

# Progressing Towards a National-Scale Wide White Rabbit Network in DWDM Telecommunications for REFIMEVE, France's T/F Network for Education and Research

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- Motivations
- REFIMEVE
- WR on xDWDM active telecom network
- WR network in Paris area
- On-going projects and outlook

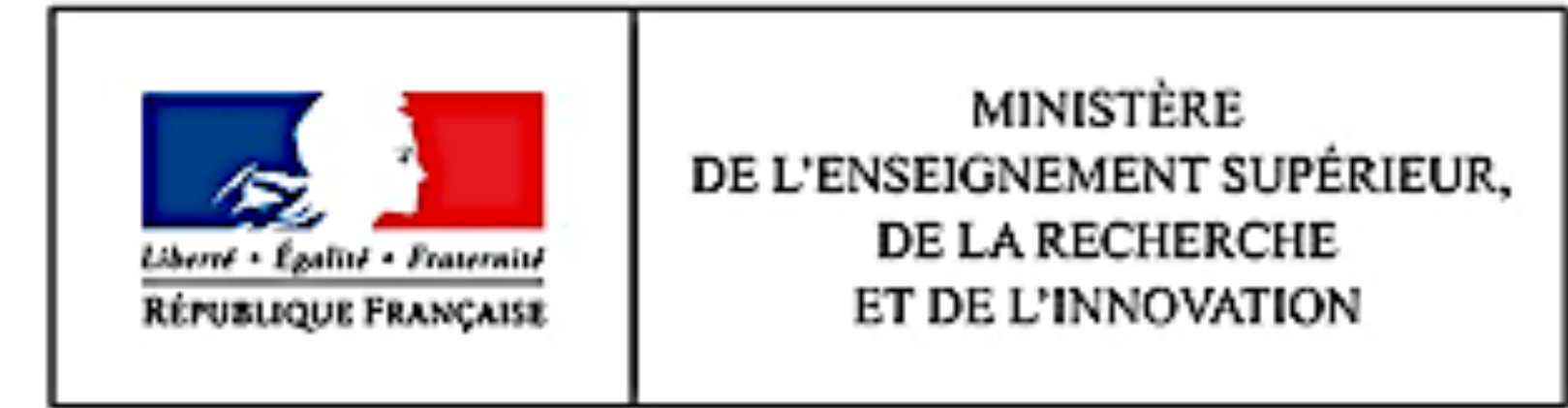
Built with 2 large investment programs

REFIMEVE+ ~7M€ (2012-2024)

T-REFIMEVE ~10 M€ (2021-2029)

Acknowledged as

**national research infrastructure by 2021**



## Key concepts

- Mutualisation
  - Time and frequency reference systems
  - Fiber networks (national, regional,...) for education and research
- T/F as a service
  - To date : ~30 academic research laboratories. +20 physically connected as of 03/2024
    - 6 research infrastructures: SOLEIL, ESRF, IRAM, LOFAR, LSM, + CERN
  - Industrial partnership & societal impact
  - Open access (FAIR)

# Partnership



Kernel



LPL (USPN, CNRS)

SYRTE (OP-PSL, CNRS, SU, LNE)



SYRTE



RENATER  
CONNECTEUR DE SAVOIRS

RENATER

Systemes de Référence Temps-Espace

exail

Syrlinks



LUMIBIRD  
MORE THAN LASERS

Industrials

30 Users

# Refimeve network map (2024)

- Optical carrier at ~200 THz (NIR)

- Fully bidirectional

- 3 international connections

PTB, NPL, INRIM > IQB

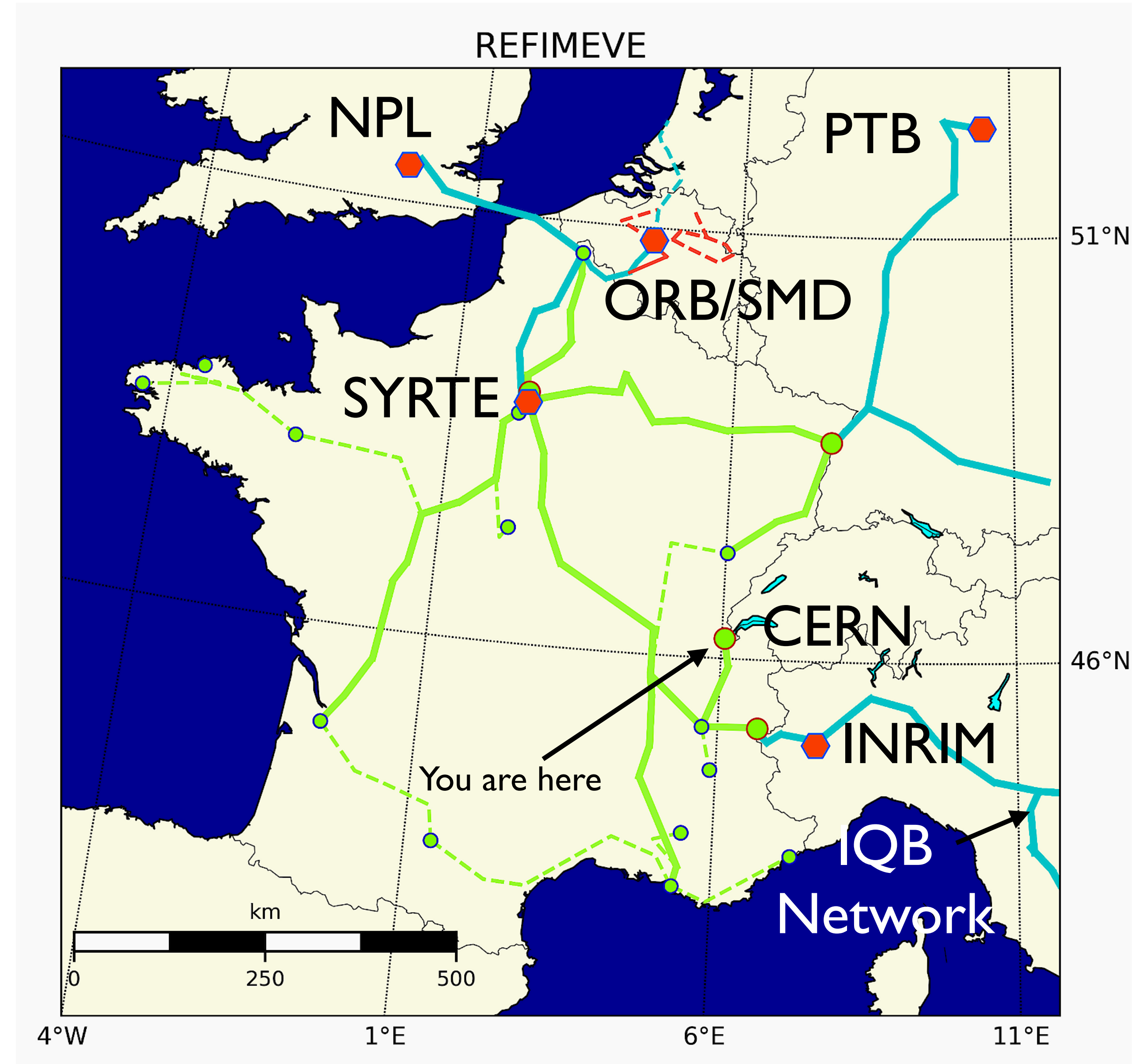
New: CERN connected March 2023

New: Belgium-France cross-connection planned

- Clocks (microwave and optical) at INRIM, PTB, NPL, and SYRTE are connected with fiber network

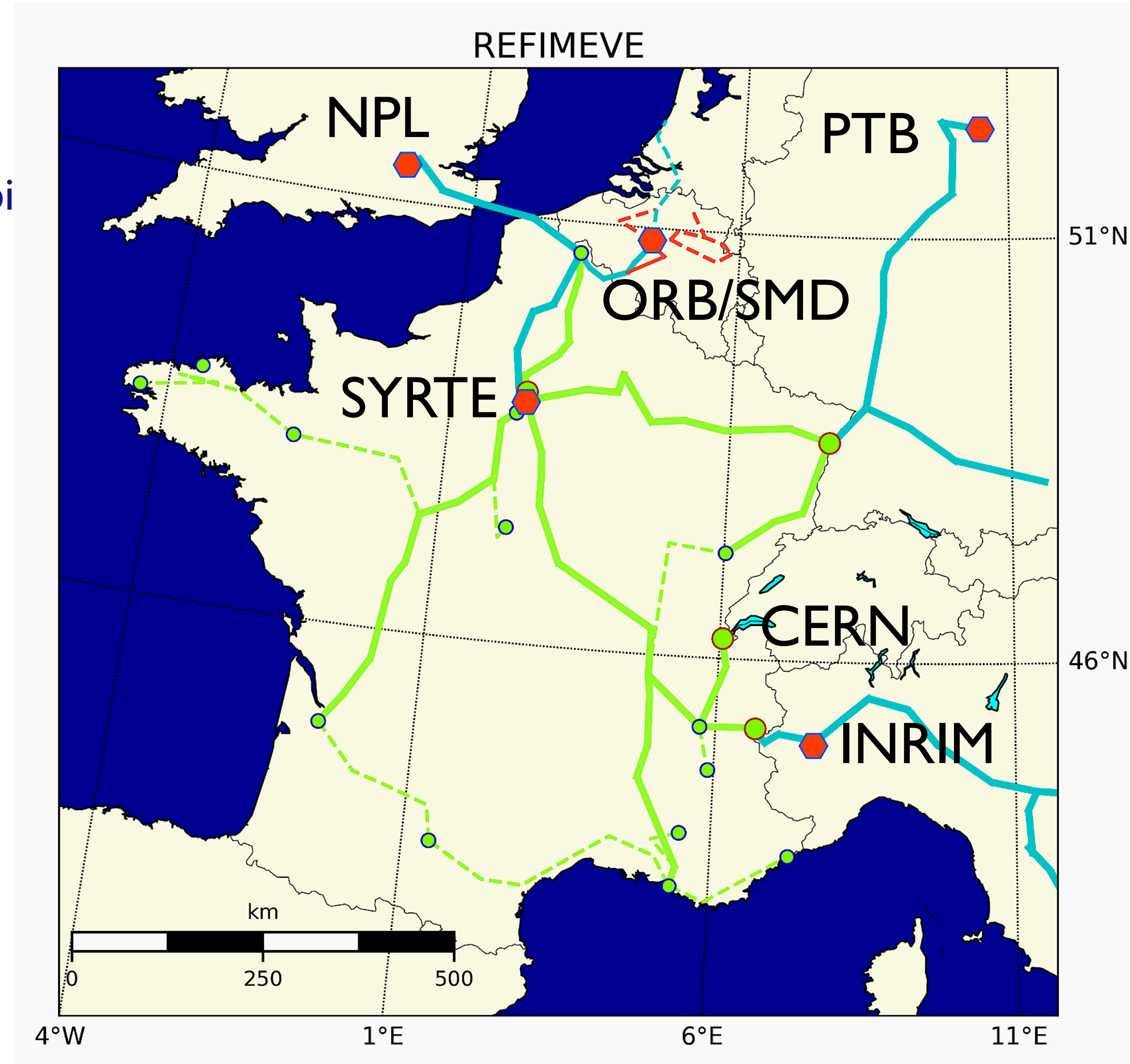
- REFIMEVE connects +20 labs by 03/2024, among which FEMTO-ST, UTINAM, IJCLAB, LAC, LPNHE

