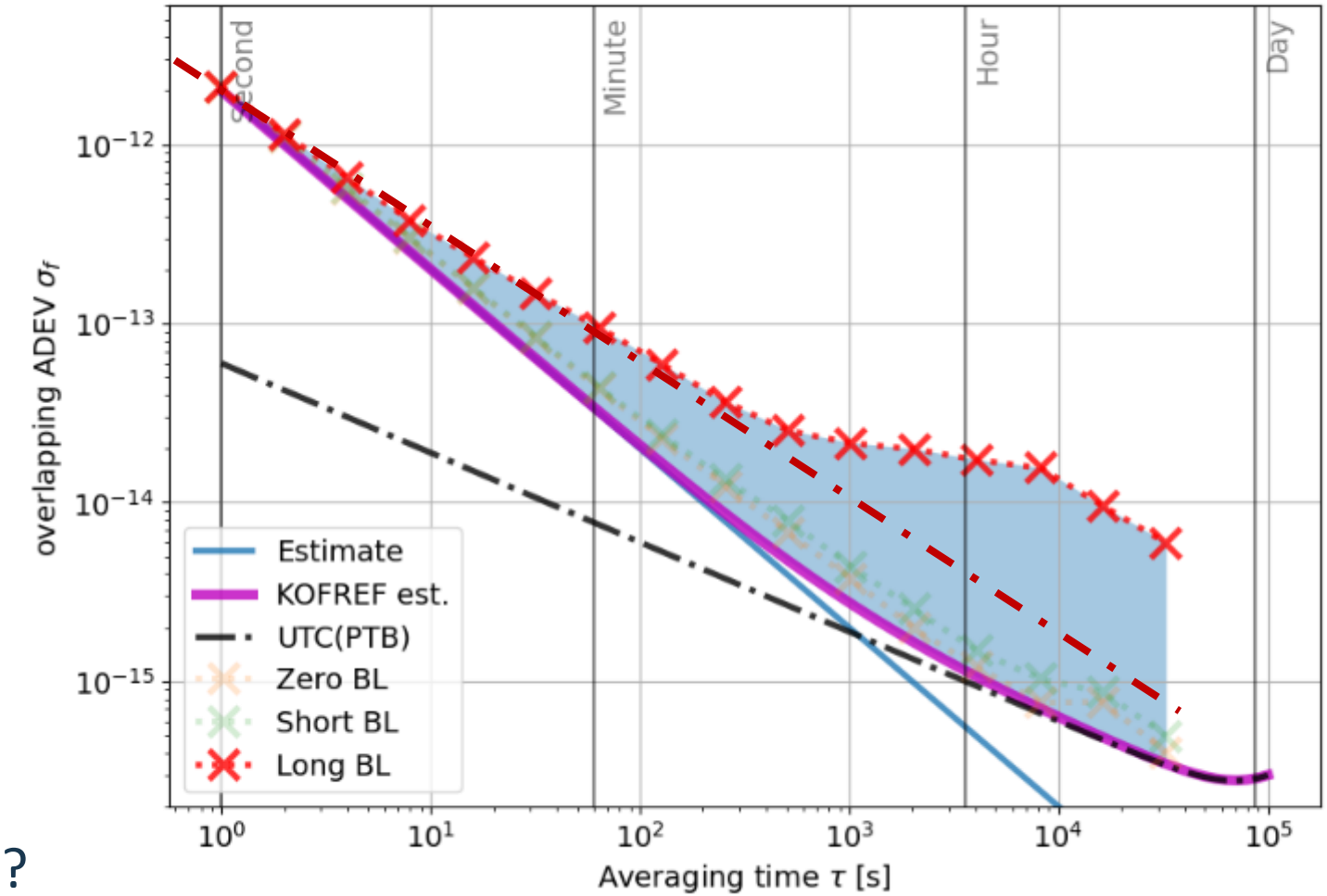
- Room for improvement
  - Better atmosphere models?



