Lien optique multiplexé pour le transfert ultra-stable de fréquences

O. Lopez, B. Chanteau, V. Roncin, C. Chardonnet, A. Amy-Klein

Laboratoire de Physique des Lasers (LPL), Université Paris 13, Villetaneuse

A. Haboucha, H. Jiang, G. Santarelli

LNE-SYRTE, Observatoire de Paris, Paris

The challenge of frequency dissemination

- High resolution comparison of distant clocks
  - T&F metrology
  - search for fundamental constants variation
  - test of fundamental physics, relativity, geodesy

- Fiber optical links
  - Rapid development for last 10 years all around the world
  - Transfer of the optical phase of an ultra-stable 1.55 µm laser
  - Transfer on distances about 100-200 km is a mature field

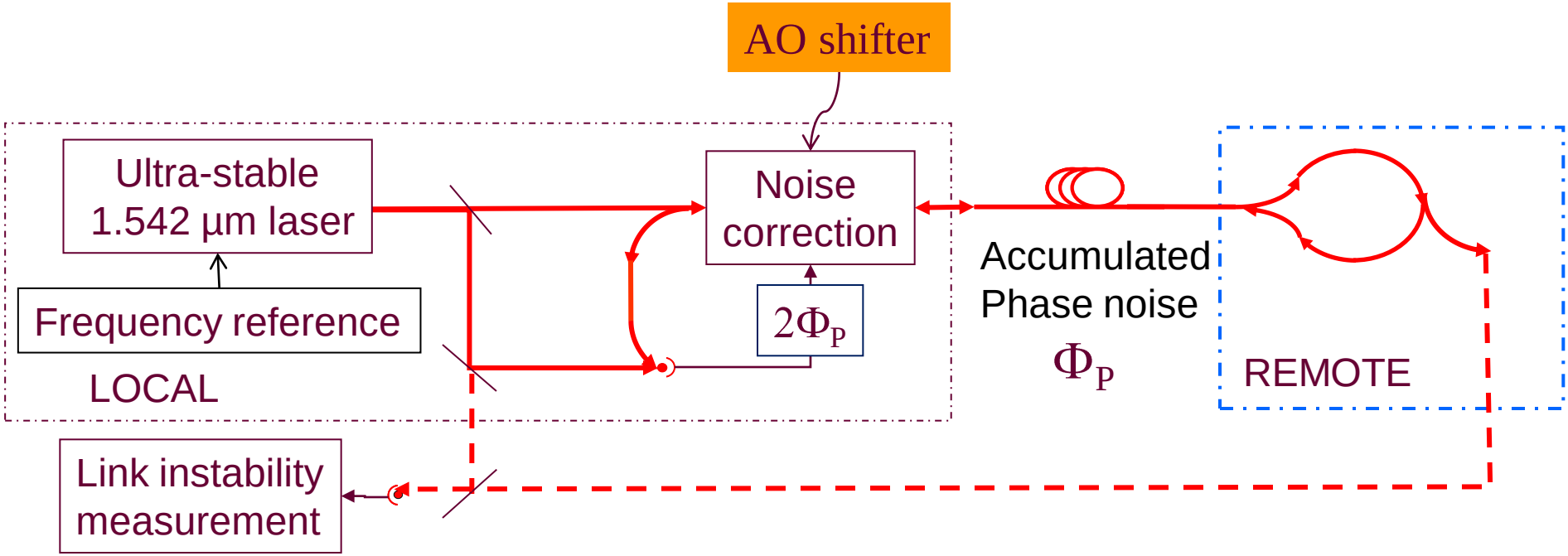
- Next challenge : transfer on continental distances

State-of-the art of fiber optical links

- JILA-NIST optical carrier phase and frequency comb transfer
- **LNE-SYRTE - LPL (microwave, optical phase)**
- **PTB-MPQ-Hanover (Germany) (143-480-900km) (optical phase)**
- Japan (NICT, NMIJ, UT) RF & optical carrier phase optical link
- NPL (GB) (frequency comb, optical phase)
- China: microwave optical link (NIM)
- INRIM (IT) (optical phase)

Simplified scheme of an optical link

- Fluctuation of the propagation delay frequency transfer
- « Round-trip » method for noise compensation



- Demonstration with 2 parallel fibers or one loop fiber

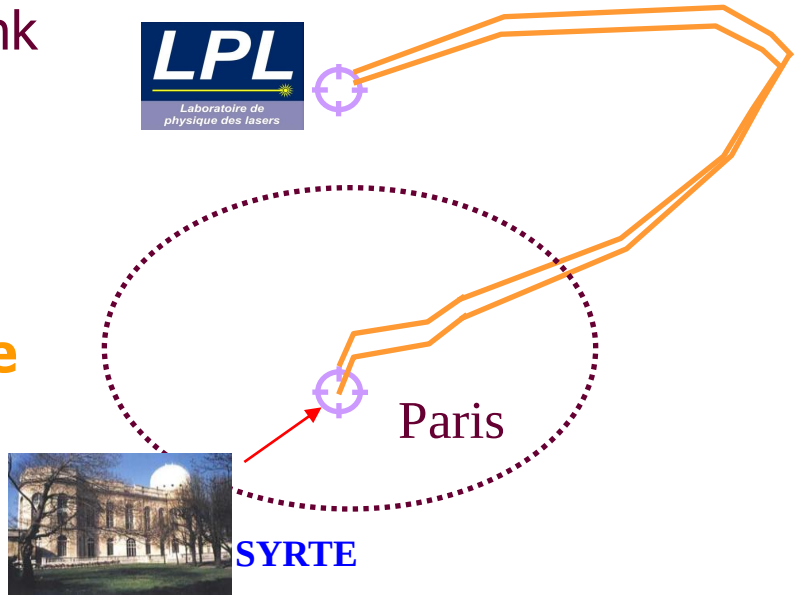
LPL-LNE-SYRTE optical link

- Two parallel 43-km "dark fibres" of the metropolitan telecom network = 86 km urban link (cascaded fibres)
  - A few different sections of buried fibre cable
  - Splicing to ensure the continuity
  - 20 dB optical losses for 86 km link

- 86-km optical link demonstration

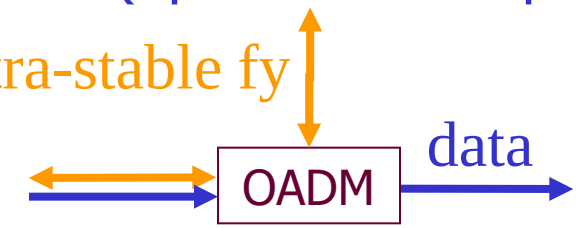
with frequency resolution :

- **2×10^{-16} at 1 s integration time**
- **8×10^{-20} at 1 day**



How to extend optical links?

