Progress on the project and deployment of the network

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Summary

1. Status of the network
2. Construction of the network and results
3. Outlook and conclusion

This presentation: technical aspects and scientific results

2nd presentation: arrival of the signal in the laboratory

→Practical guide for the users

Status of the national network

Core of the network <u>operational</u>:

Multibranch laser stations

5 operational links:

SYRTE-LPL

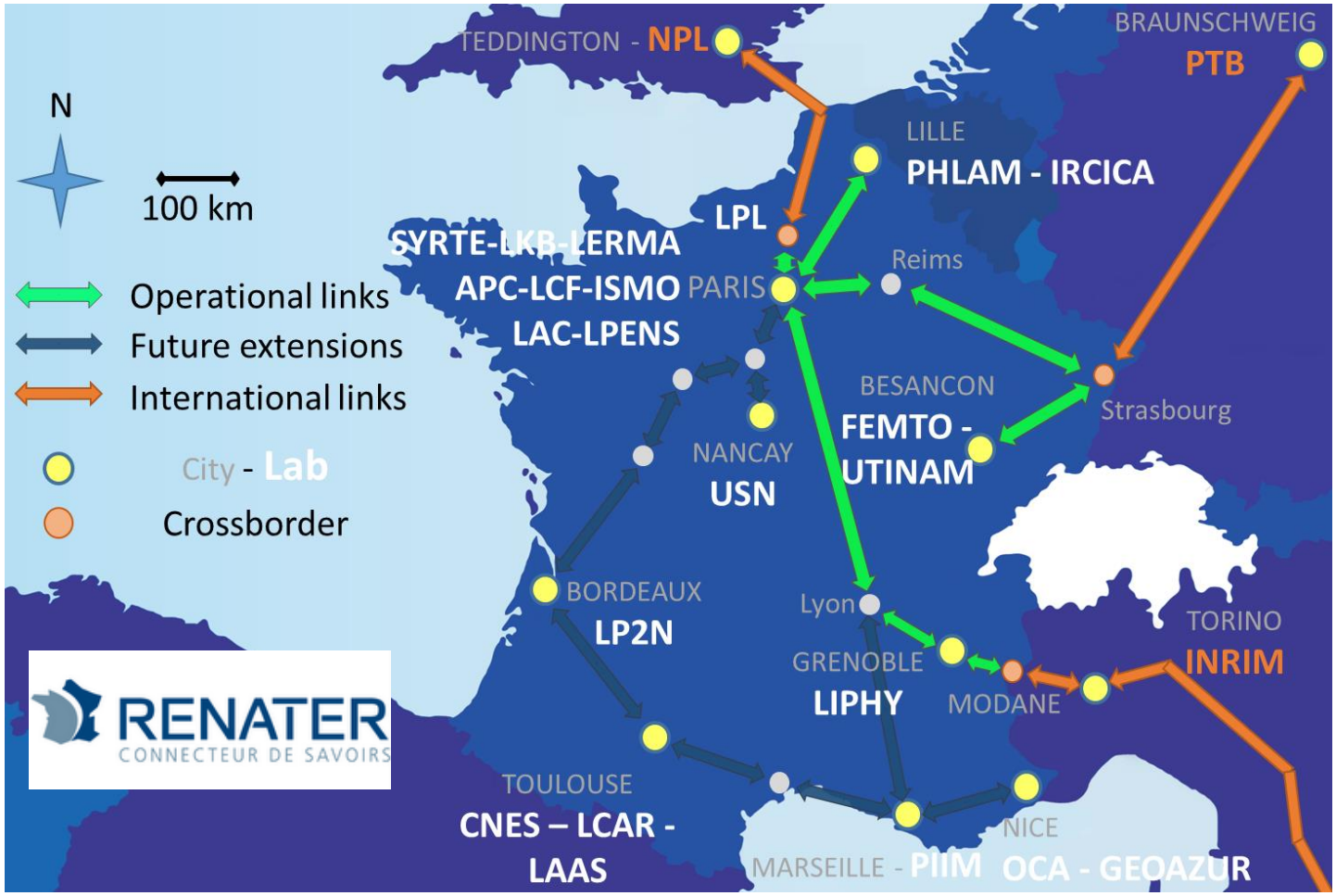
Paris-Lille

Paris-Strasbourg

Besançon-Strasbourg

Paris-Grenoble-Modane

+ regional network



→ **2 x 2400 km of fiber equipped (50% of the network)**

→ **8 users with the signal** (3 in Paris region)

→ **3 National Metrological institutes interconnected**

Status of the regional network

Core of the network <u>operational</u>:

3 Multibranch laser stations

3 operational links:

