

SENSEI:

Smart European Networks for Sensing  
the Environment and Internet quality

C. Clivati

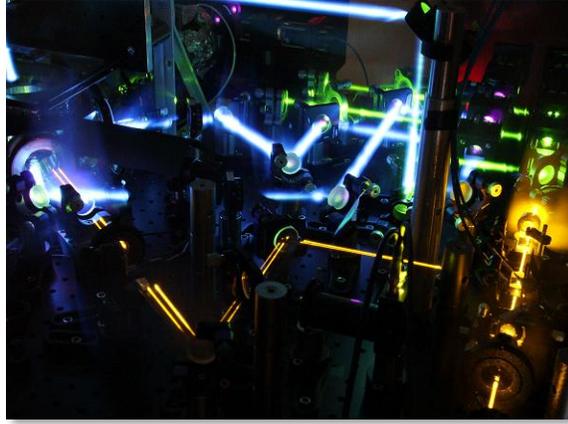
Istituto Nazionale di Ricerca Metrologica – INRIM, Torino, Italy

# The Italian National Metrology Institute

Cs fountain clock



Yb/Sr optical clocks



Italian National Time



Rb cell clocks



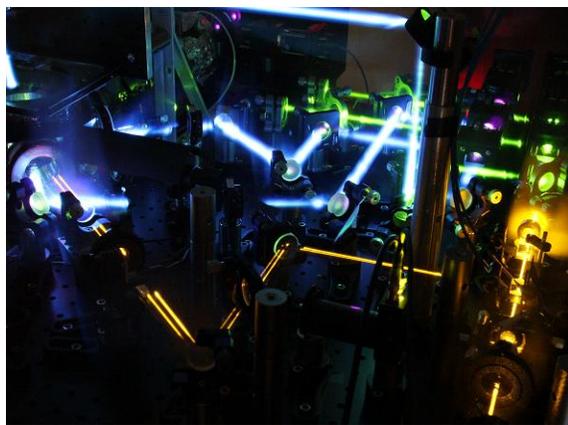