- Dedicated fiber
  - difficult to obtain and expensive
  - one uses only a very small part of the fiber transmission bandwidth: 100 MHz over ~5 THz
- Public telecommunication networks
  - already existing and potentially less expensive
  - simultaneous transmission of signals on different channels in the same fiber: **dense wavelength-division multiplexing DWDM**
- OADM (optical add drop multiplexer) to add and extract signal



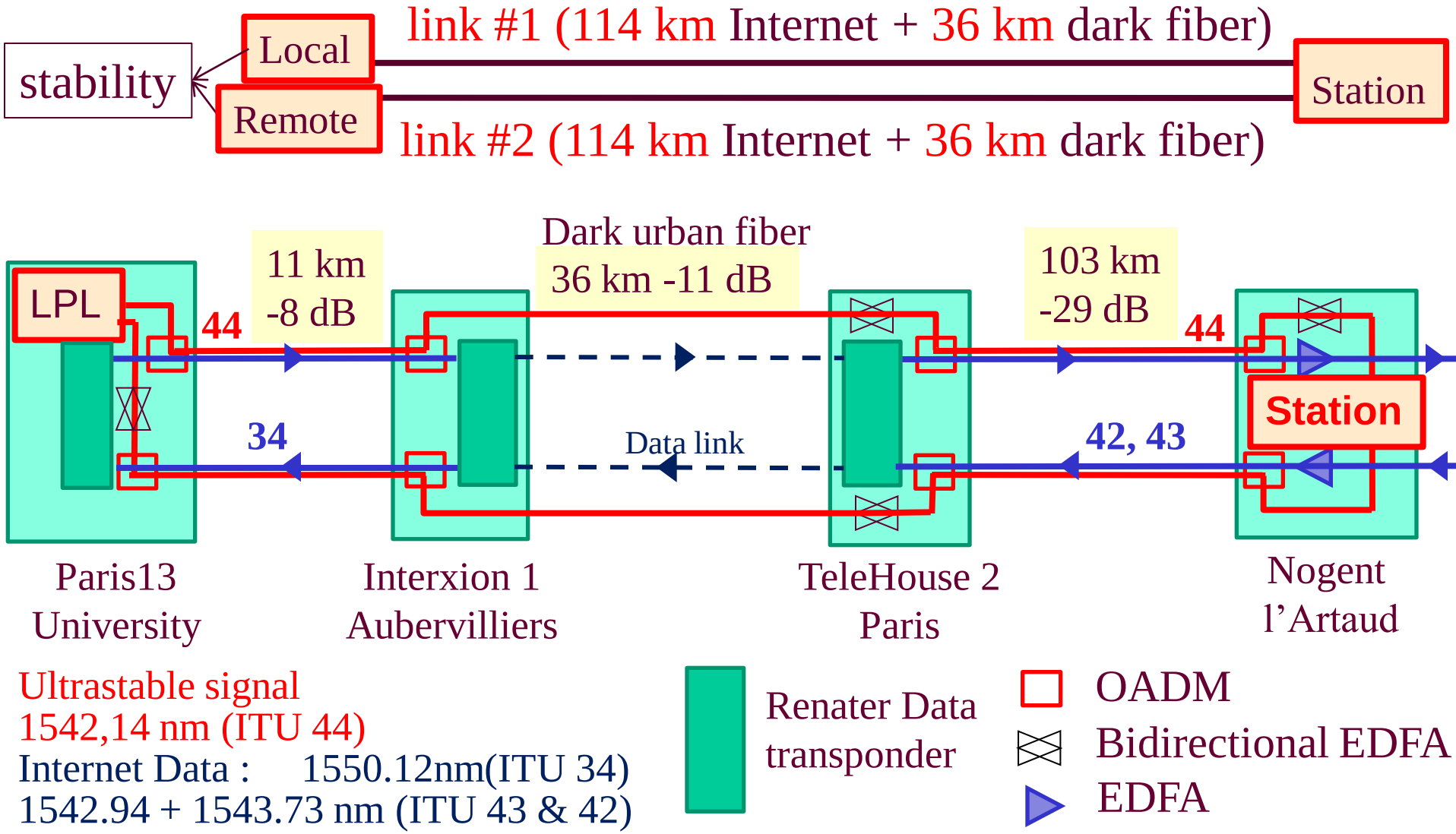
  - Commercial components (100 GHz filters)
  - Losses < 1dB, Isolation > 25 dB
  - Bidirectional
- Collaboration with RENATER

Long distance multiplexed optical link

- Key issues :
  - Bidirectional propagation (for noise correction)
  - Continuous propagation : all-optical transfer
    → **bypass** all telecommunication unidirectional equipments
- Multi-segments approach :
  - Link is divided into a few segments, depending on noise and attenuation
  - → shorter propagation delay
  - → larger bandwidth and better noise rejection
- Repeater stations are needed