ESRF, SOLEIL, IRAM to be connected < 06/2025



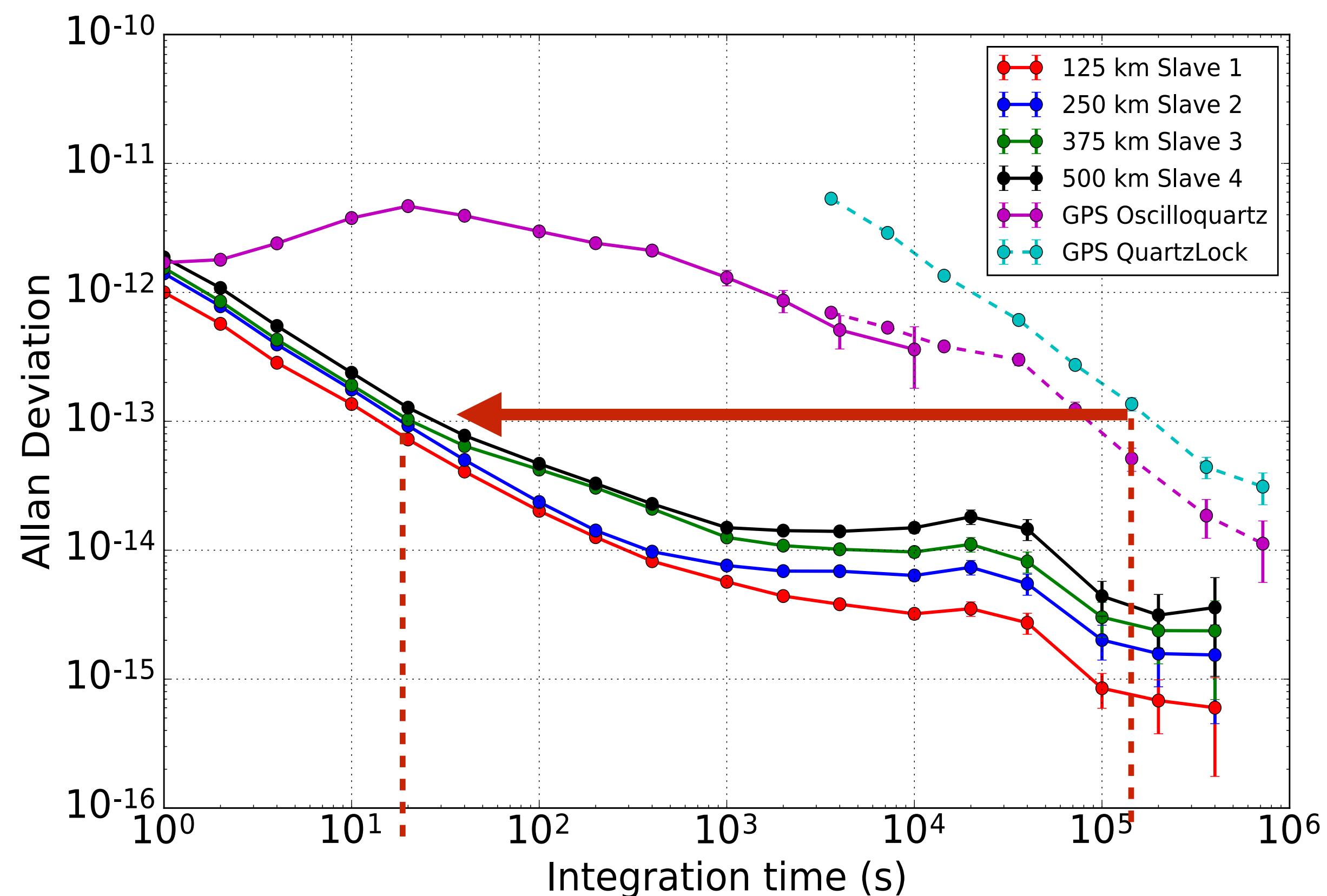
# T-Refimeve: 8-years project to extend the network

- Extension to Brest
- +14 new users
- RF (1 GHz) and time signal on the optical carrier (bi directional, highest performance)
- WR: 10 MHz and time signal, additional channel, mono-directional
- Mobile platform:
  - A test facility for the REFIMEVE users and exploration of chronometric geodesy
  - Extraction of the REFIMEVE signal
  - Transportable shelter with ultra-stable cavity, comb, and room to host a transportable clock or a transportable quantum sensor



# Why White Rabbit when you have optical carrier ?

- Complement the optical carrier service with RF and time services
- For REFIMEVE:
  - RF and time dissemination
    - for measurements at nodes
    - For measurements at user's end
  - Allows cross-comparisons and self-assessment
  - For industrial applications :
    - 1E-13 accuracy in 10 s instead of 1-2 days

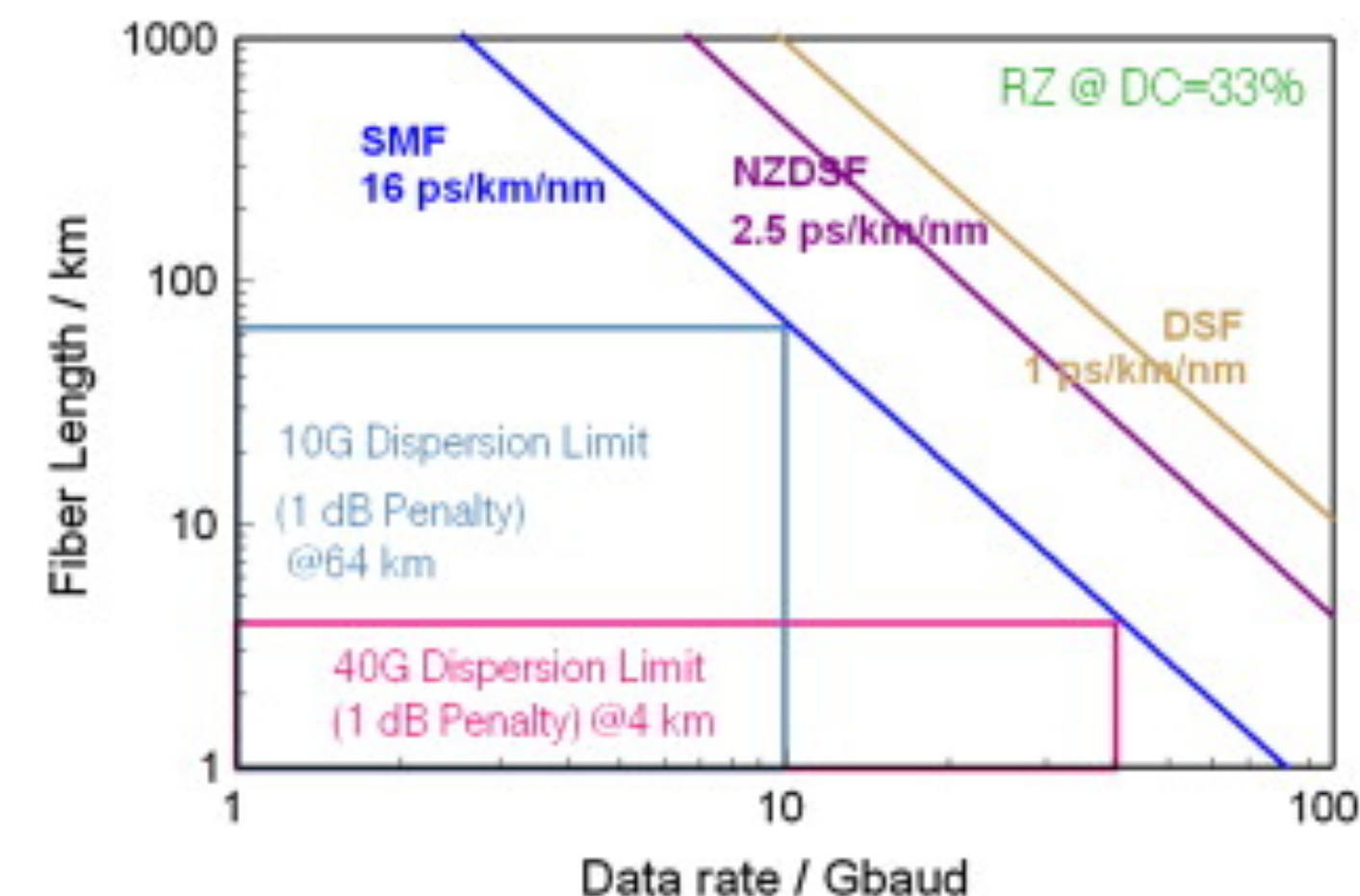
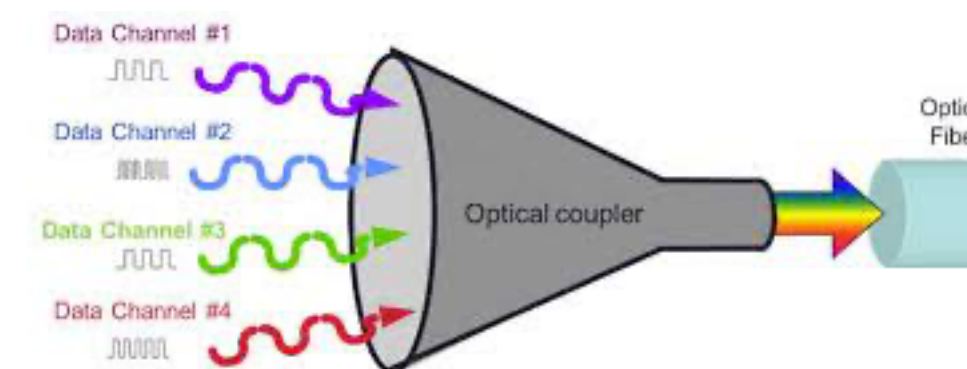