**SENSEI**

# The Italian Quantum Backbone

Cs fountain clock



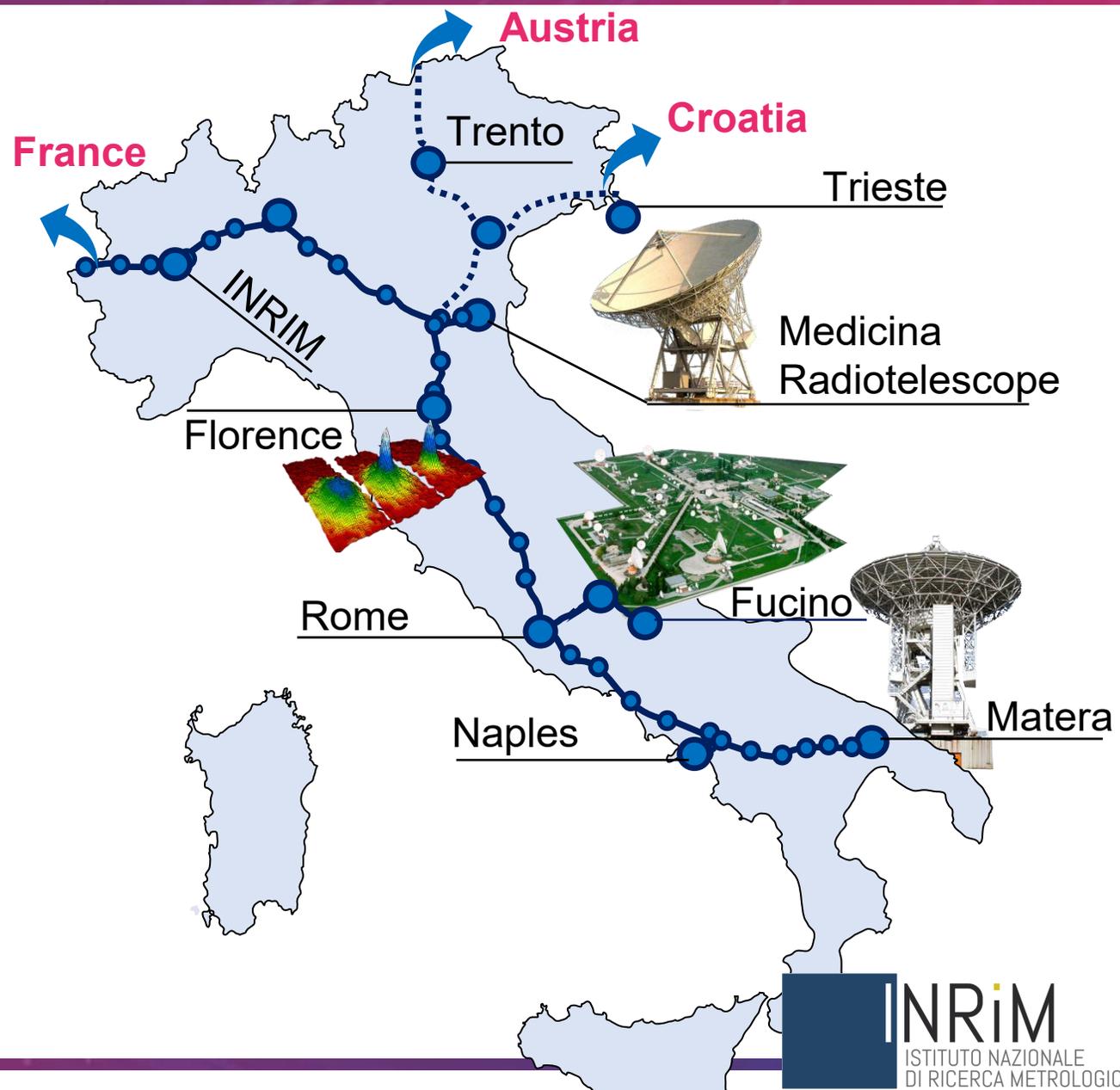
Yb/Sr optical clocks



Italian National Time



Rb cell clocks



# Metrology & more

- T&F for spectroscopy, geodesy, VLBI...

Clivati, Opt. Exp. (2016);  
Clivati, Optica (2020)

- Large EU optical clock comparisons

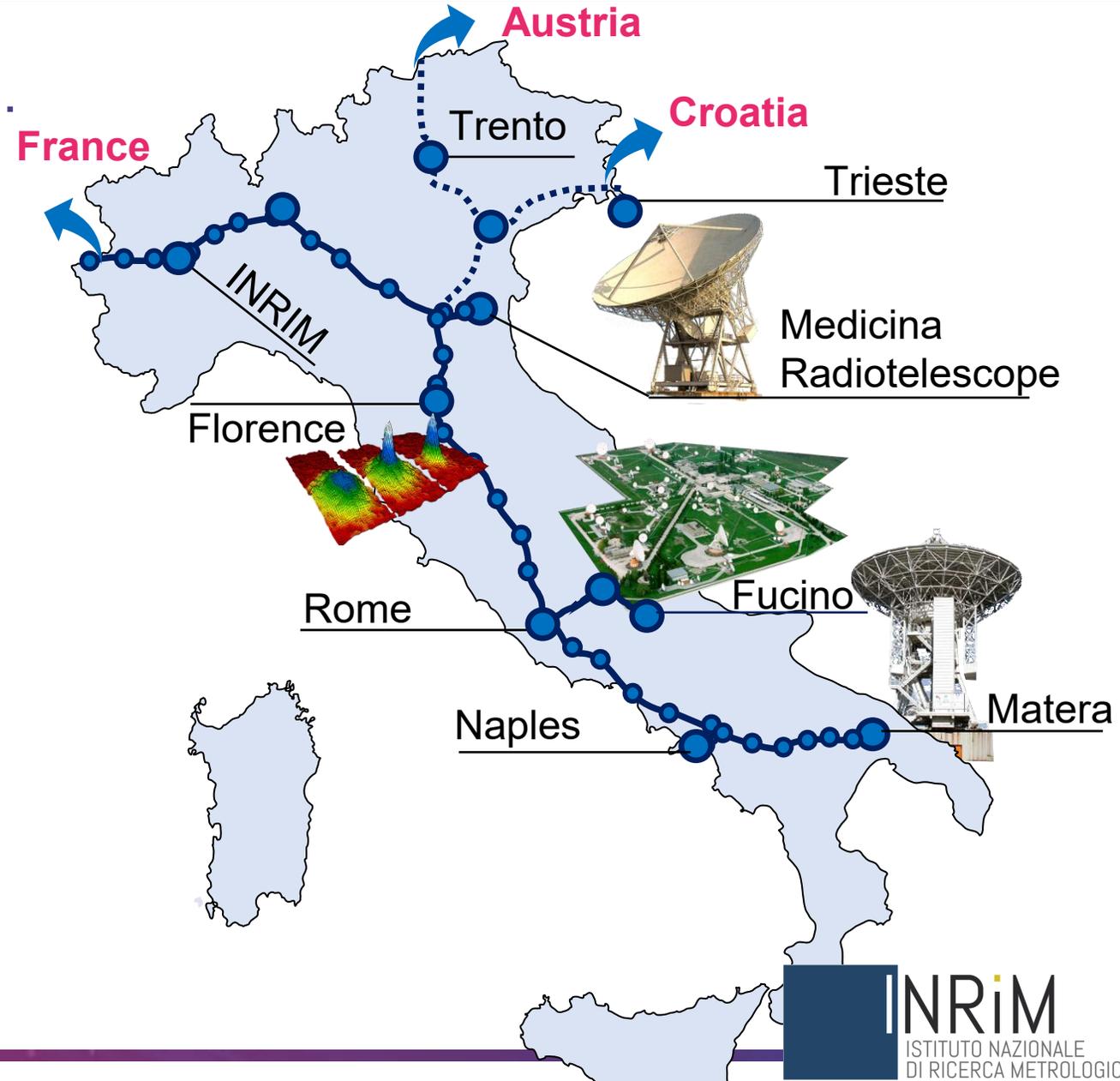
Clivati, PRApp. (2022);  
Lindvall, Optica (2025)