300-km multiplexed optical link Paris-Nogent l'Artaud-Paris

2x150-km cascaded optical link

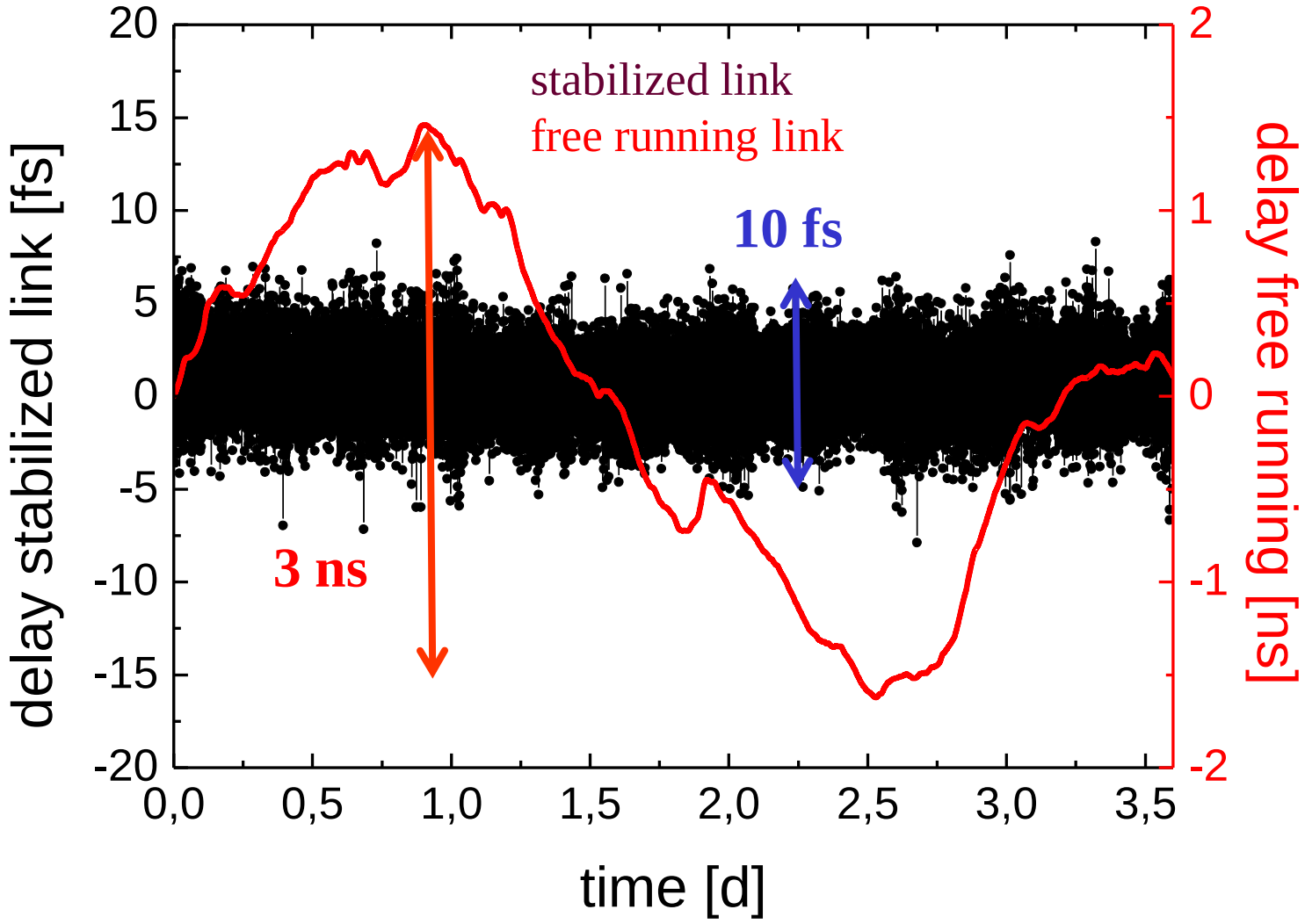


Ultrastable signal
1542,14 nm (ITU 44)
Internet Data : 1550.12nm(ITU 34)
1542.94 + 1543.73 nm (ITU 43 & 42)