SYRTE-LPL

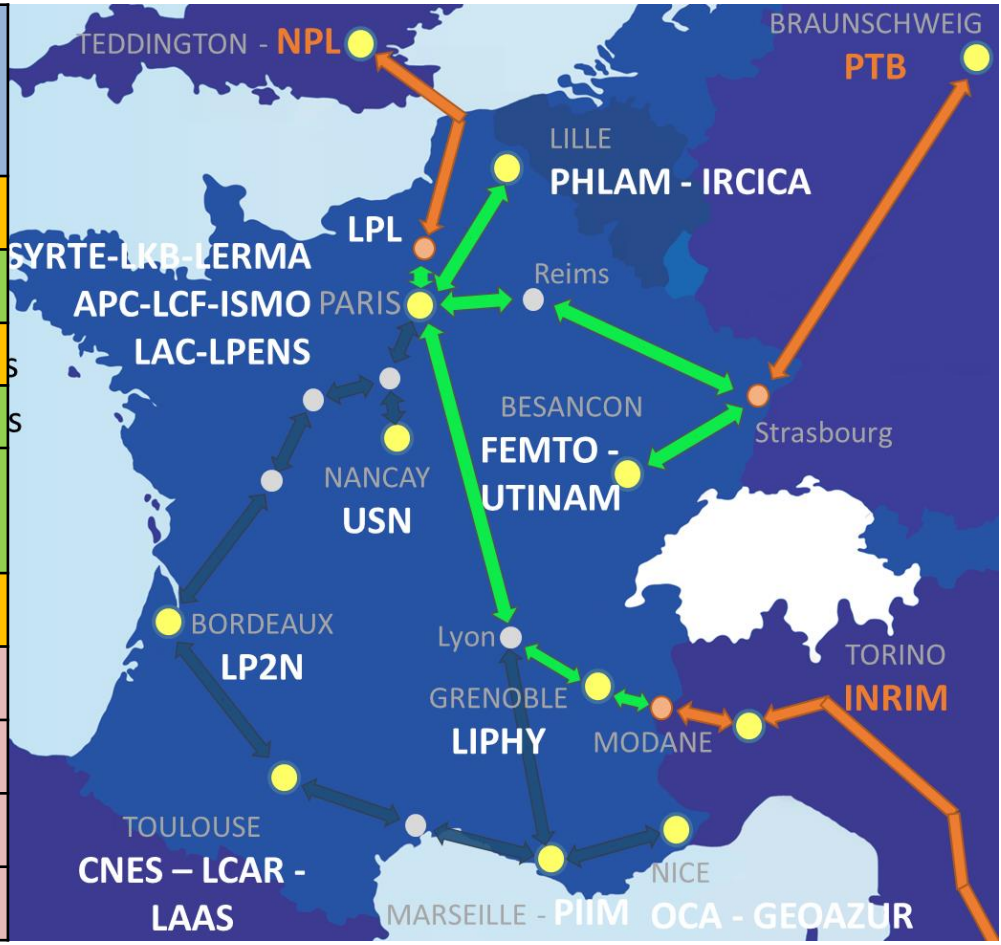
SYRTE-TH2 (→ national)

SYRTE-LKB-APC

→ 3 users with the signal in Paris

Next deployments

Links	Calendar
Regional -Île de France	Ongoing – early 2021
Paris - Lille	Operational
Paris - Strasbourg	Maintenance
Strasbourg - Besançon	Operational
Paris - Grenoble - Modane	Operational
Paris - Marseille	Early to Mid 2021
Paris - Bordeaux	Early to Mid 2021
Paris - Toulouse	Mid to End 2021
Toulouse - Marseille	End 2021
Marseille - Nice	End 2021



Fibers available or soon available

Fibers not available yet

Summary

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Frequency transfer through optical fiber

- **Attenuation of the fiber: 25-30dB for 100 km**→Bi-directional amplification EDFA 
- **Accumulated noise:** it can vary for orders of magnitude depending on the fiber location
  - ✓Two-Way technique: passive compensation

Frequency transfer through optical fiber

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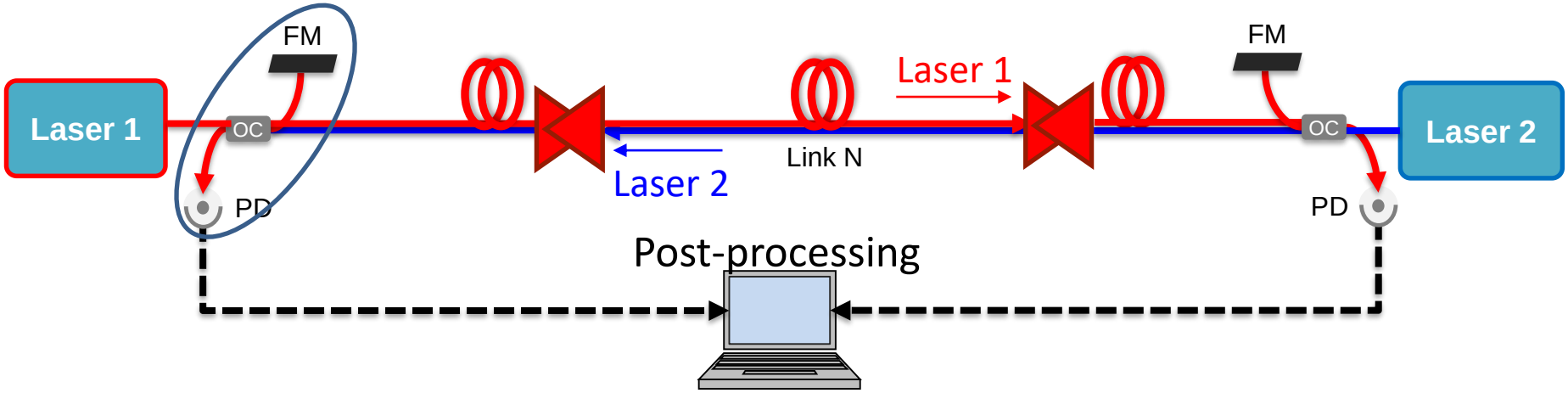
Michelson interferometer