N. Kaur doi: 10.1109/TUFFC.2021.3134163. (2022)

N. Kaur, phdthesis <https://hal.archives-ouvertes.fr/tel-01909292>

# WR network: plans and challenges

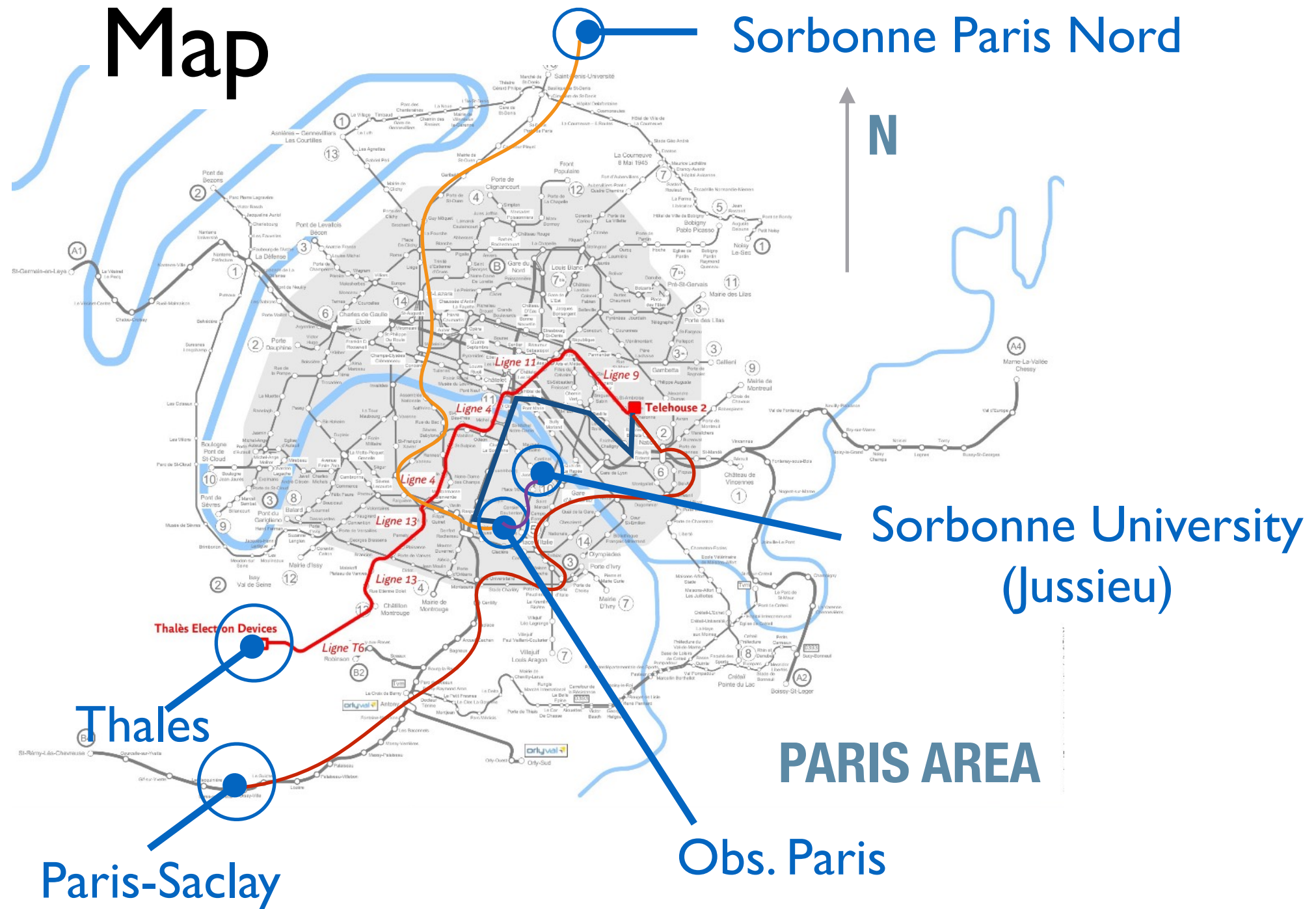
- DWDM:
  - No dedicated optical amplifiers : no CAPEX, no OPEX
  - No allocation of a single-one wavelength
  - Integration as an alien wavelength for RENATER
    - 1 Gb/s. Transport at 10/100 Gb/s ?
- Challenges :
  - Mitigate link asymmetry
  - Mitigate chromatic dispersion for link  $> 1000$  km
  - Interface with critical infrastructures:
    - Decision processes
    - Live monitoring, network security,...
    - Traceability
  - R&D : High performance WR node and capability at 10 Gb/s : see Daniel Charlet's talk this morning



From Werner Weiershausen, Malte Schneiders, Optically Amplified WDM Networks, Chap. Transport Solutions for Optically Amplified Networks, p. 297-339 (2011)  
<https://doi.org/10.1016/B978-0-12-374965-9.10011-1>

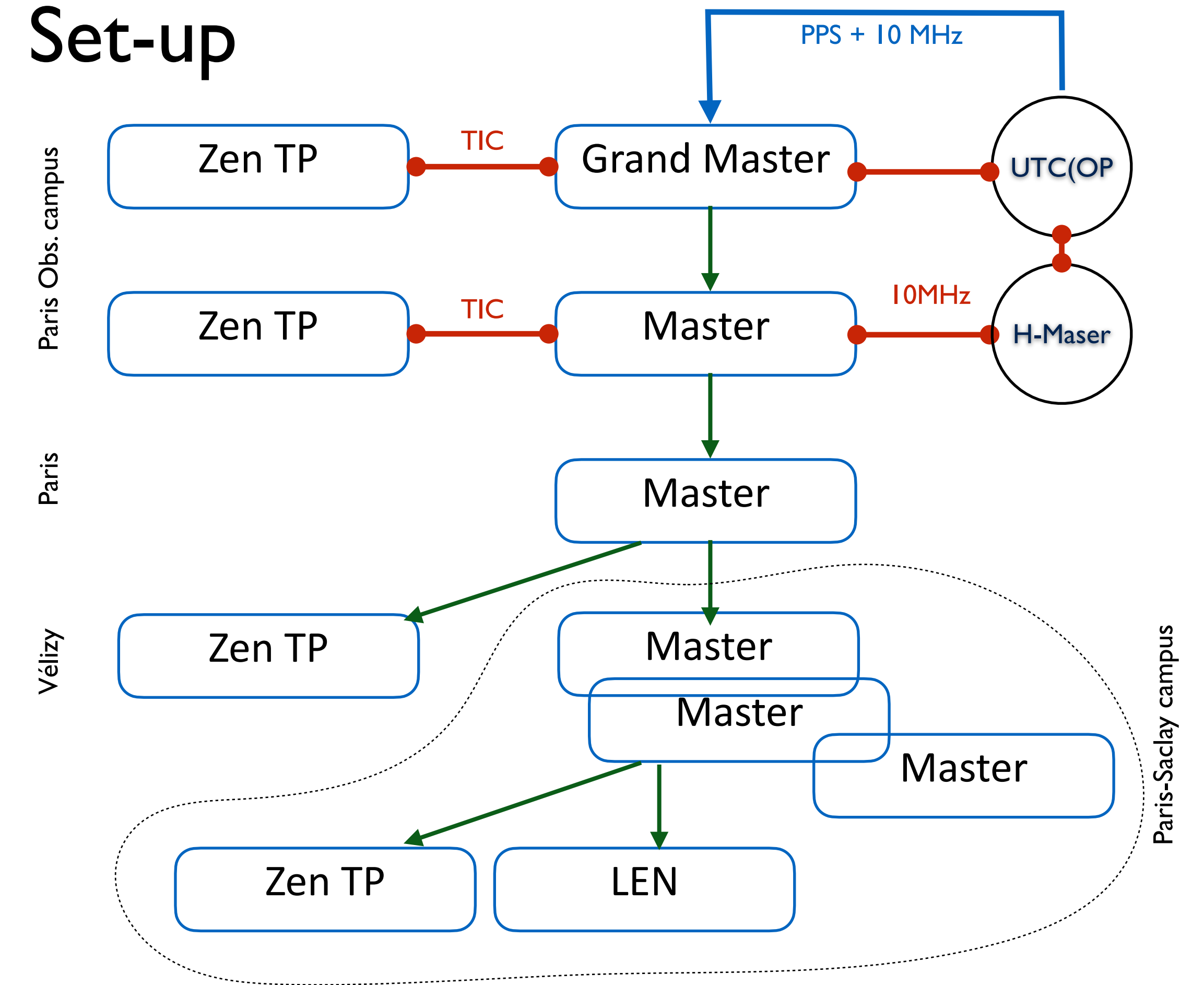


# WR network: regional area by Paris



- Grand Master seeded with UTC(OP)
- In campus: closure measurements on PPS and 10 MHz
- At Thales : measurement versus atomic clock
- At LPNHE: measurement versus passive H-Maser
- At LPL: measurement versus fiber links (optical + RF) + GNSS
- Elsewhere : only self monitoring