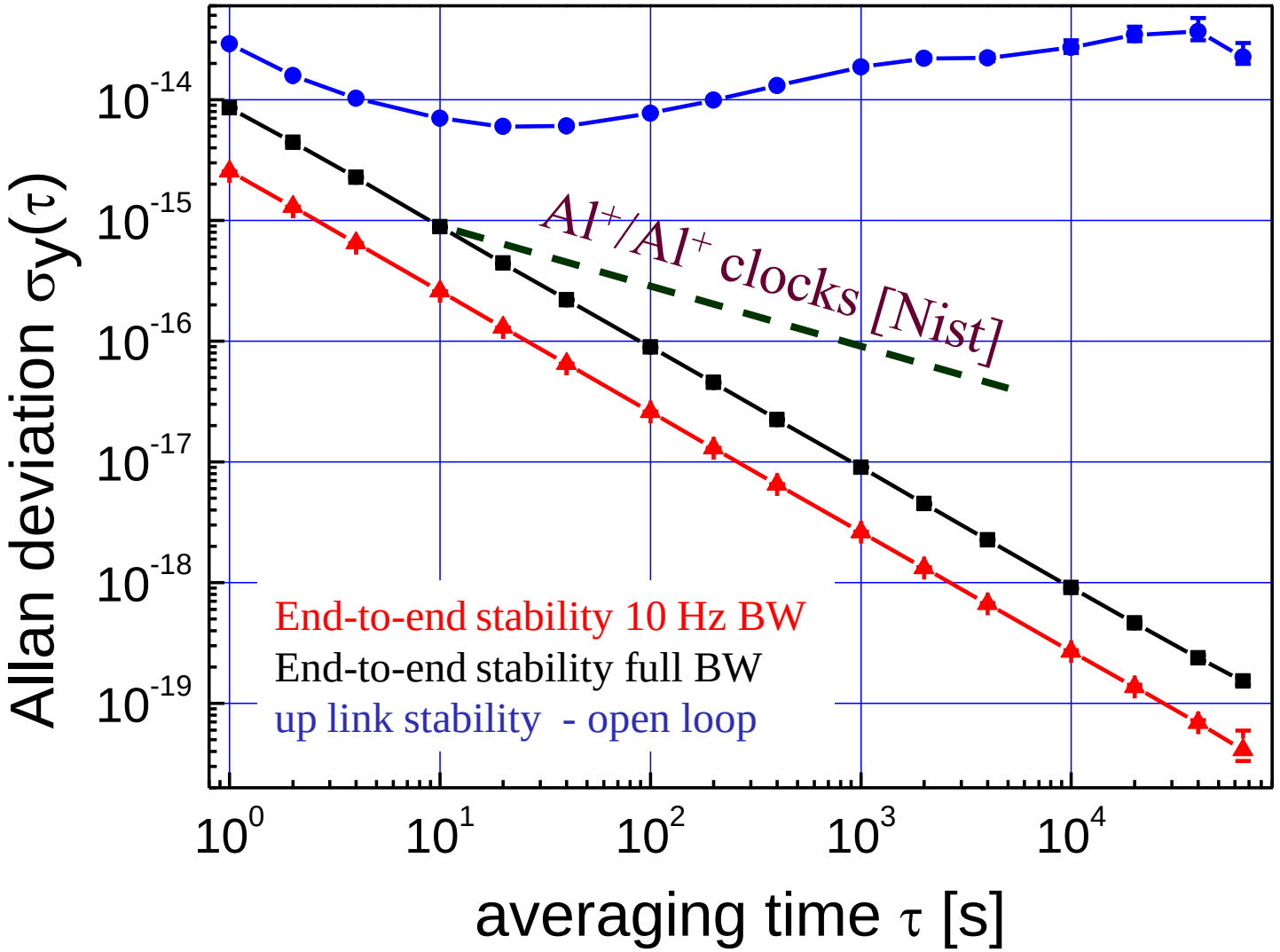
Renater Data transponder

OADM
Bidirectional EDFA
EDFA

Delay fluctuations LPL-Nogent l'Artaud-LPL

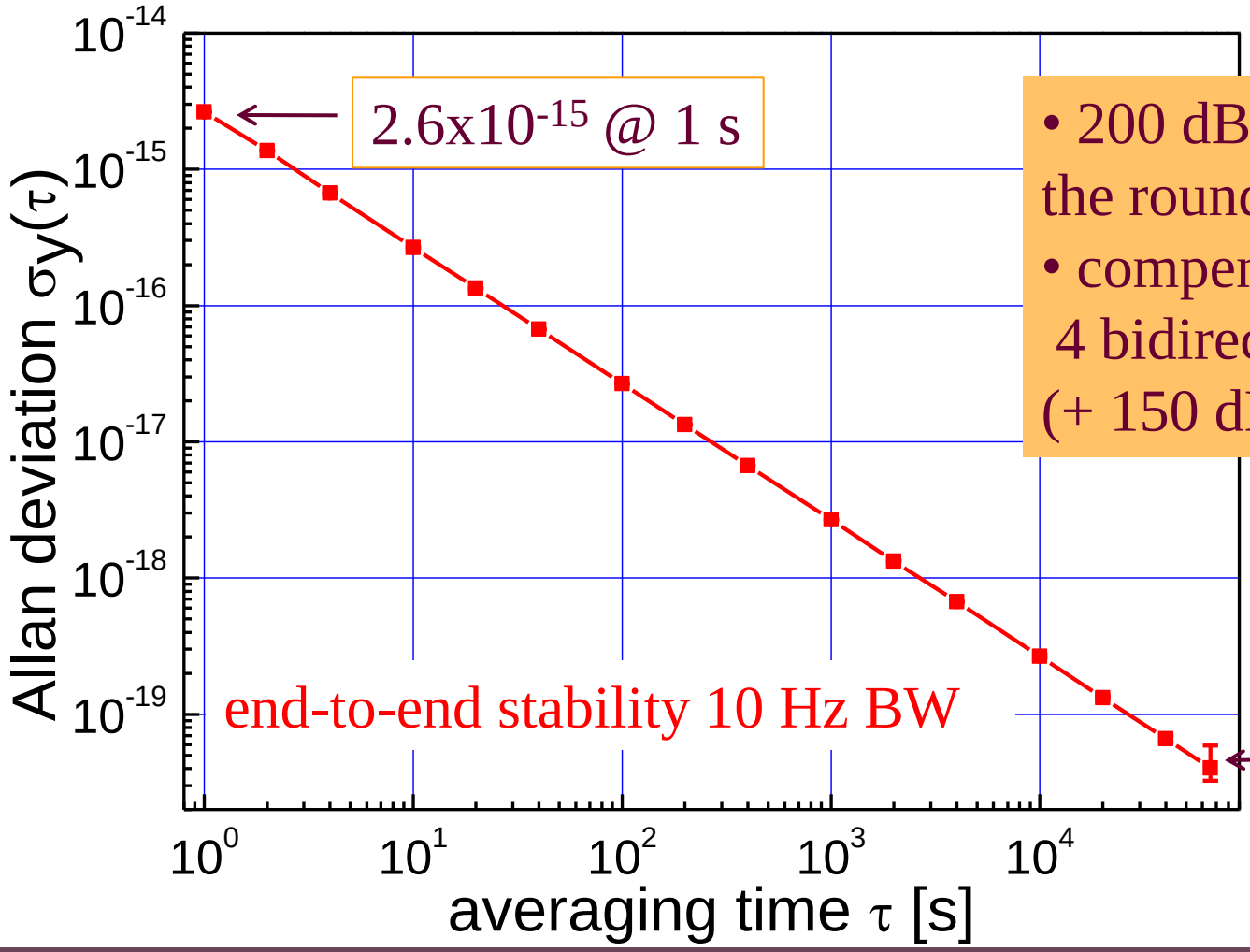


End-to-end stability of the 2x150-km link



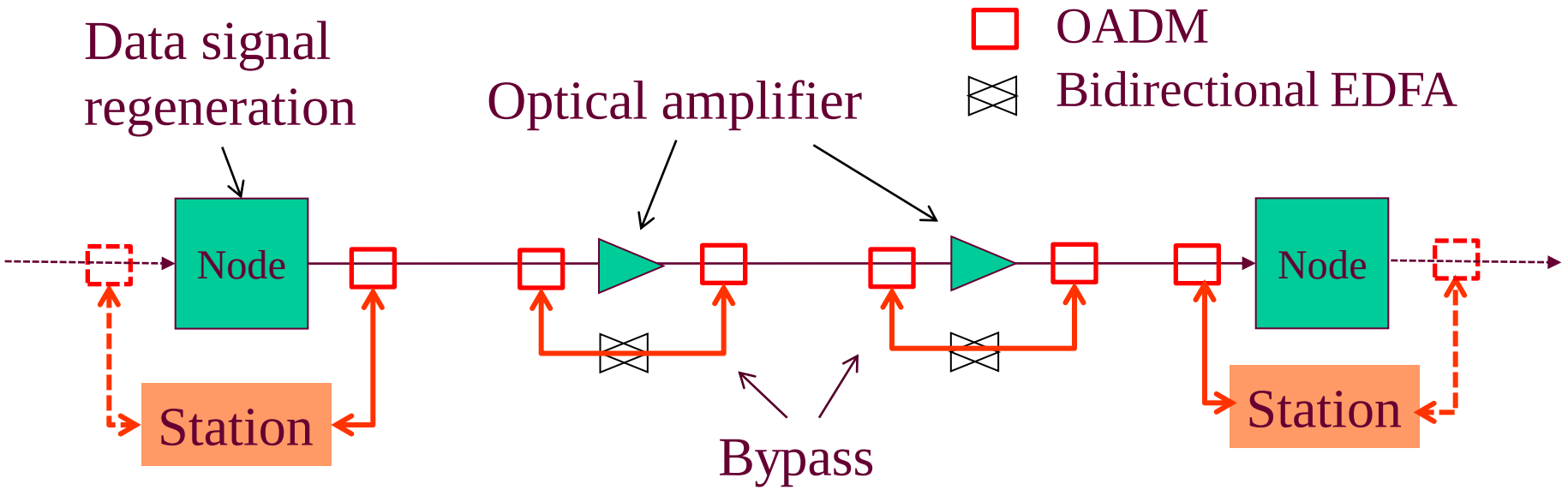
300-km optical link LPL-Nogent l'Artaud-LPL

One-segment link, without any station



- 200 dB attenuation for the round-trip signal
- compensated by 4 bidirectional EDFAs (+ 150 dB amplification)