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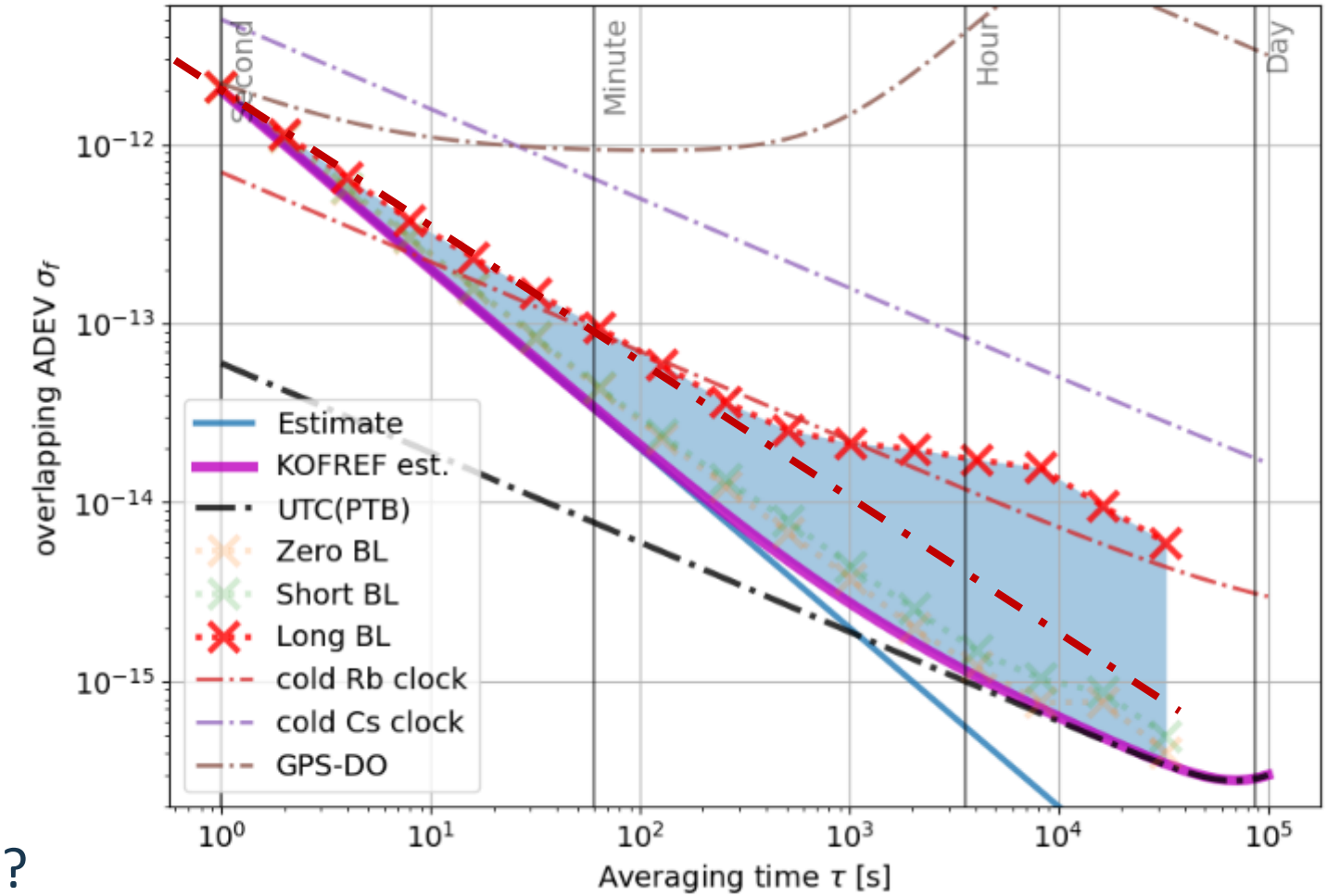
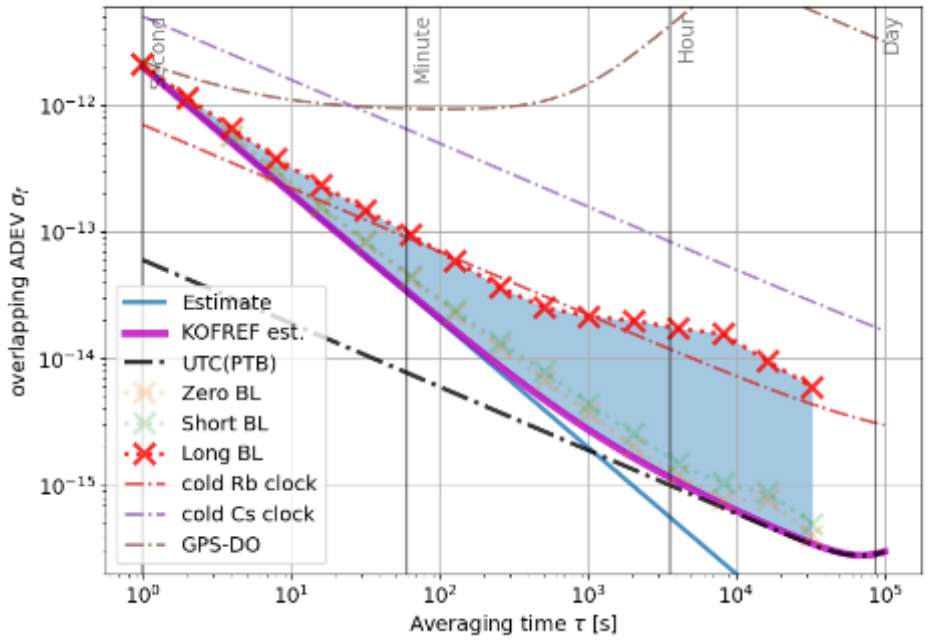
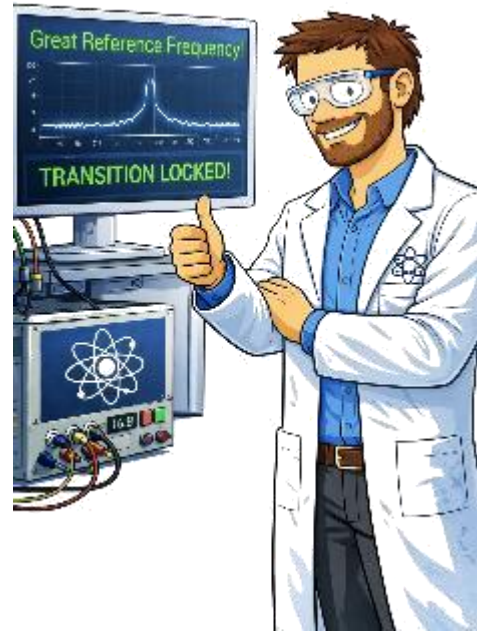