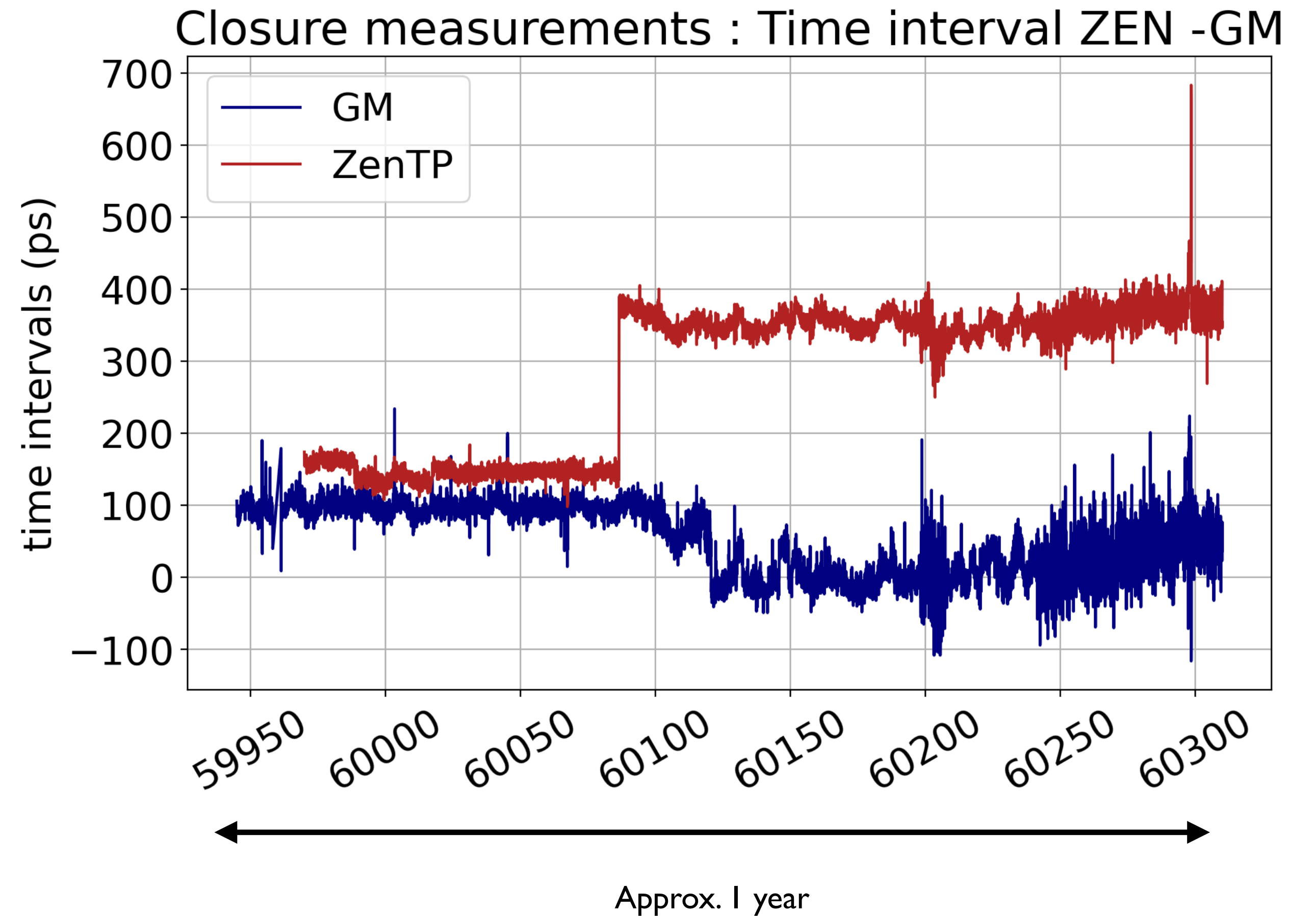
## Set-up



- 1310/1490 when link < 5 km
- 1510, 1550, 1560 nm, ... (DWDM) when link > 10 km

# WR network: traceability to the source

- We measure time intervals between PPS outputs at RNT.
- Link length  $\sim 2 \times 300\text{m}$ ,  $\text{rtt} \sim 2 \times 3 \mu\text{s}$ .
- Time offset  $\sim 200 \text{ ps}$
- We measure time intervals between PPS outputs **and** frequency of clock outputs at Lab3.
- Link length  $\sim 2 \times 10 \text{ km}$ ,  $\text{rtt} \sim 2 \times 100 \mu\text{s}$ .

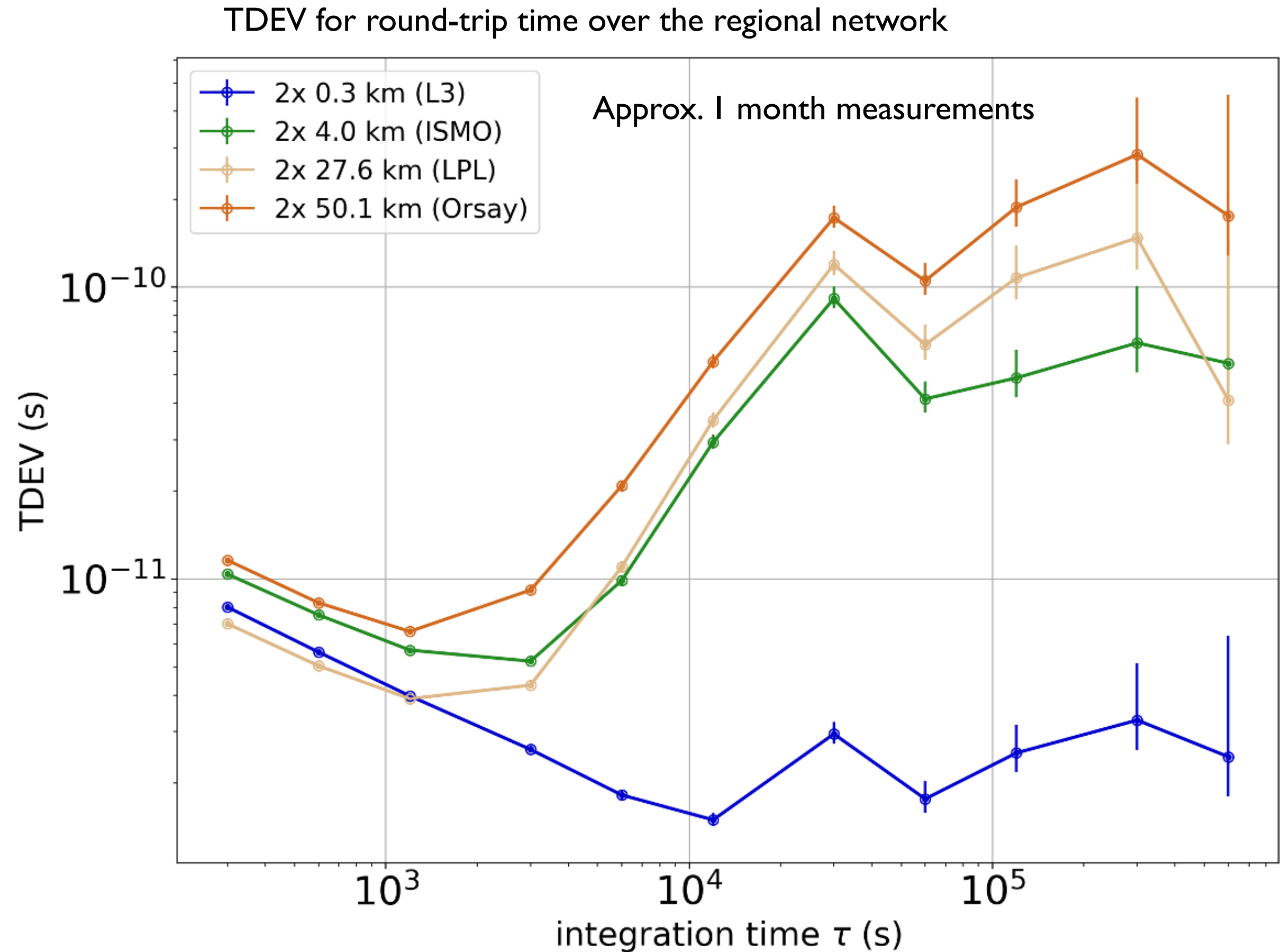
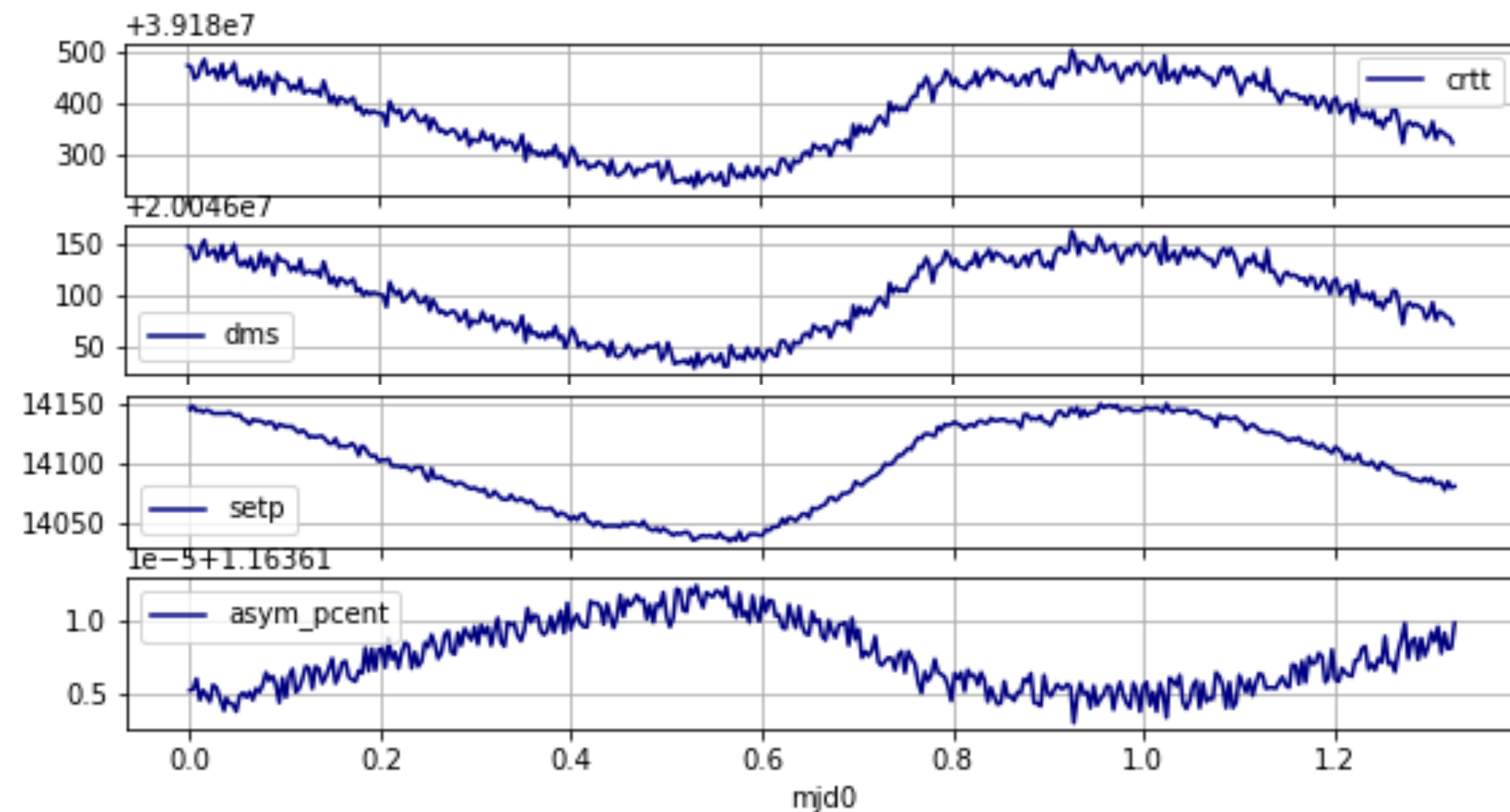