- Quantum communication

Clivati, Nat. Comm. (2022);  
Meda, Sci. Rep. (2025)

- Distributed sensing

Marra, Science (2018),  
Donadello, Comm. Earth Env. (2024)



# The SENSEI project

---

## Smart European Networks for Sensing the Environment and Internet quality

- **Programme:** Horizon Europe (Digital and Emerging Technologies)
- **Call:** Smart photonics for joint communication & sensing and access everywhere
- **Budget:** 5 M€
- **Duration:** Dec.2024-Nov. 2027



Funded by  
the European Union

# SENSEI in a nutshell

---

- Turn the global telecom. fiber network into a **pervasive distributed sensor**
- Make the network **more resilient and efficient** thanks to improved supervision ability



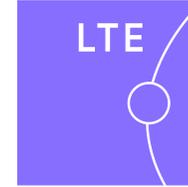
Science, citizen protection, alerting



Network operation & maintenance

# The Consortium

Research institutes  
(photonics, T&F)



Research institutes  
(Earth science)



L-Università  
ta' Malta



LABORATOIRE de RECHERCHE  
TERRE - OCÉAN - ESPACE

Optical networking



Politecnico  
di Torino



UNIVERSITY OF  
PATRAS  
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

Network Operators



Companies  
(photonics)



# SENSEI objectives

---

- Novel **photonics techniques** for sensing in coexistence with data traffic
- Integration into the **network control** architecture
- **Field tests** on deployed cables, **data** management & interpretation
- **Use-cases** within the stake-holder community

# Conventional photonic sensing (DAS)



## Earthquakes / faults:

Jousset, Nat. Comm. 13, 1753 (2022)



## Ice:

Walter, Nat. Comm. 11, 2436 (2020)

Klaasen, JGR Solid Earth 126 (2021)



## Volcanos:

Currenti, Sci. Rep. 13:4641 (2023)

Jousset, Nat. Comm. 13, 1753 (2022)



## Oceanography:

Lindsey, Science 366, 1103 (2019)

Landro, Nat. Comm. 13, 1753 (2022)



## Intrusions, vehicles, cable safety:

Wang, Opt. Expr. 27, 23682 (2019)