- **First proposed in optical domain** by C. E. Calosso et al., Optics letters, vol. 39, (2014)
- **See also:** A. Bercy et al., *Phys. Rev. A*, vol. 90, no. 6, (2014)
- **Used for example:**
  - locally to compare two different signals
  - Between two outputs of the same instrument: to measure the noise floor of the optical setup

Frequency transfer through optical fiber

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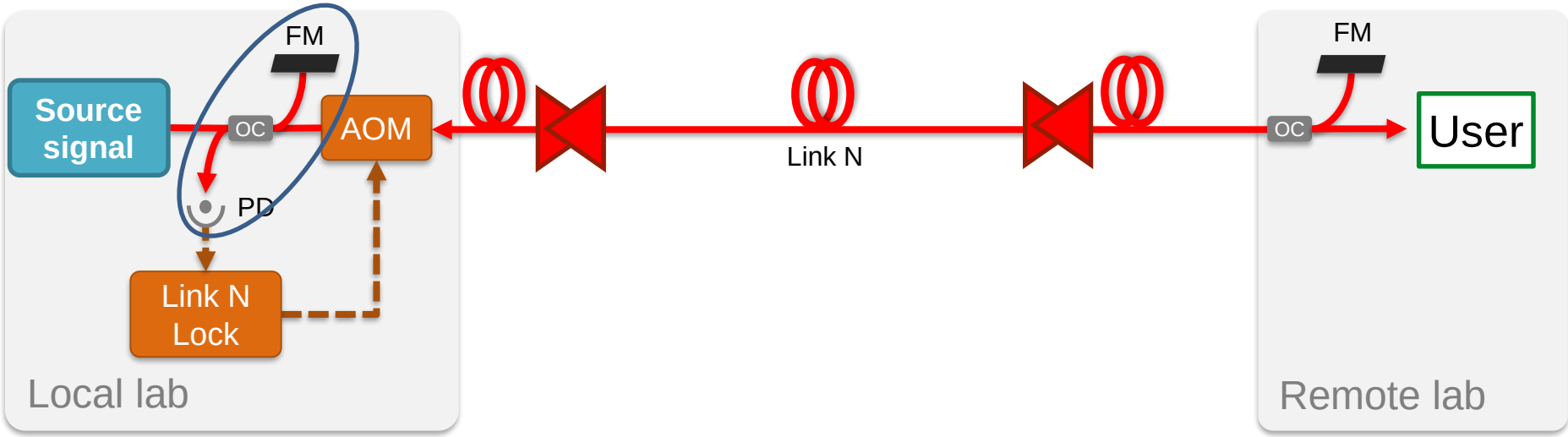
  - ✓ Two-Way technique: passive compensation
  - ✓ Active Noise compensation