We observe excellent behaviors over long term.

# WR network: monitoring and supervision

- REFIMEVE supervision and computing center
- Data aggregation
- Host virtual machines for subcontractors
- Implement monitoring of *wrs* and *zen-tp y* *periodic poling of the devices*

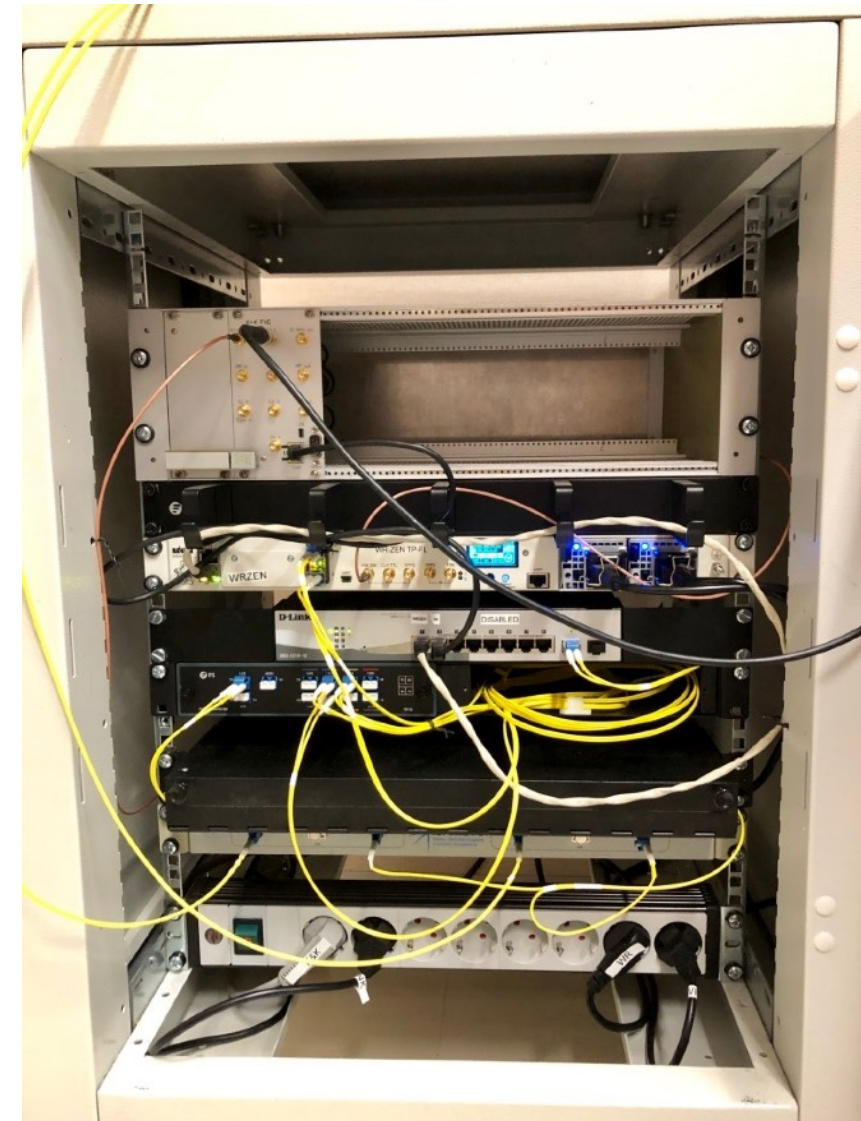
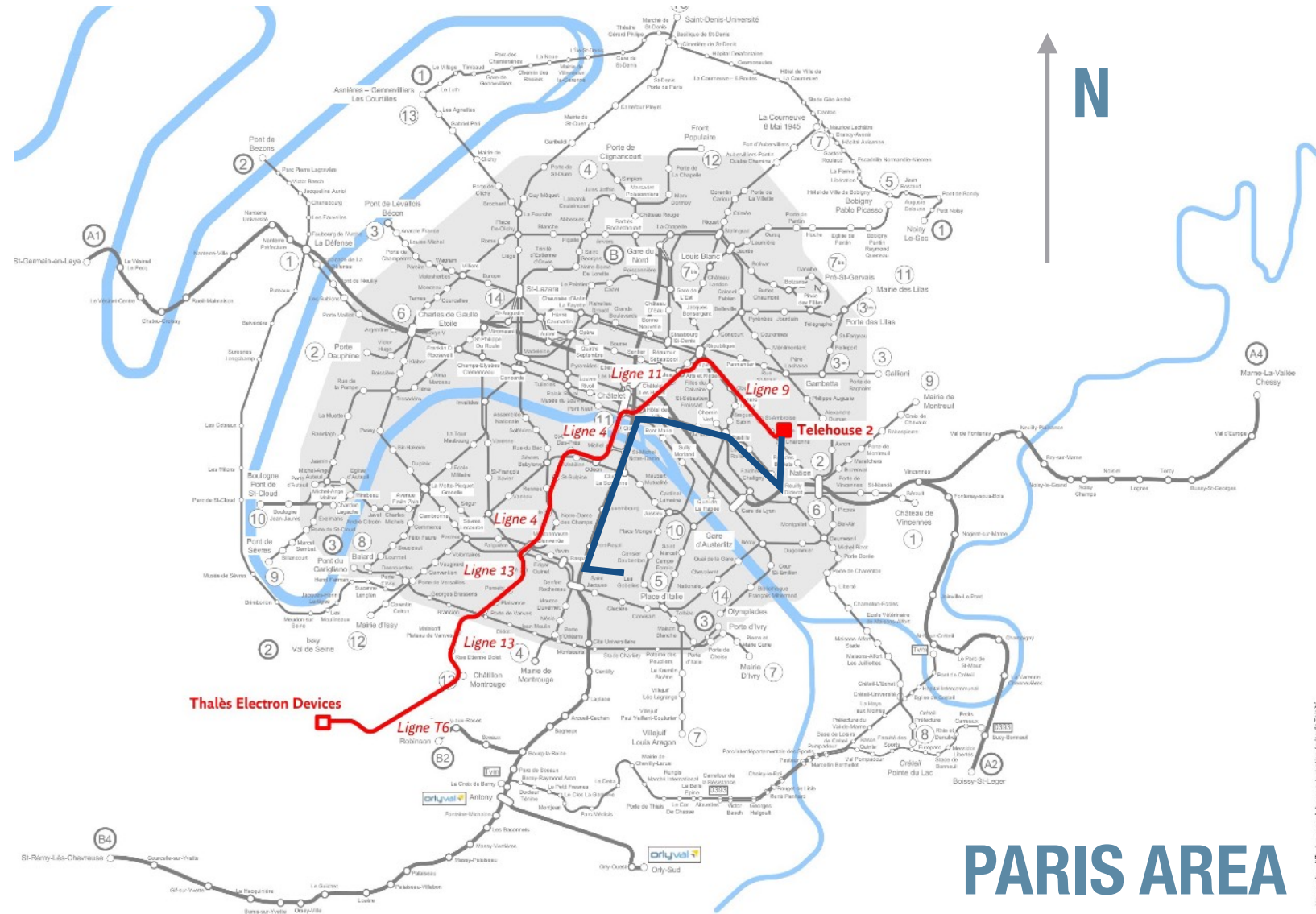
Exemple of monitoring for wr switch at ISMO (Paris Saaly), for 1 day