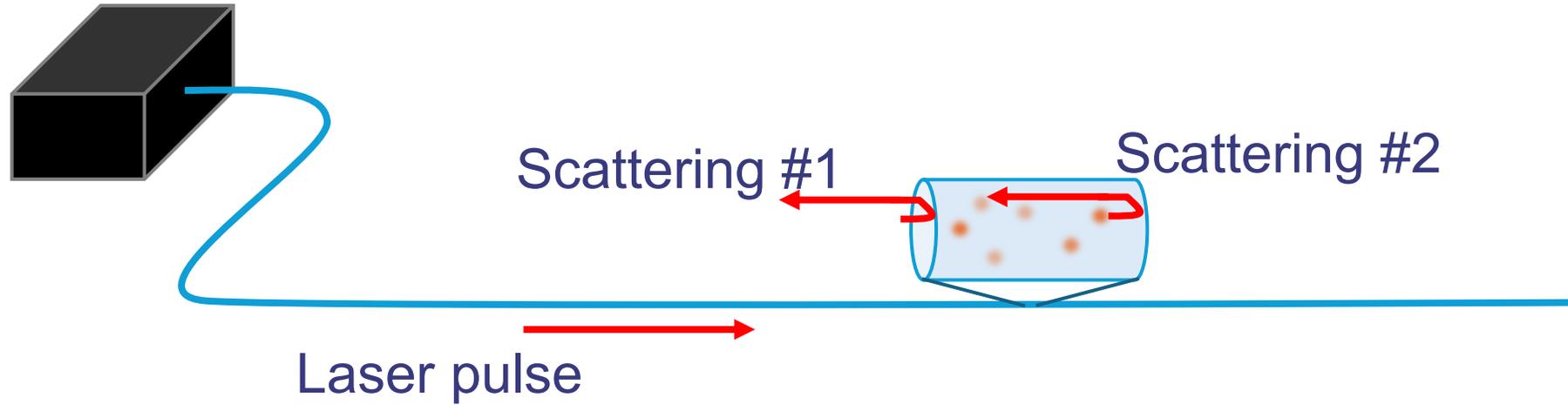


## Structural Health Monitoring:

Liu, Struct. Control Health Monit., (2023)

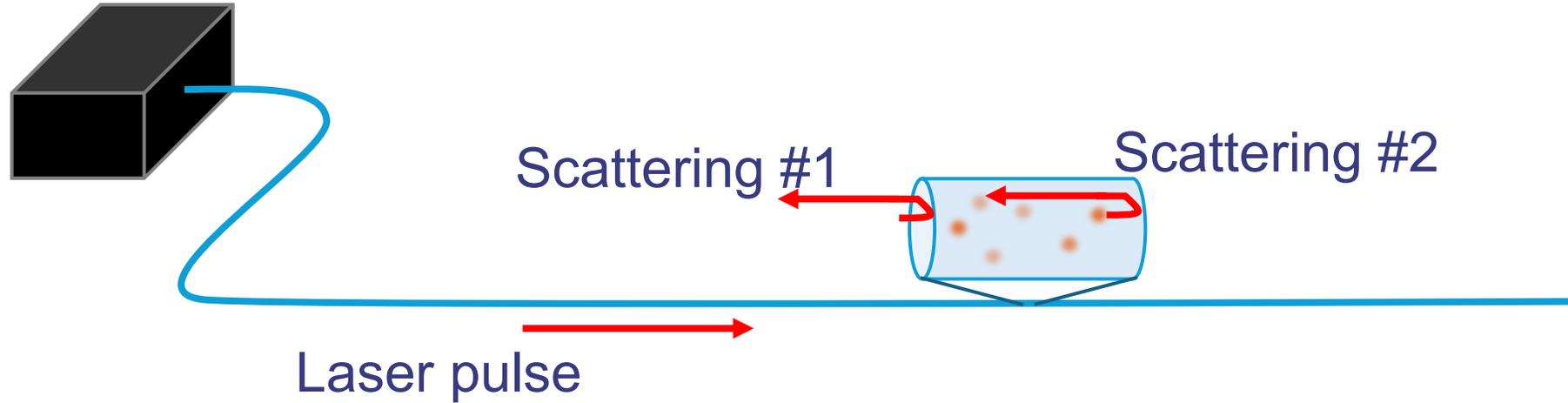
# Conventional photonic sensing (DAS)