Michelson interferometer

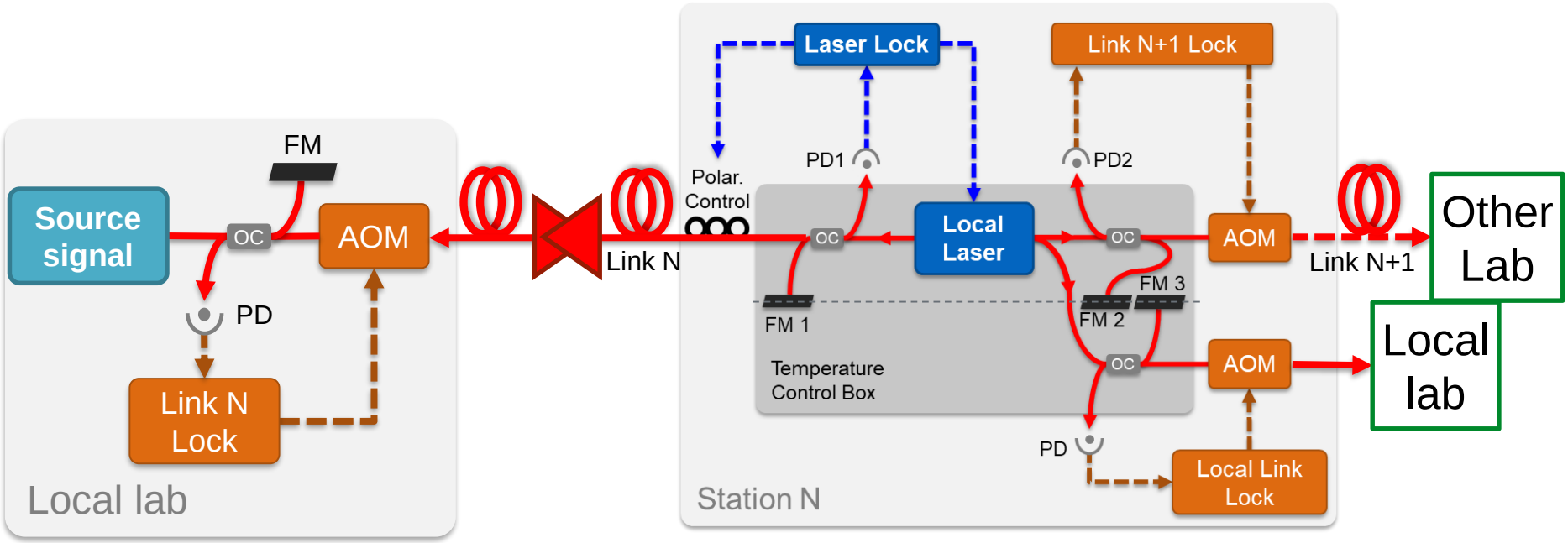


- **Round-trip noise detection** → limited by propagation time

  L > 50 km = bandwidth < 1 kHz

Regeneration Laser Station

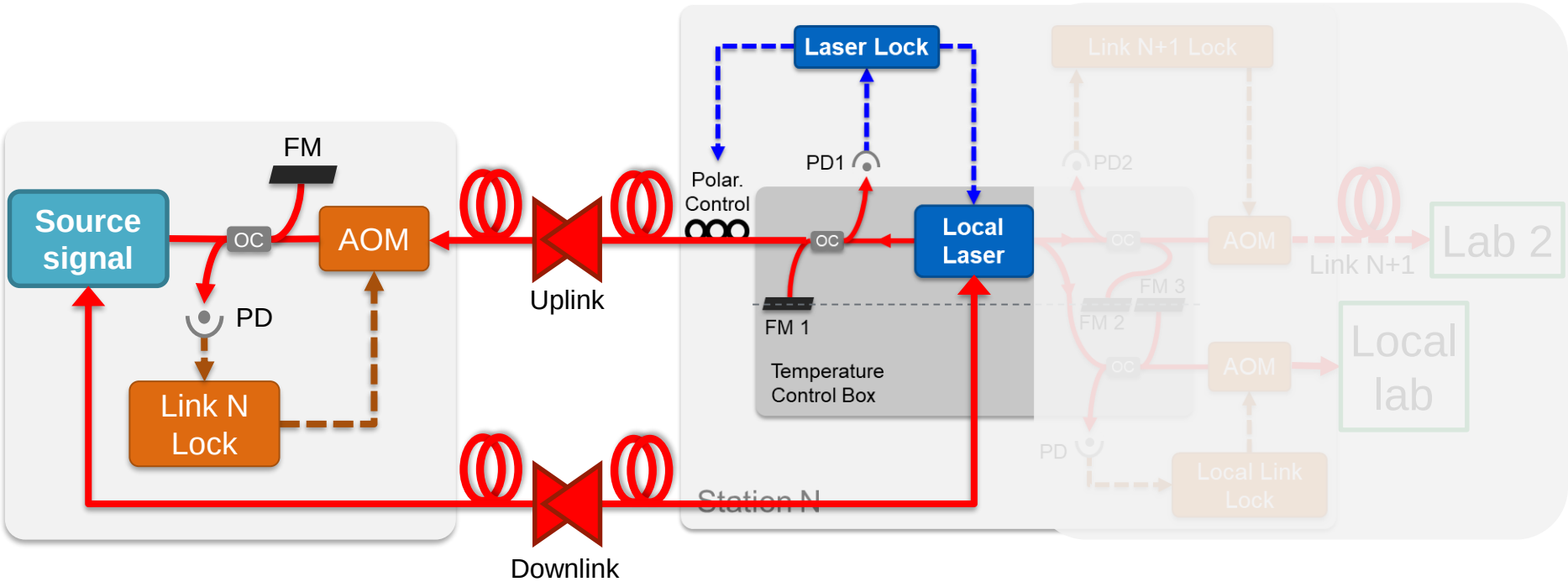
- **Attenuation of the fiber: 25-30dB for 100 km** → Bi-directional amplification EDFA
- **Accumulated noise:** it can vary for orders of magnitude depending on the fiber location
  - ✓ Two-Way technique: passive compensation
  - ✓ Active Noise compensation **+ Regeneration laser station**
- **Polarization change:** automatic adjustment