Embedded monitoring resolution  $\sim 10$  ps  
Round-trip time  $< 1$  ns / 40 days

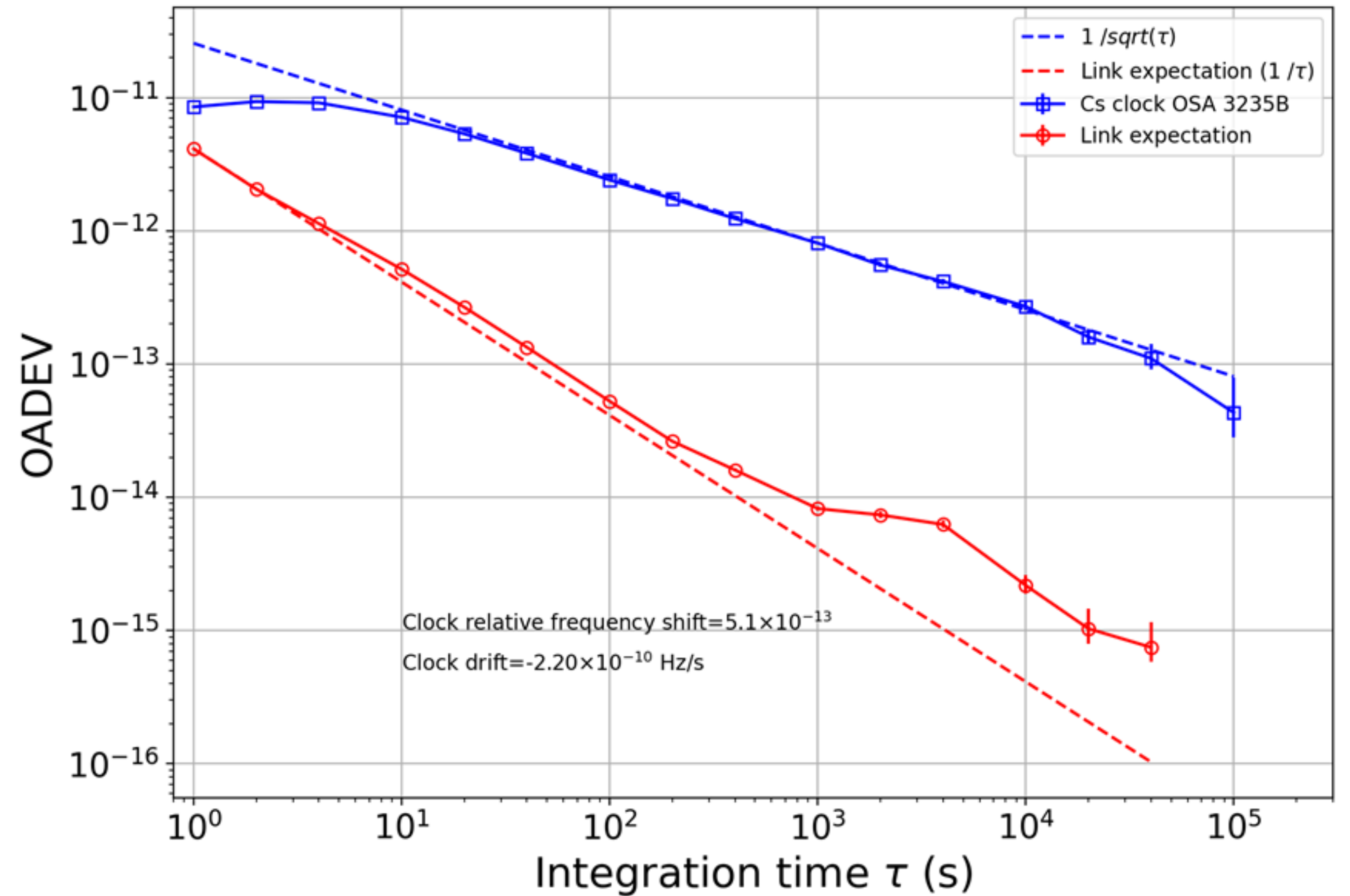
We observe diurnal perturbations on mid-range links.

# Use case: remote measurement of Cs clock at Thales



Credit : O. Lelievre, R. Schmeissner, F. Frank

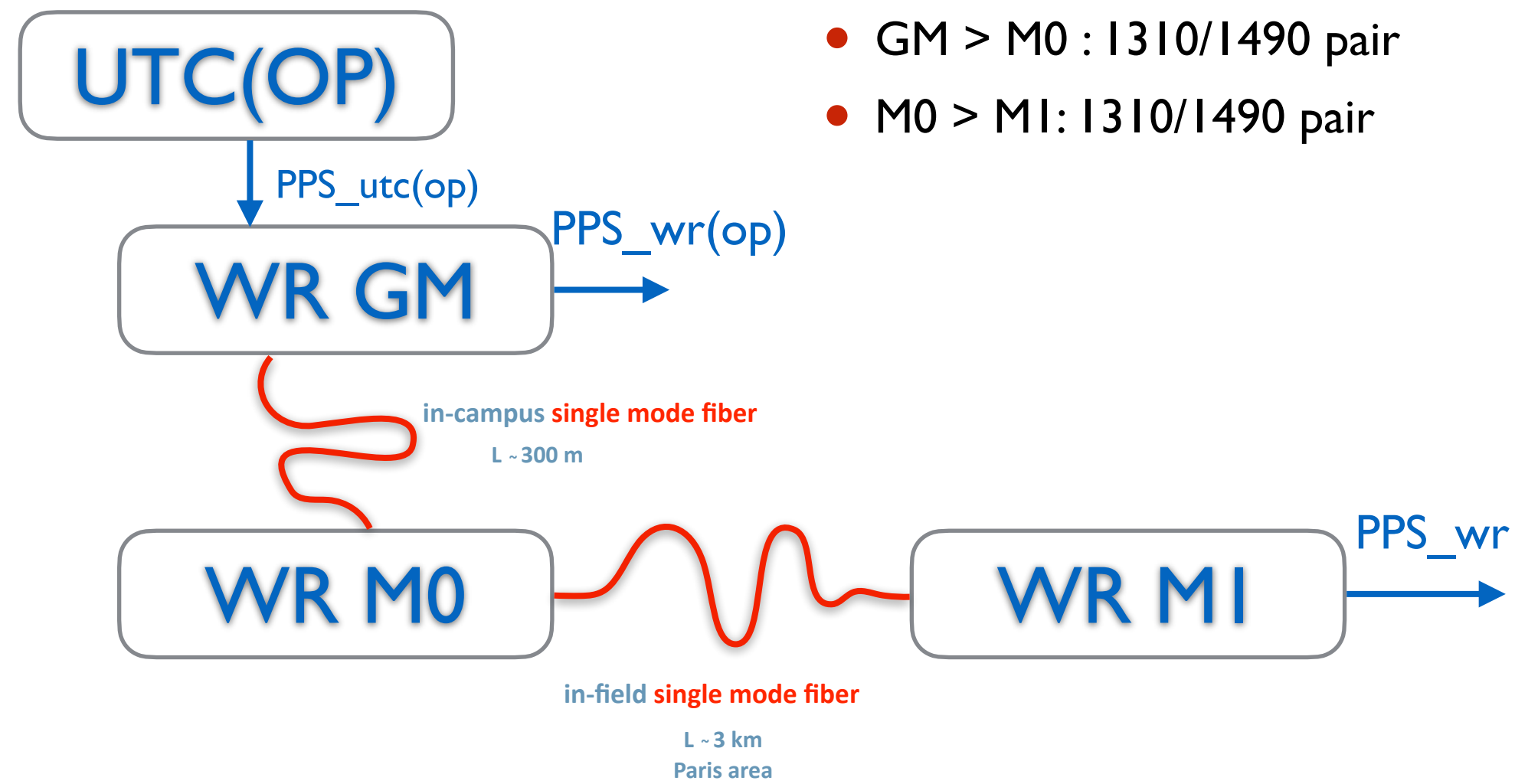
- Atomic clock : Oscilloquartz OSA 3235B
- Prior deployment: clock is measured in the lab versus H-Maser, link is simulated on spools.
- Measurement session in real conditions at Vélizy