Laser + measurement

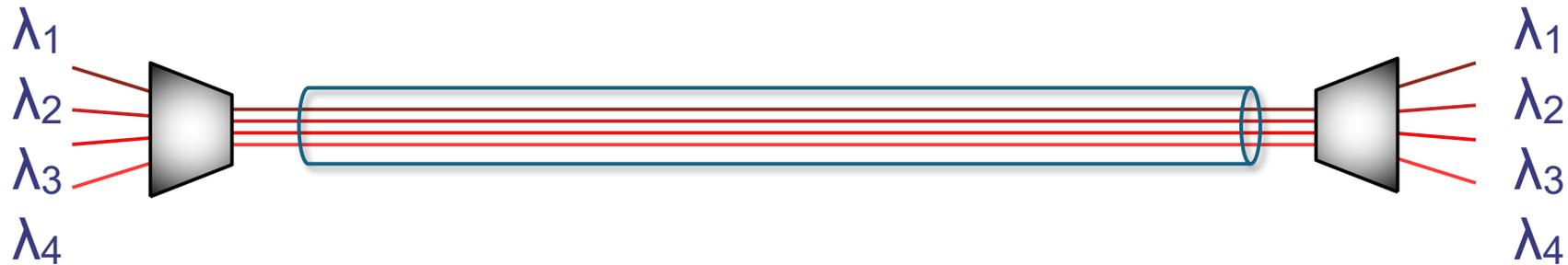


# Conventional photonic sensing (DAS)

Laser + measurement

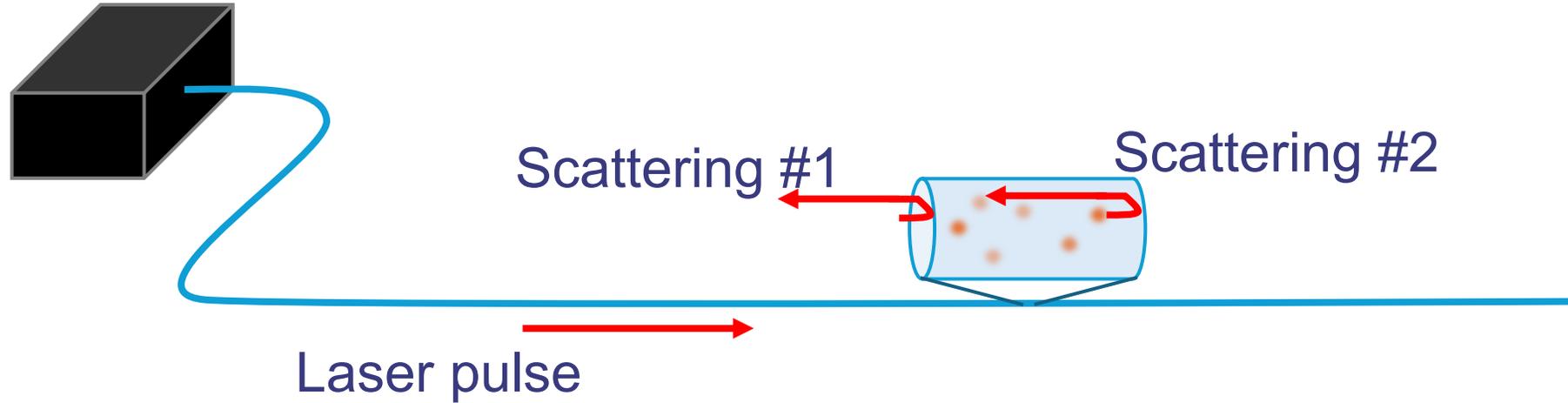


1) Dense **Wavelength-division multiplexing**: requires constant launch power

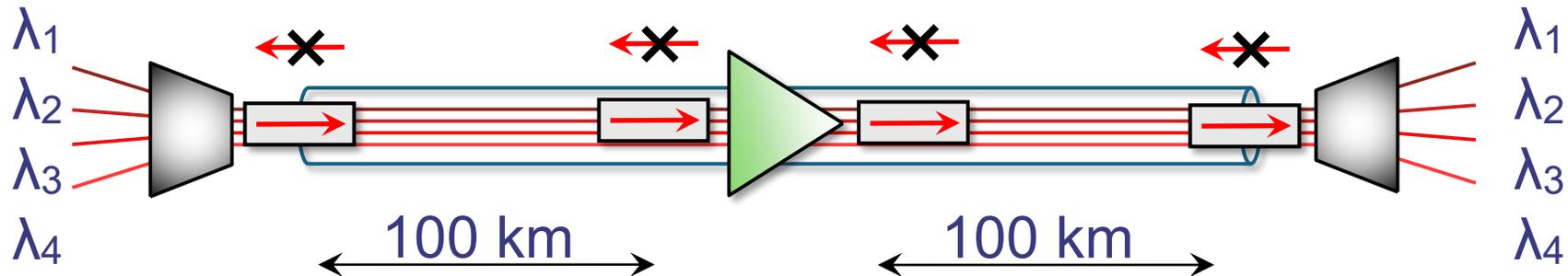


# Conventional photonic sensing (DAS)

Laser + measurement



- 1) Dense **Wavelength-division multiplexing**: requires constant launch power
- 2) Data links are protected by **isolators** that block backscattered light