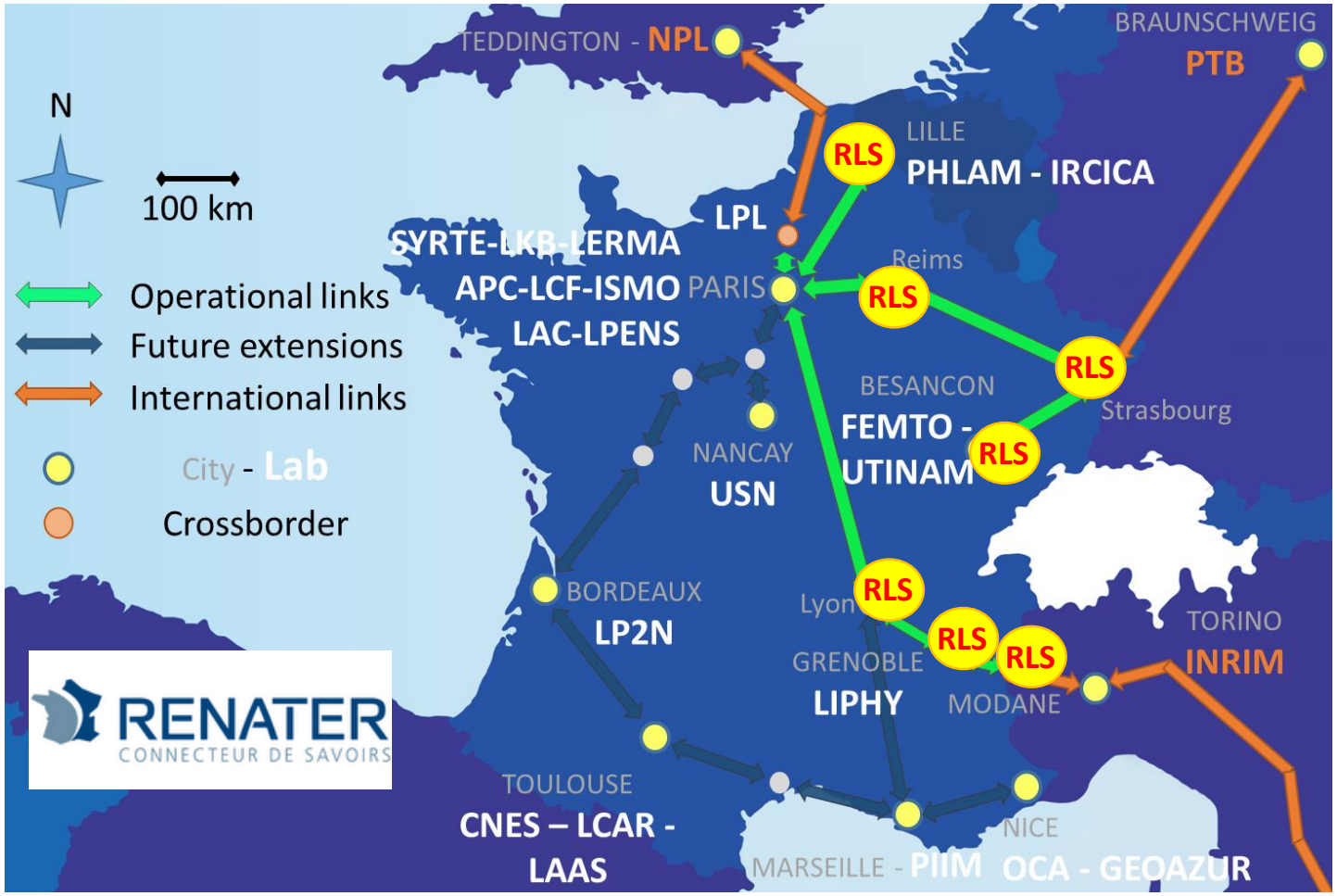
- **User module to disseminate locally** (connected to the station to compensate for the noise)
- Remote control, automatisation