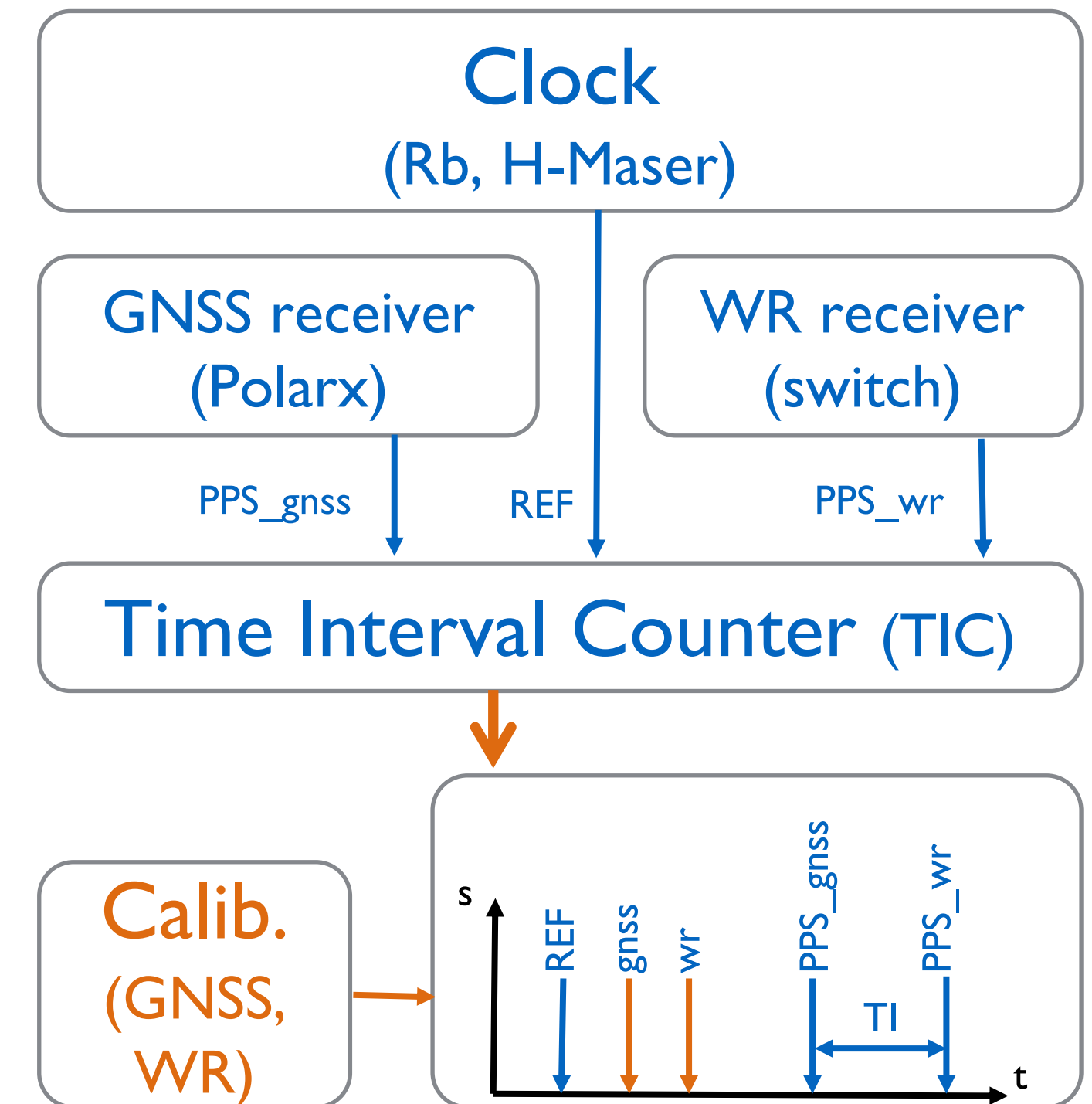
- GM > M0 : I310/I490 pair
- M0 > M1: I310 pair
- M1 > Zen : I530 pair

# Use case: remote measurement of passive H-maser at LPNHE

Comparison of time transfer using GNSS and a 3km-WR link (1310/1490nm)

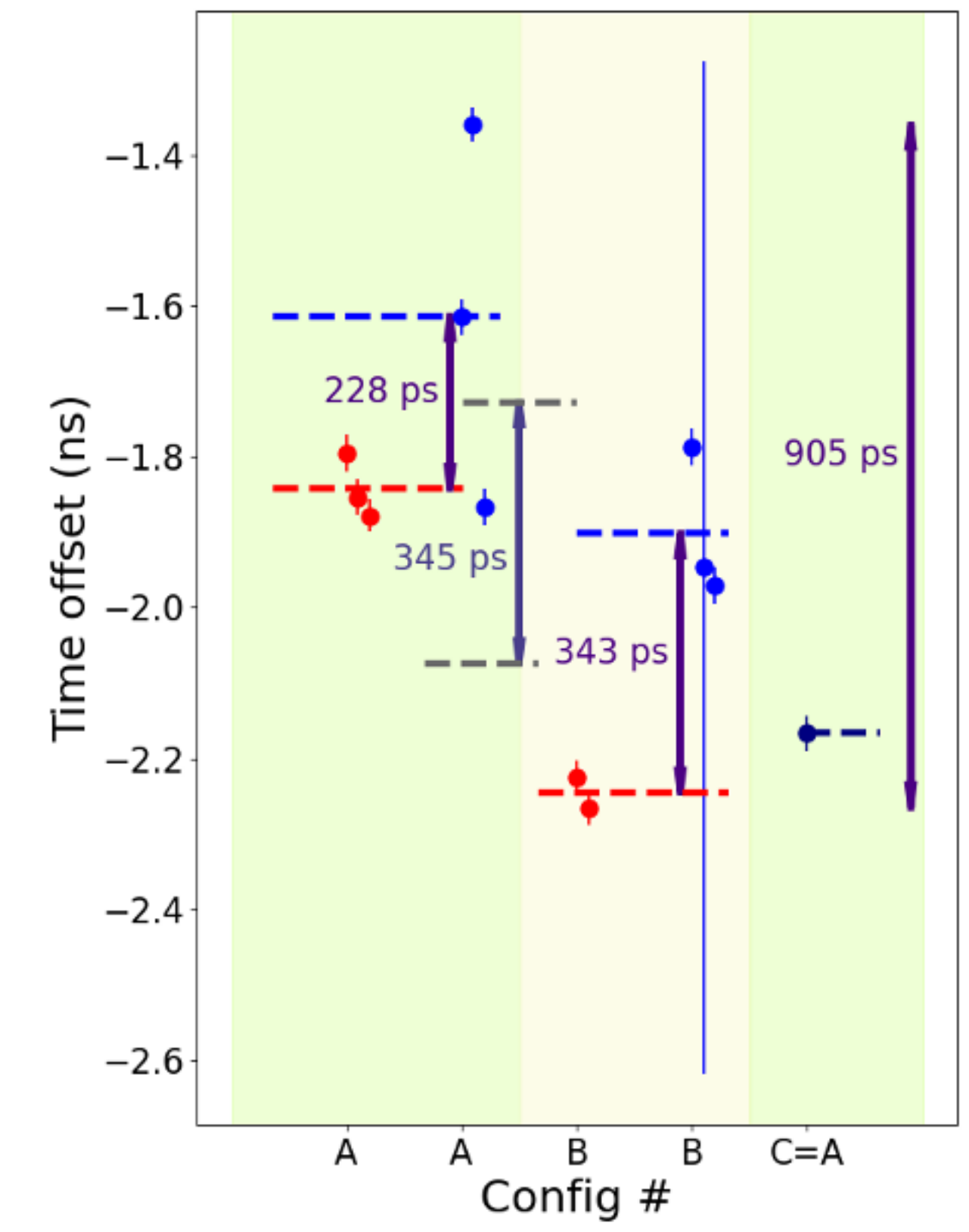
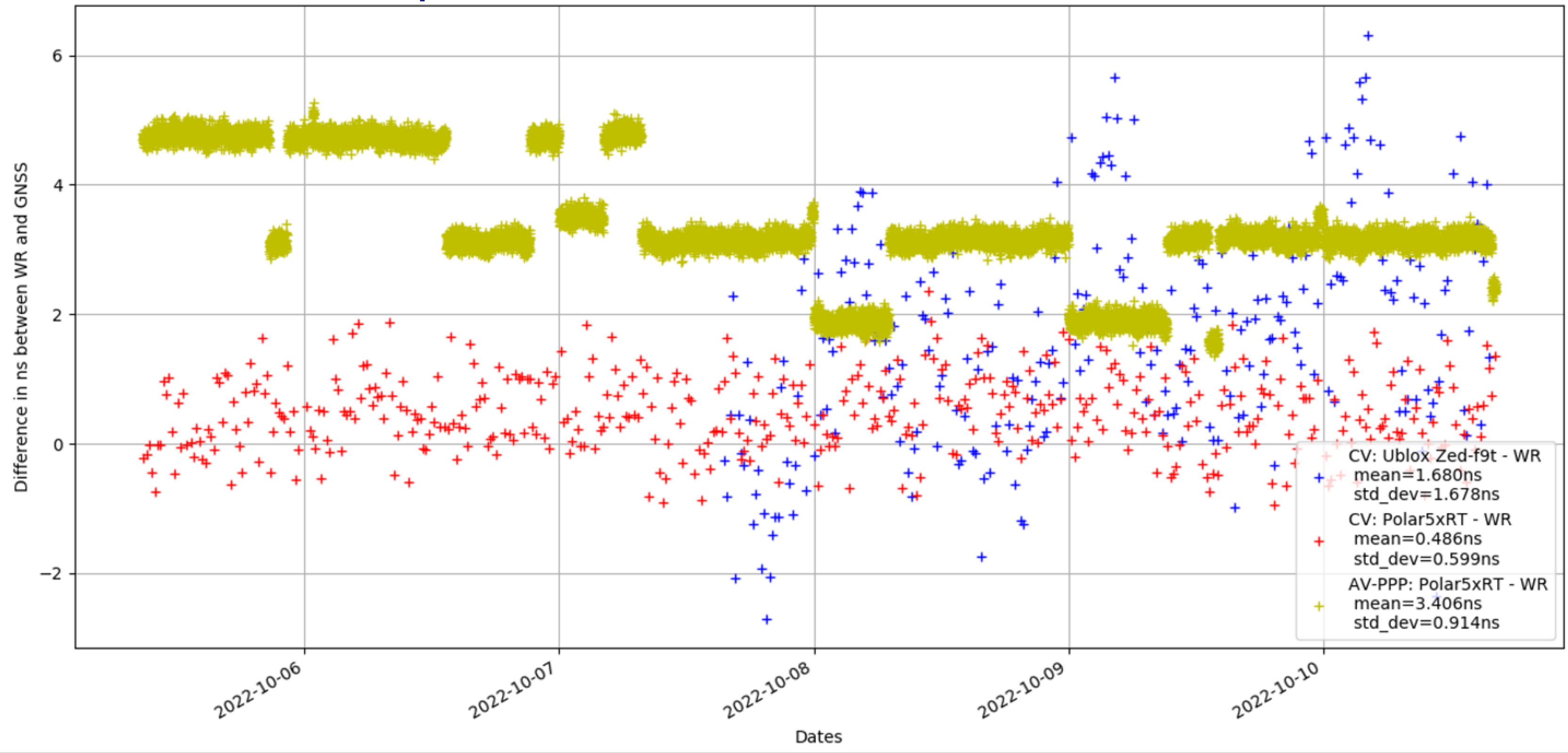