Towards an effective network

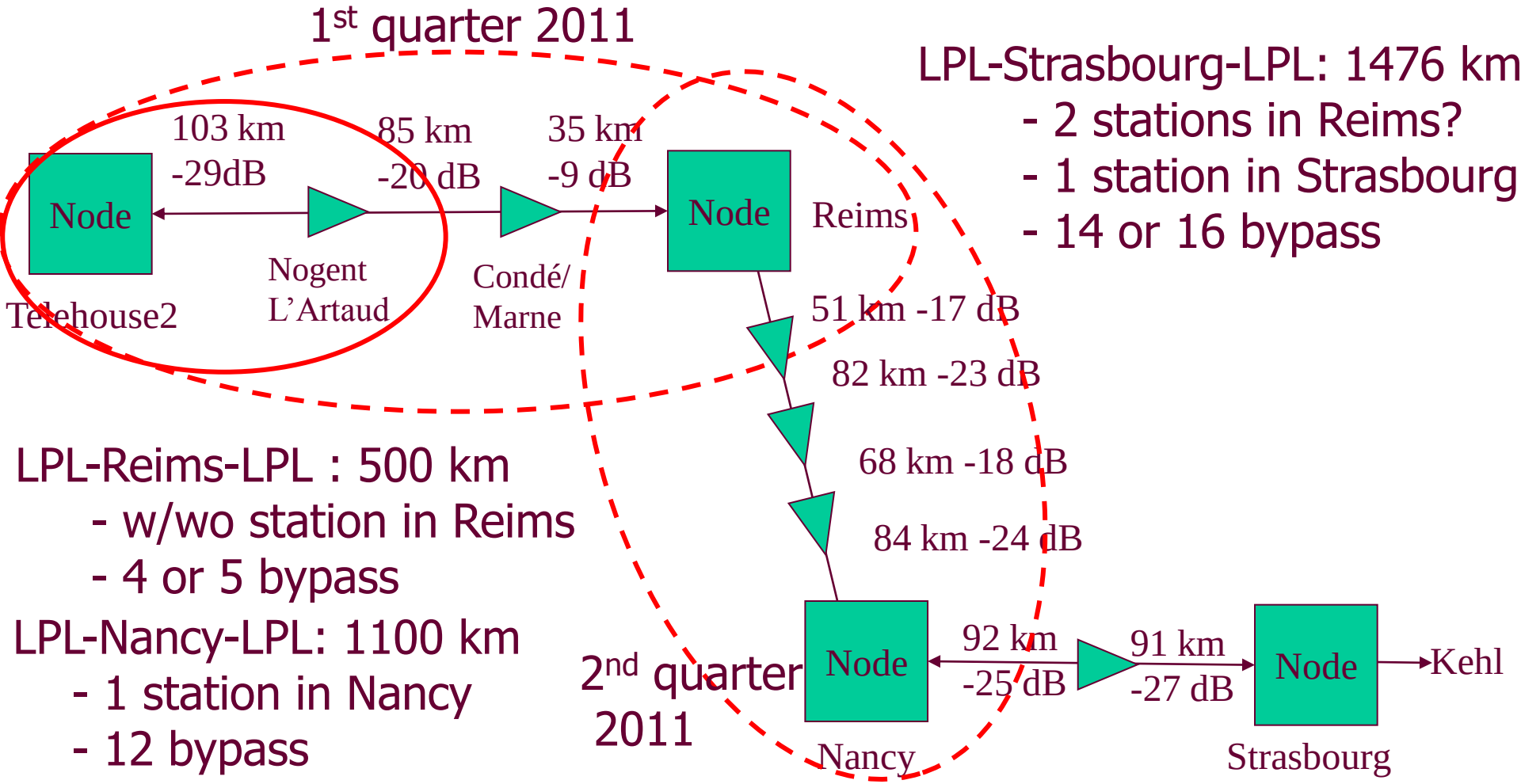


- Current developments
  - Automated polarization controller
  - Simplified Bypass (no AOMs)
  - Optimization of the optical bidirectional amplification stages

→ **single span 500-600 km optical link feasible?**

Near future : towards Germany

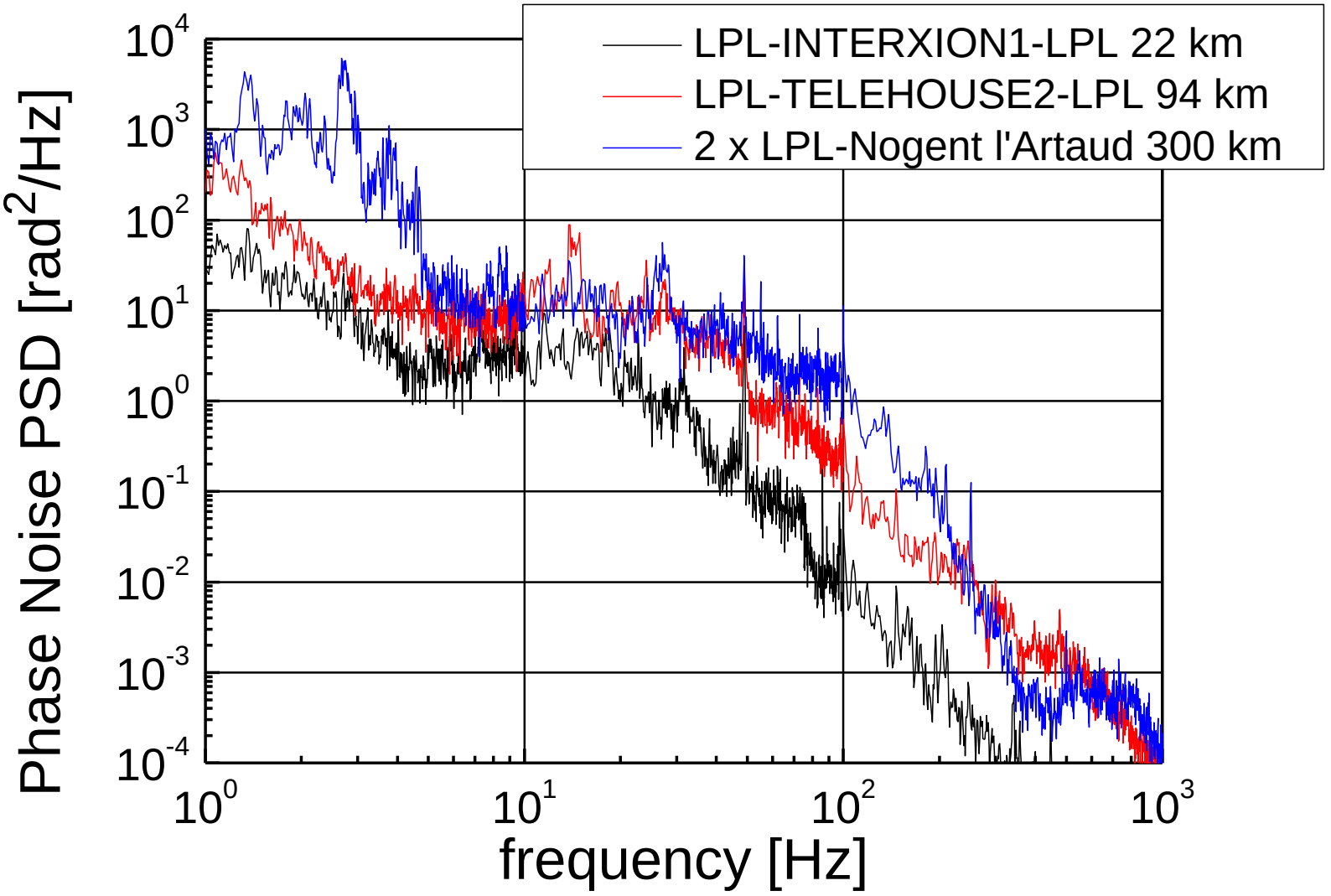
Project : link towards Strasbourg ~750 km (- 230 dB)