# Dedicated fibers?

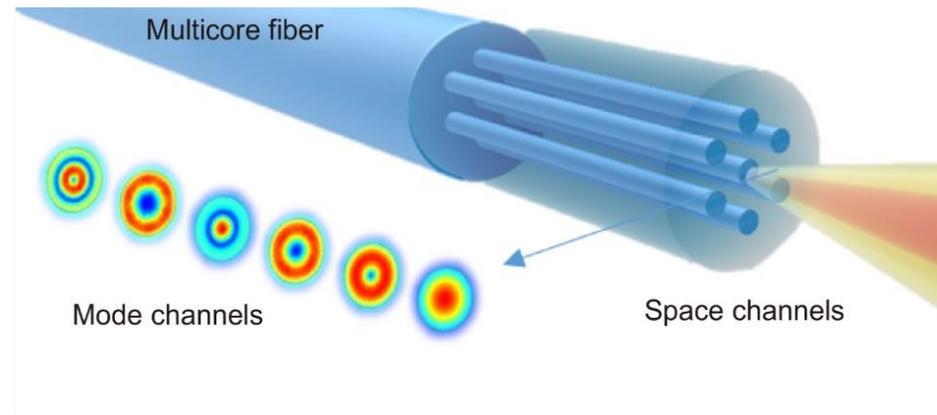
- Deployment & maintenance costs (surveys, digging, repairs...)
- Regulations and permits (government, ecosystem...)
- Revenue uncertainty (geophysical hotspots, borders, subsea...)
- Space occupation (conduits and endpoints)
- Power consumption (amplifiers & terminal equipment)

More fibers per cable...



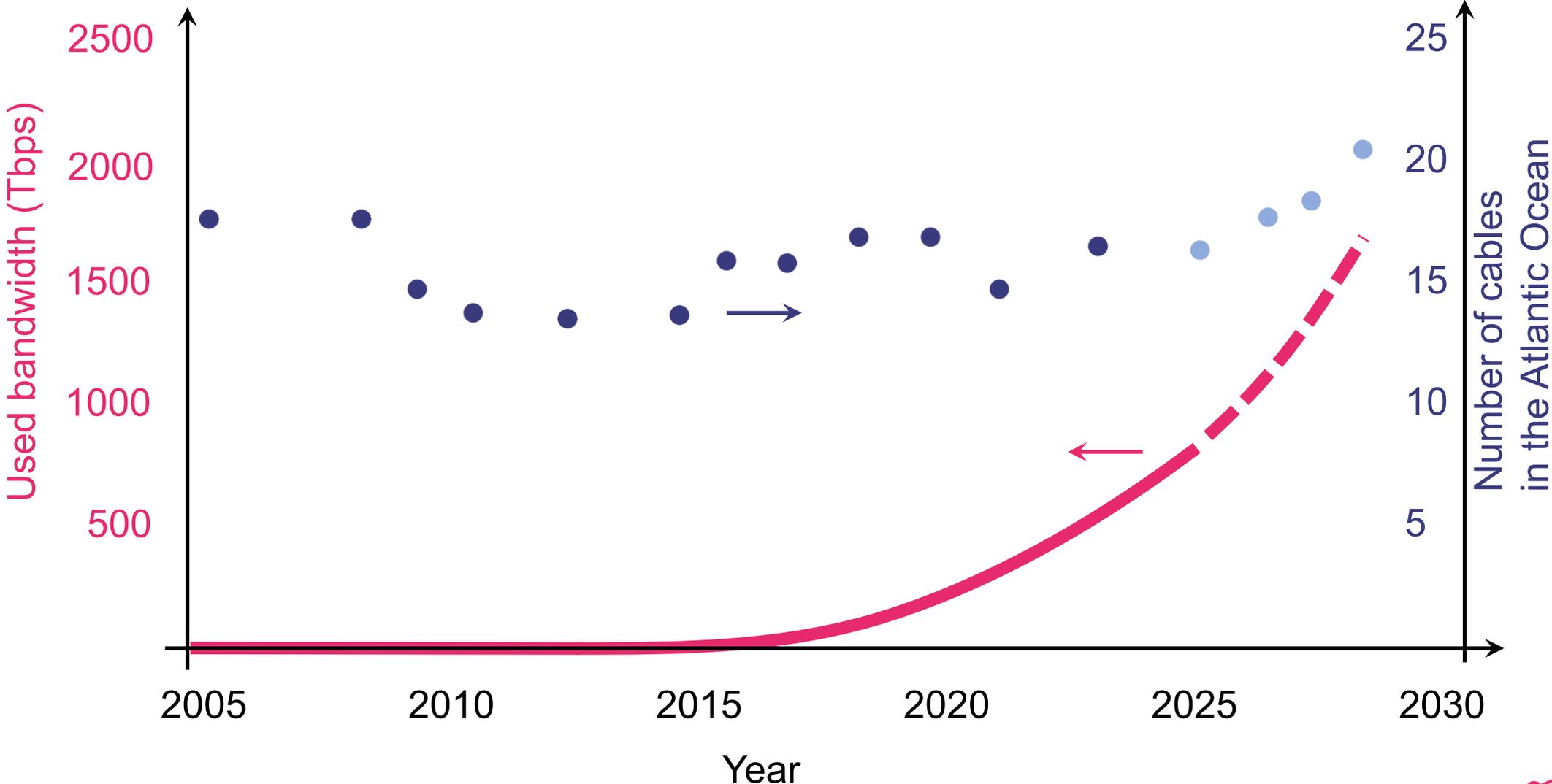
Diam: 32 mm, 3456 fibers (thefoa.org)