Measurement of the performances

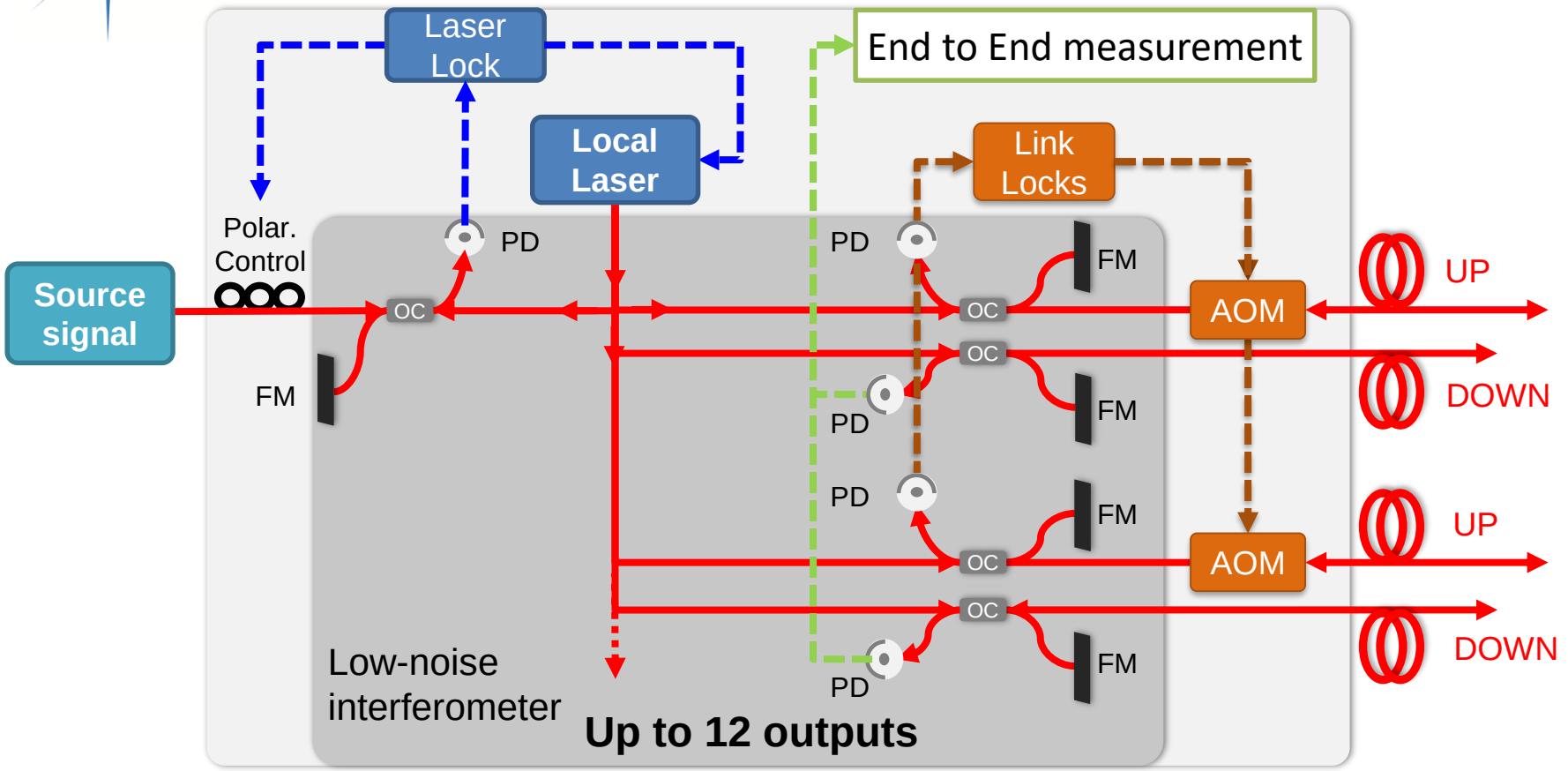
- **Assessment of the performances:** End to End measurement
  - Out of loop measurement with a second fiber (**downlink**)
  - Performances of the round-trip: **overestimation for the dissemination**