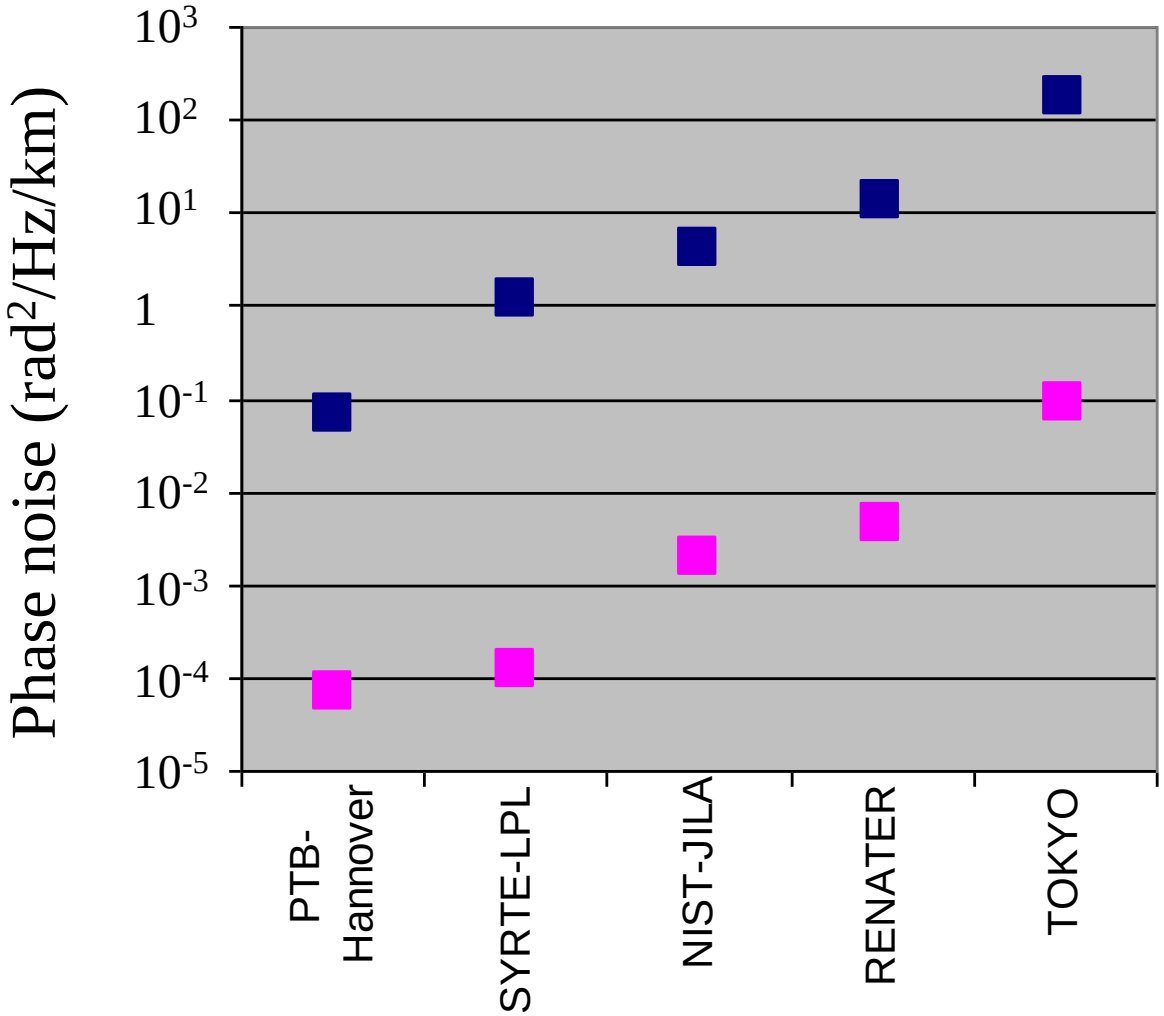
Summary and perspectives

- 300-km or 2x150 km multiplexed link (with/without station)
  - Stability @ 1s : $<3\times10^{-15}$, stability @ 10^4s : 3×10^{-19}
- Reliability
  - No cycle slips, unbiased frequency transfer
  - Continuous operation (weeks)
- Current project : Equipex Refimeve
  - Fiber infrastructure for ultra-stable optical signal dissemination
  - In all France, and towards Europe
- A lot of applications
  - Clocks comparison, measurement of fundamental constants, search of variation of fundamental constants, parity violation in molecules…
  - Time transfer
  - Giant gyrometer: earth rotation/deformation measurement (Sagnac effect)

Inhomogeneity of the phase noise



Phase noise per unit of length



3 orders of magnitude

Estimation of transfer stability is challenging !