...more cores per fiber



M. V.d. Hout, Nat. Comm. 16, 3833 (2025)

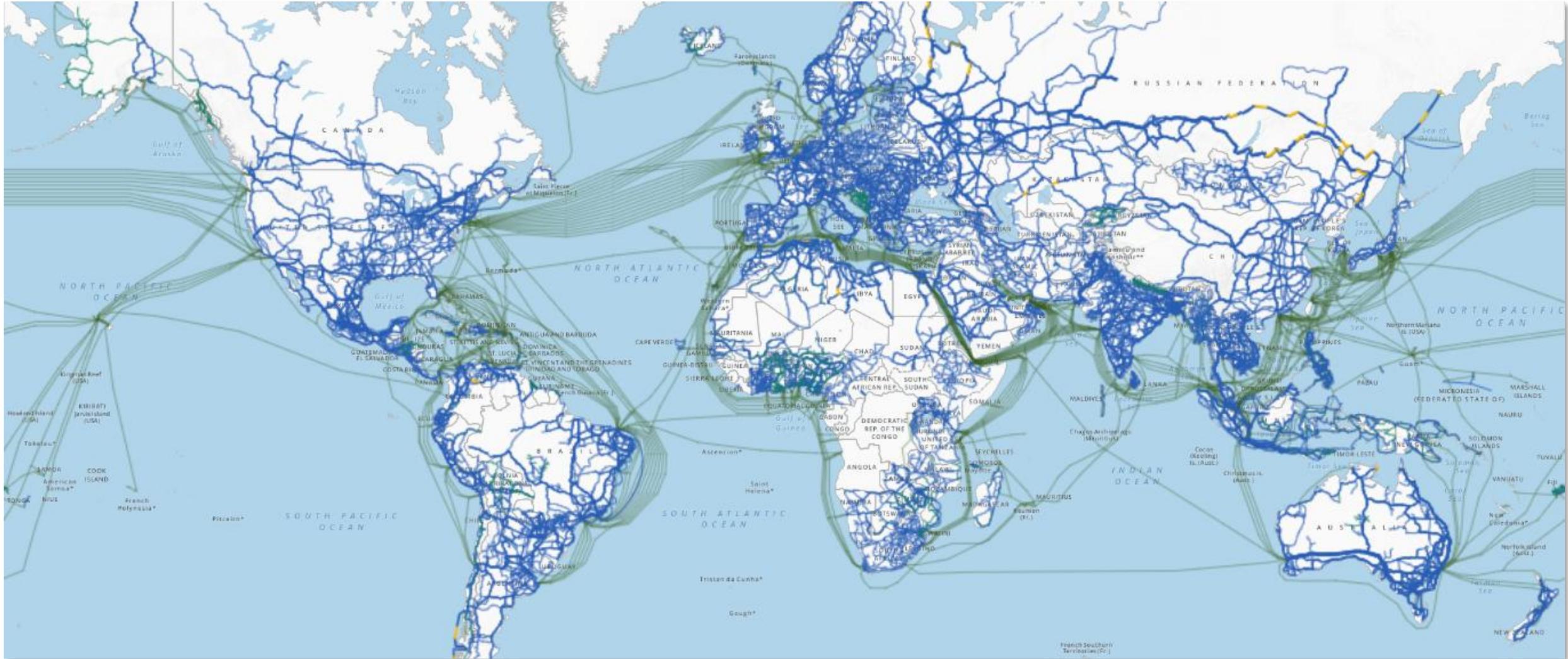
# Dedicated fibers?