Status of the national network

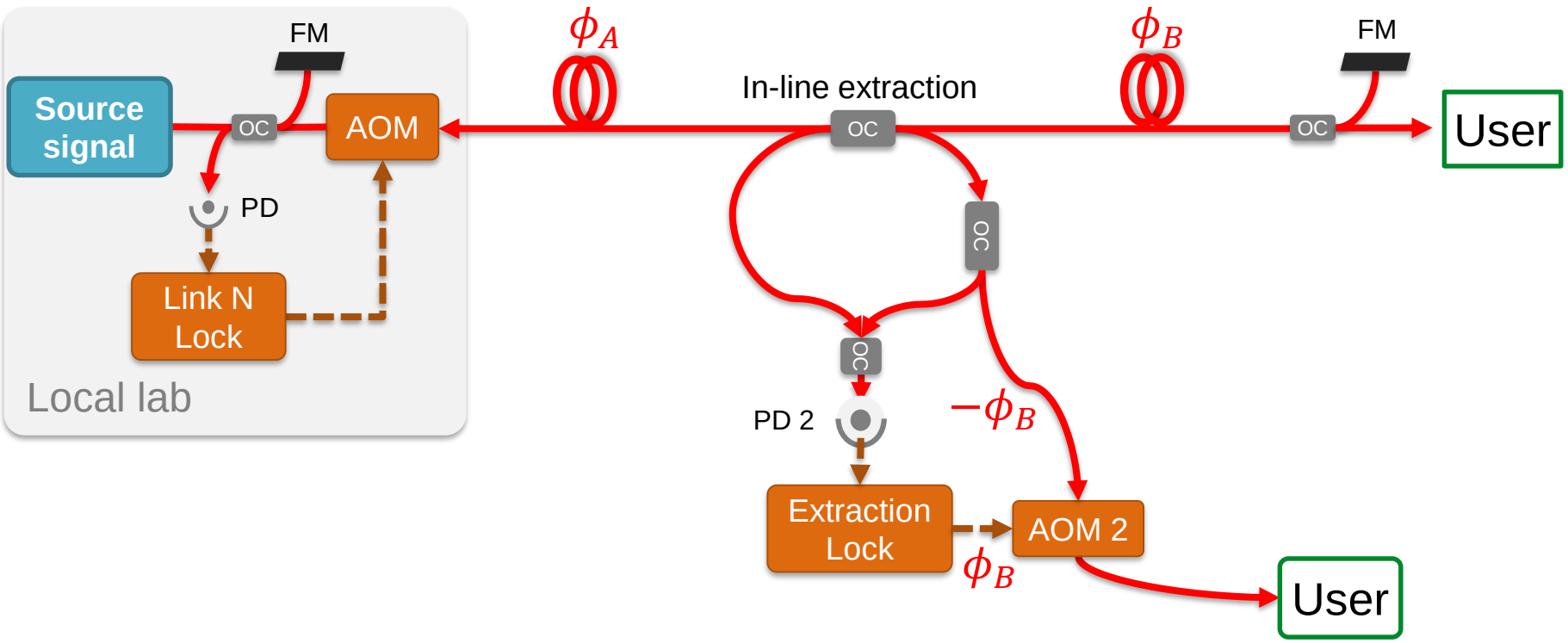


Multibranch Laser Station



- New conception of the interferometric ensemble:
  - **Multibranch**
  - **Performances at the state-of-the-art** in frequency transfer: stability at 10^{-21} @ 10'000s
- Measurement of the **link performances** embedded to the station
- Based on RLS: electronics, remote control, automatisation