REFIMEVE Project

Proposal for 2010 call of French funding agency

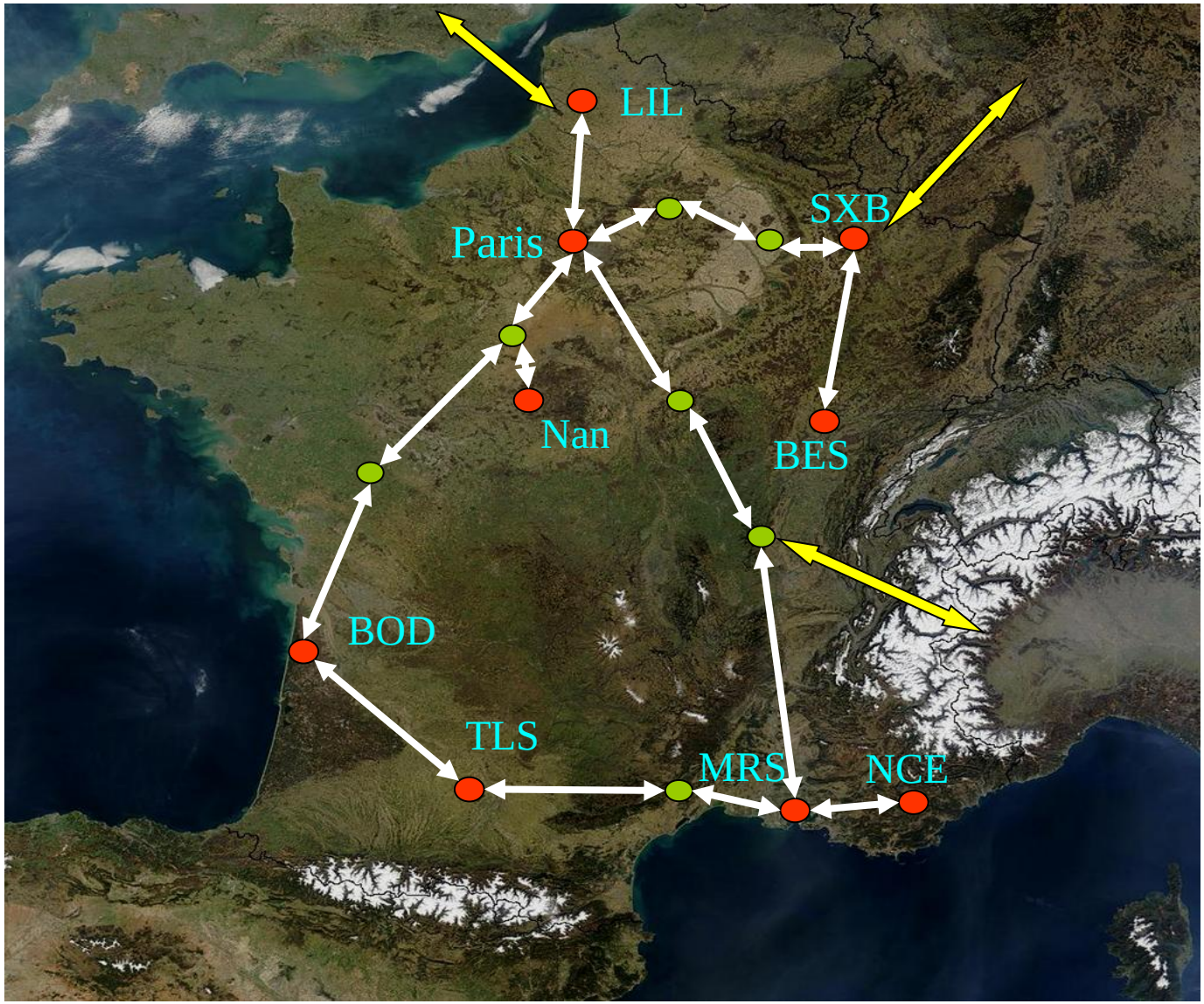
Partners :

- 12 research labs+CNES (Space Agency)
- RENATER
- SME (system supplier)

Fiber infrastructure for ultra-stable optical signal dissemination

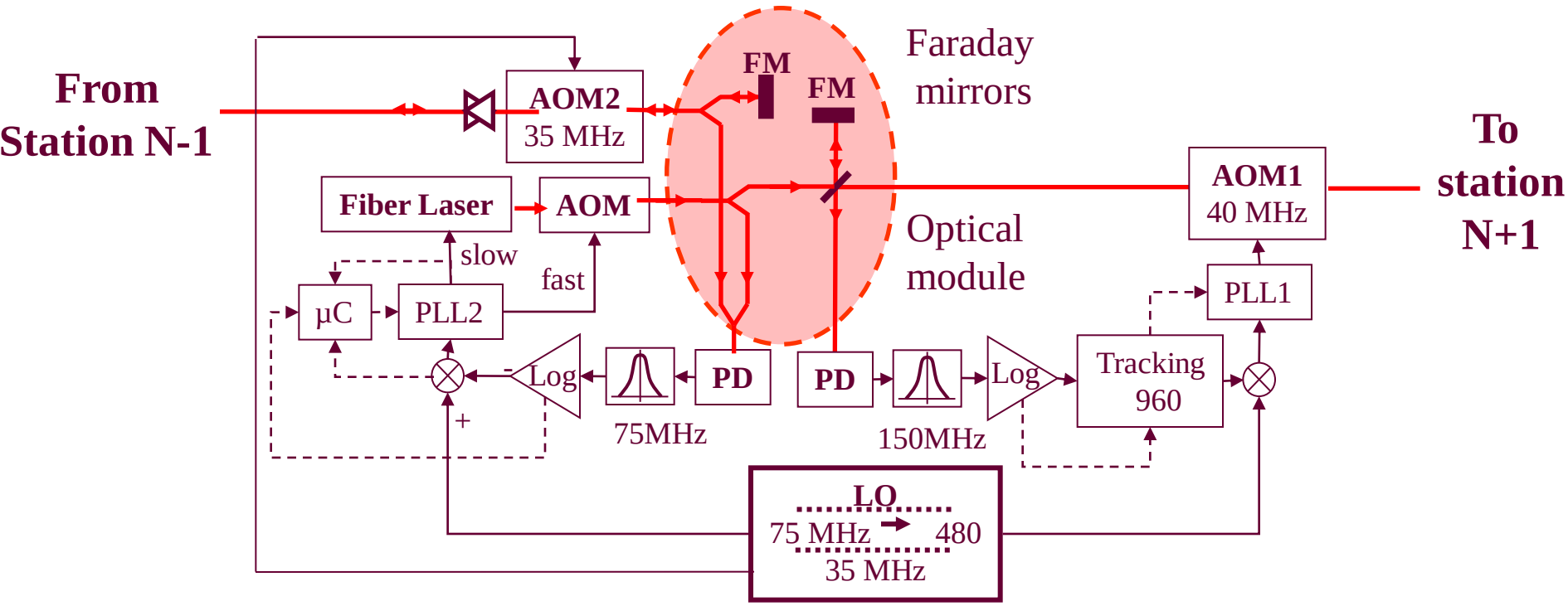
- ~80 bypass
- ~60 stations
- supervision system
- installation