- PPS\_wr(OP) is continuously measured versus UTC(OP)
- WR M0 is sent back by WR to another WR device, continuously measured versus UTC(OP)
- wr(OP) is calibrated versus its source

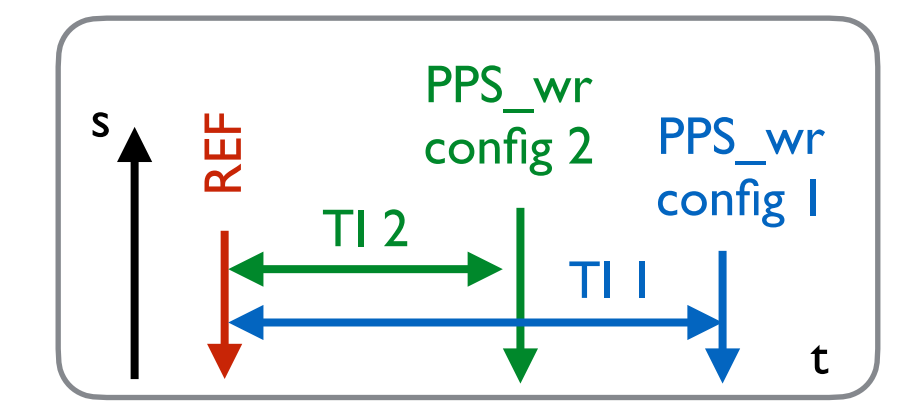


# Use case: remote measurement of passive H-maser at LPNHE

Time delays GNSS vs WR with the clock in common view, after calibration procedures

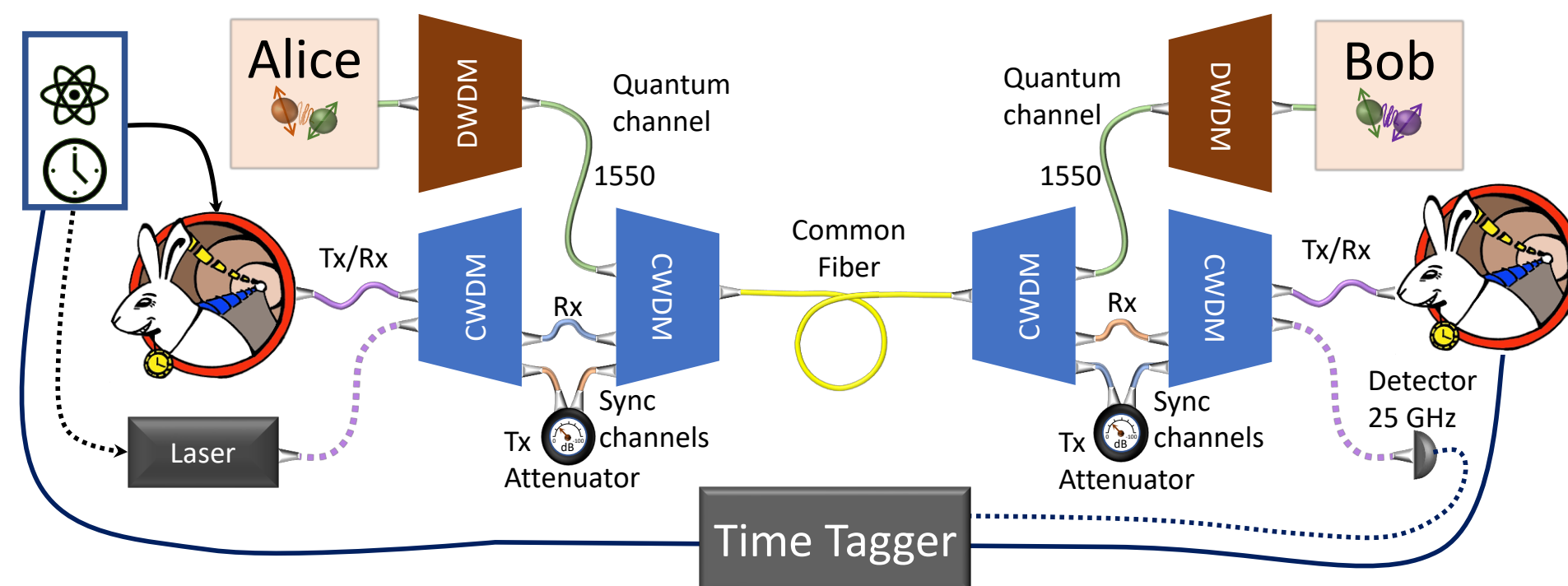
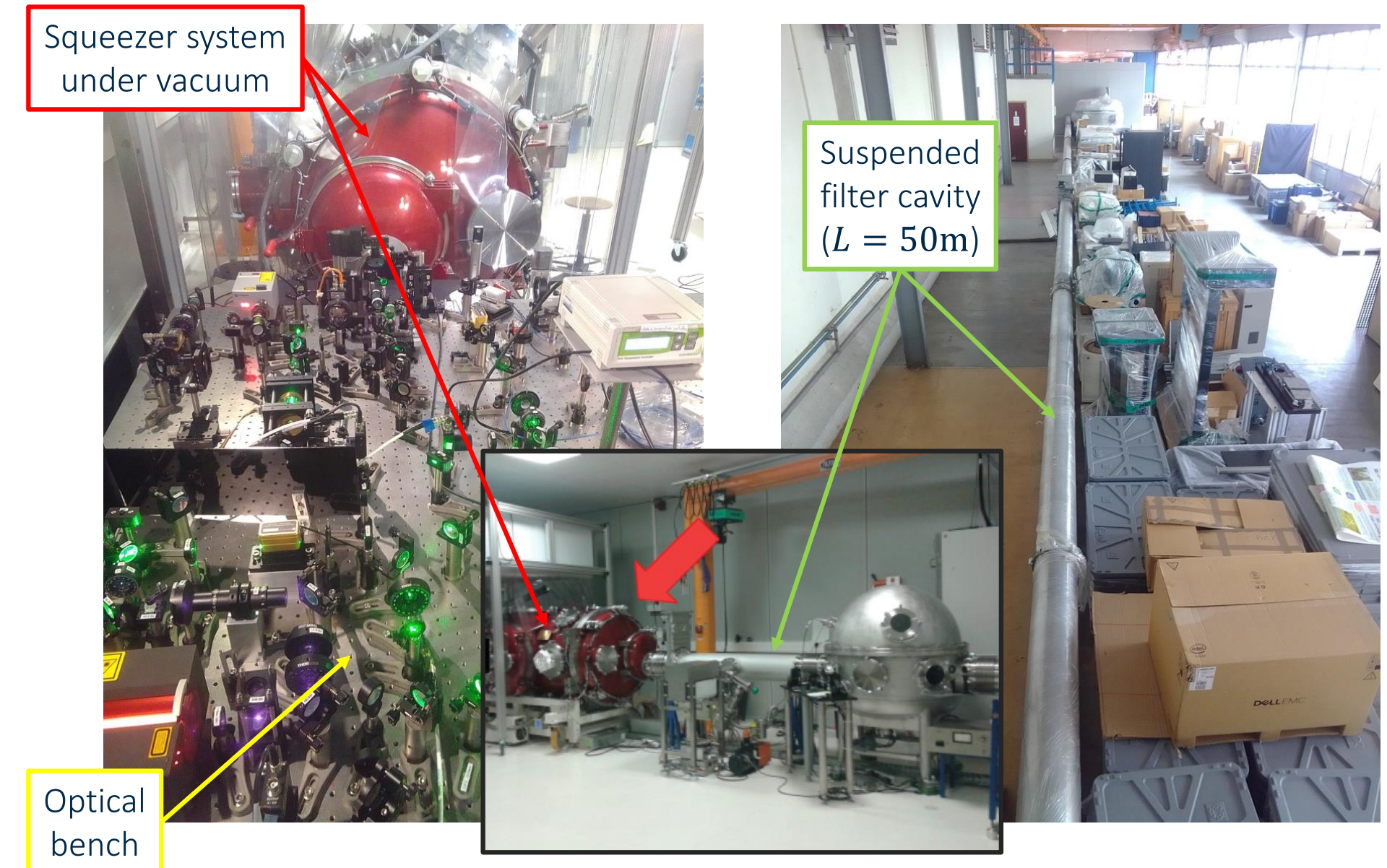


Credit : V. Voisin, L. Mellet, S. Russo, M. Guigue, B. Popov



- Remote measurements for molecular spectroscopy (Lab. Aimé Cotton, O. Dulieu, Amit Nanda)
- IJCLAB
  - Electronics developments (Idrogen)
  - Gravitational wave detectors using squeezed light (Nicolas Leroy's group)
- Future :
  - Quantum communications ?
  - Industry and defense

Experiment at IJCLAB on squeezed light  
Credit : M. Andia



A. Burenkov et al., Opt. Express, vol. 31, no 7, p. 11431, mars 2023, doi: 10.1364/OE.480486.

- REFIMEVE will implement a national-wide VWR network
- The regional VWR network around Paris connects already about 6 laboratories
  - Exploitation is going on in various field of physics
  - Monitoring shows interesting capabilities
- Next steps
  - Connection to Obs. Nançay (radio-telescope) planned.
  - Deployments at larger scale in Europe
  - Traceability and procedures, standardization
- R&D :
  - Better hardware performance
  - Link asymmetry and *optimal* network



# Fundings



LIOM, REMIF, REFIMEVE+, T-REFIMEVE, FIRST-FT

LOFIC



INSU  
GRAM



JRP: NEAT FT, OFTEN, WRiTE, TIFOOON  
ITOC, ROCIT (clock comparisons)  
H2020: ICOF

ROME, LICORNE, TORTUE, (...)

## EU Research infrastructure



CLONETS  
CLONETS-DS



TOCUP, ONSEPA, (...)

Thank you for your attention