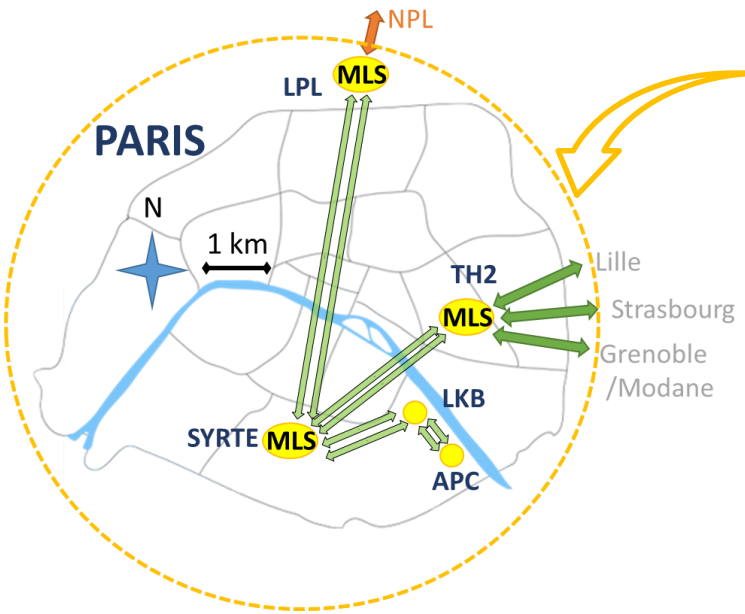
Extraction Station

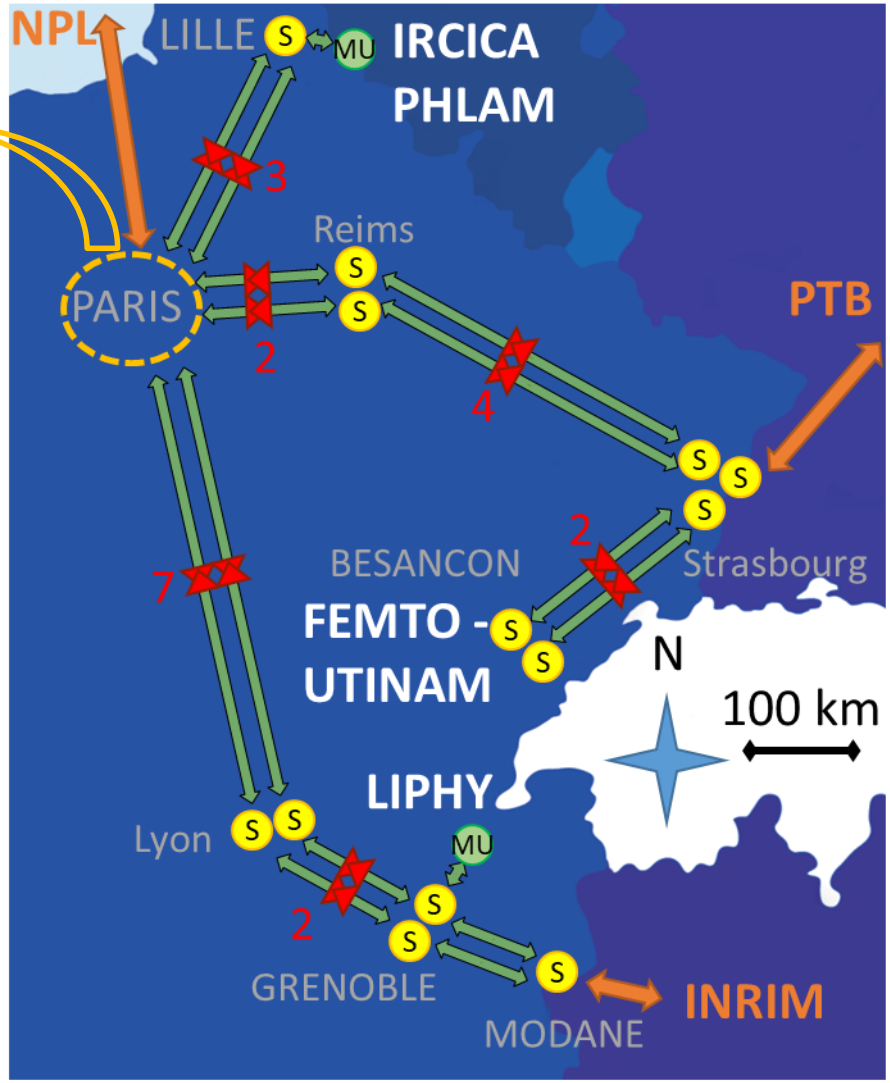


- **Overcorrection at extraction point measured at PD 2 and compensate at AOM 2**
- **First proposed in optical domain** by G. Grosche, German patent + Optics letters, vol. 39 (2014)
- **See also**: A. Bercy et al., Opt. Soc. Am. B **31**, 678-685 (2014) + Appl. Phys. B, vol. 122, no. 7, (2016)

- **Extraction stations are ready** (re-work this year on the polarization sensitivity): mainly used on the regional network

Construction of the network





Many equipment:

- **13 Regeneration Laser Station**
- **3 Multibranch Laser Station**
- **20 double amplifiers**
- **2 user modules**

→ Need of robustness and reliability

→ Need of supervision

See Martin's talk

Results – Stability & accuracy

→Performances calculated from the end-to-end measurement

Phase and stability on the 4 links over 3 days

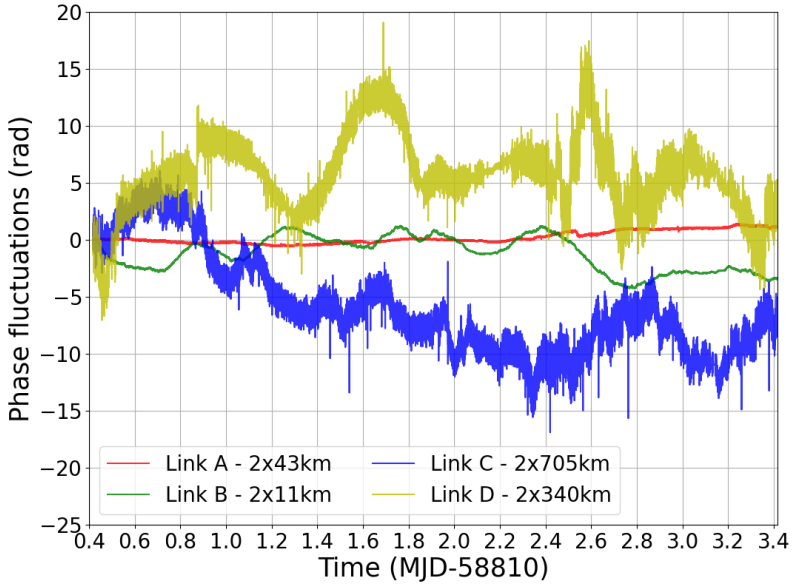
SYRTE-LPL – Link A – 43km

SYRTE-TH2 – Link B – 11km

Paris-Lille – Link C – 340km

Paris-Strasbourg – Link D – 705km

(Paris-Modane → See Anne and Paul Eric's talk)



Conclusion

- **Construction of the network**
  - Different type of equipment to construct an efficient network
  - All the different equipment are **industrial-grade** and are constructed
  - **Multibranch laser stations**: current state-of-the-art in frequency transfer

- **Performances**
  - Performances below **10^{-18} for stability at long term and accuracy**
  - Network **robust** and **reliable**
    - Repeatability of performances over time
    - Mean uptime over 2 years > 66% (**>95%** with great effort)

Outlook

- **Instrumental aspect**
  - **Knowledge transfer** on the multibranch laser stations
  - **Enhancement** of the robustness & reliability

- **Deployment of the network and future extensions**
  - Dissemination to Marseille, Bordeaux and Toulouse
  - Regional network: dissemination to south of Paris

- **Global supervision of the network (operational and metrological)**
  - User interface → See Martin's talk

Thank you for your attention!