Summary

KOFREF (compact reference frequency)

- Transfer of regional reference frequency, such as UTC(k)
- Short-term stability of $2*10^{-12}$
- $1/\tau$ averaging behaviour targeted
- Cost-efficient approach
  - Utilizes existing regional networks
- Atmospheric corrections using SSR
  - Dense reginal network

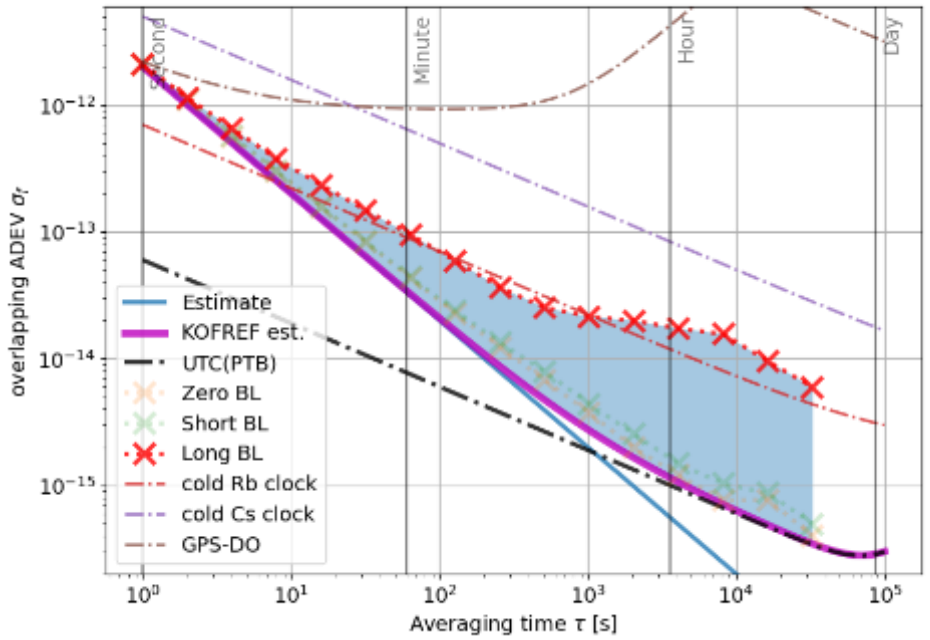


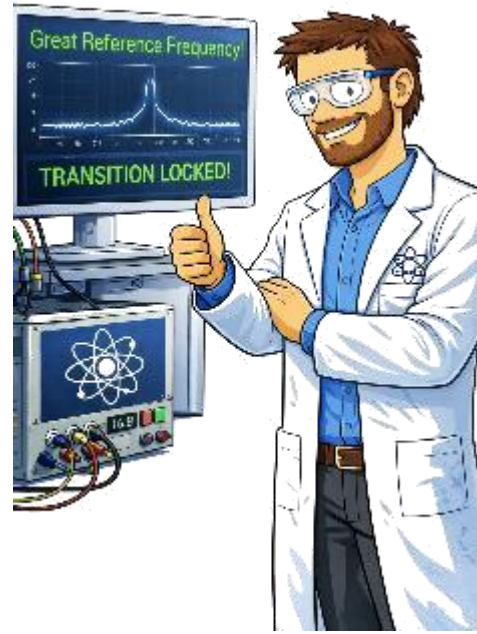


Outlook

KOFREF (compact reference frequency)

- Hardware with an integrated local oscillator under development
- Improve averaging through enhanced tropospheric modelling





Acknowledgements

Thanks go to …

- DLR
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- QVLS-iLabs

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With funding from the:

CLUSTERS 4 FUTURE
Next generation innovation networks

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Thank you for your attention!

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