REFIMEVE project



- labs
- stations

Scheme of the Nth repeater station



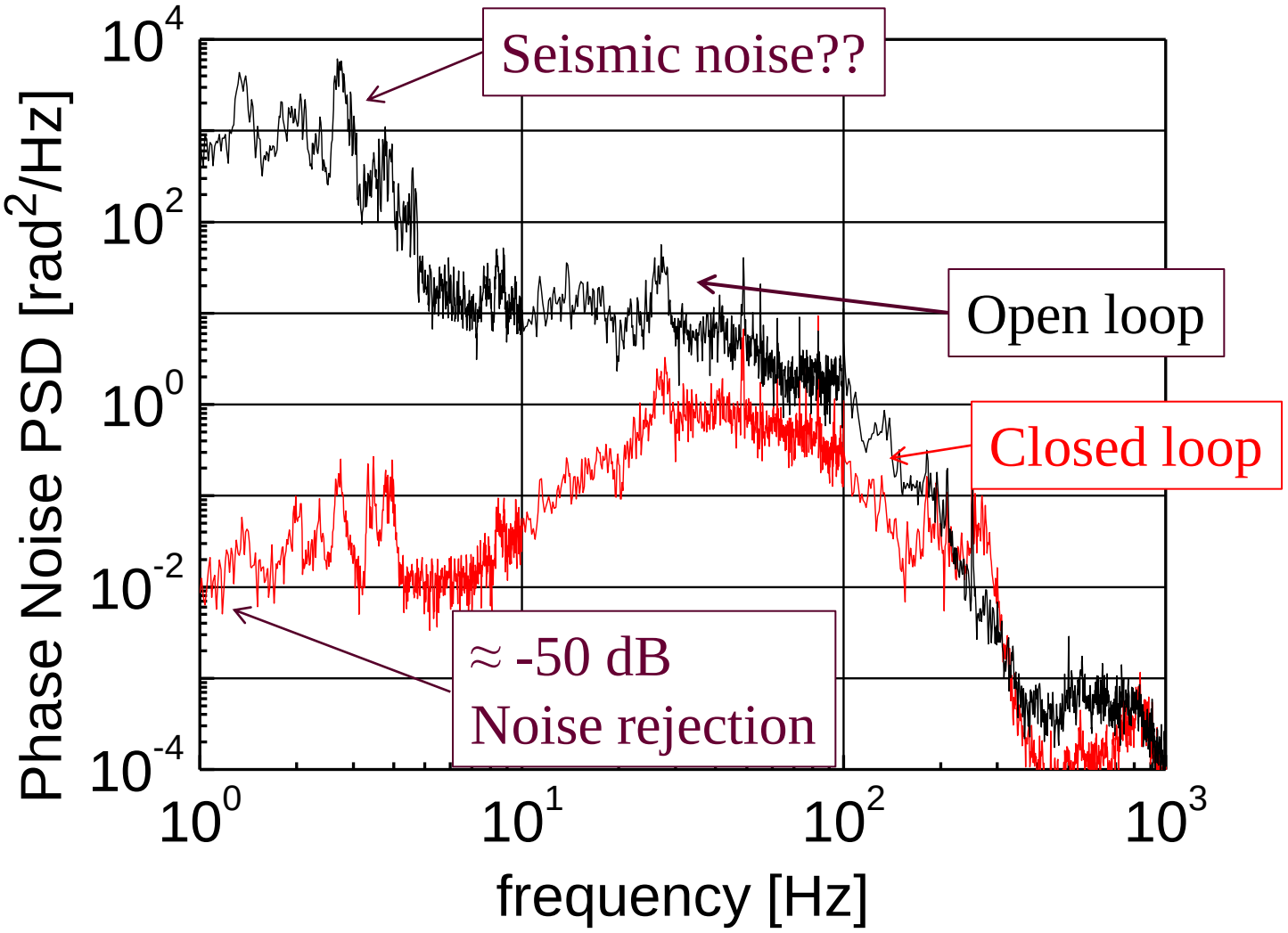
- Send back signal to station N-1
- Amplify and filter
- Correct LinkN noise

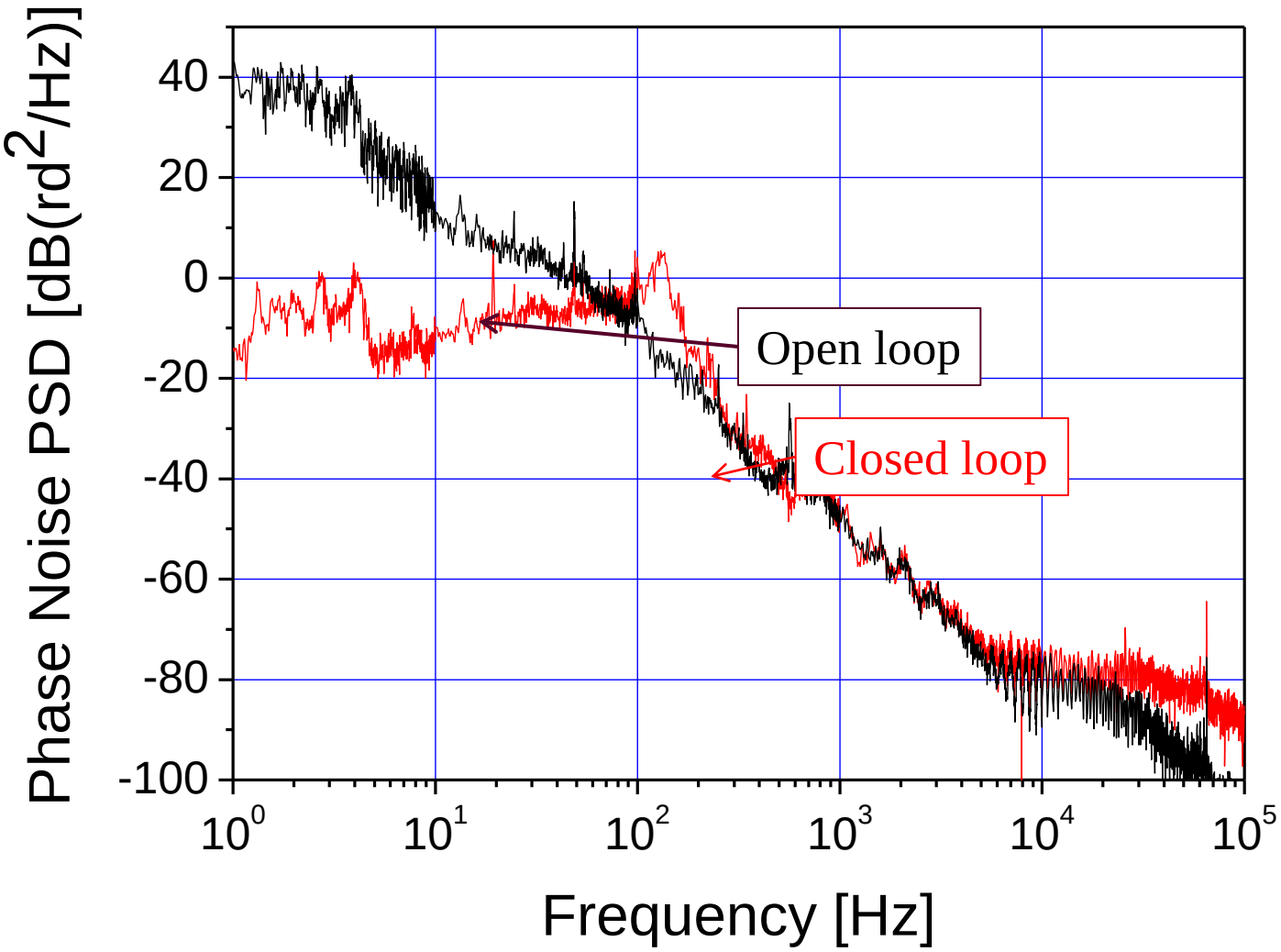
Autonomous

Low power consumption

No needs of stable clock

Multiplexed cascaded optical link - 2 x 150 km




Phase Noise PSD [dB(rd2/Hz)]
40
20
0
-20
-40
-60
-80
-100
10^0
10^1
10^2
10^3
10^4
10^5
Frequency [Hz]
Open loop
Closed loop