Source: telegeography.com



# Global network sensing



Source: telegeography.com

# Coexisting with data

Optics Letters Vol. 34, Issue 10, pp. 1573-1575 (2009) • <https://doi.org/10.1364/OL.34.001573>

OPTICA  
PUBLISHING  
GROUP

## High-resolution optical frequency dissemination on a telecommunications network with data traffic

Fabien Kéfélian, Olivier Lopez, Haifeng Jiang, Christian Chardonnet, Anne Amy-Klein, and Giorgio Santarelli

Author Information ▾ Find other works by these authors ▾

## Cascaded optical fiber link using the internet network for remote clocks comparison

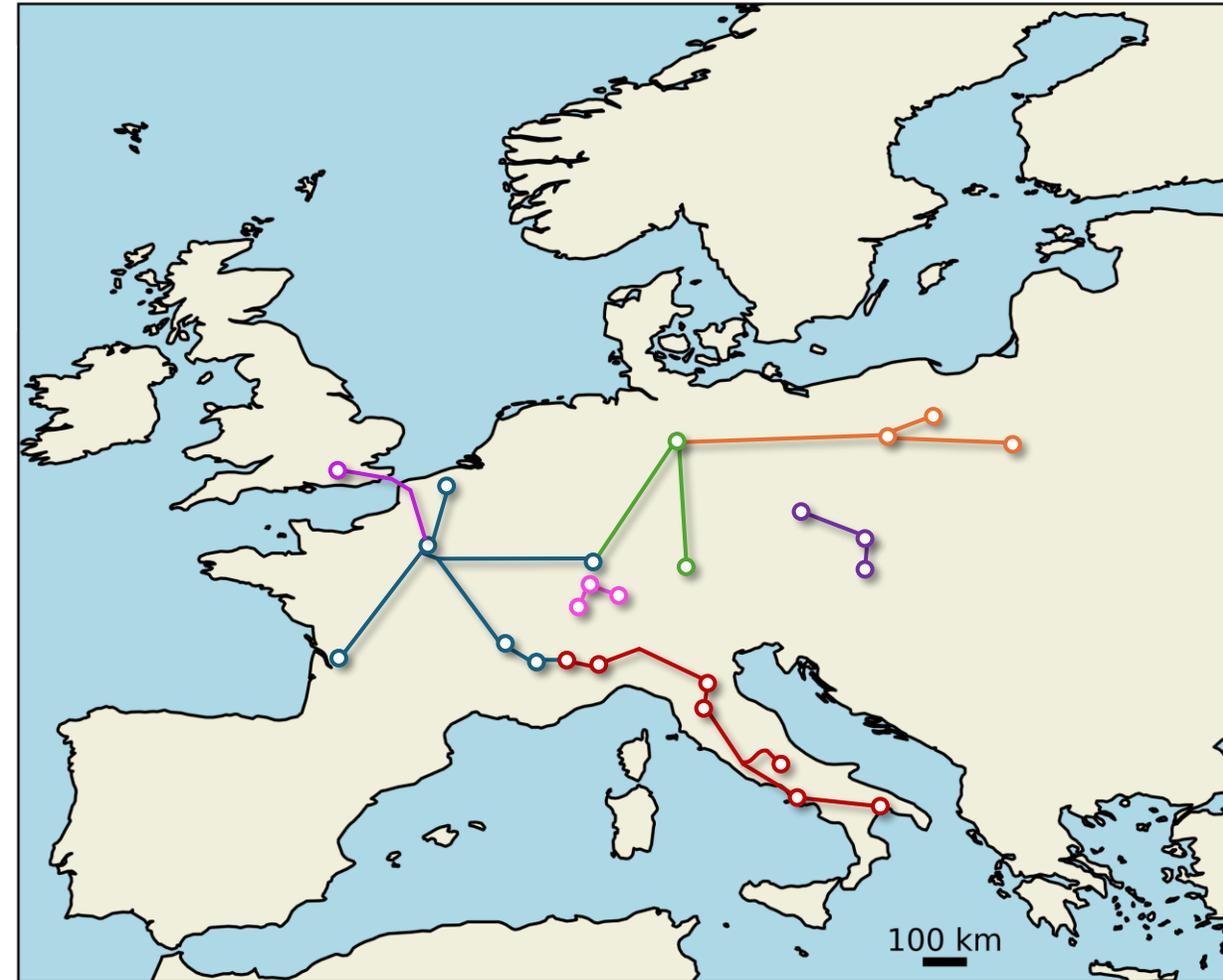
Nicola Chiodo,<sup>1</sup> Nicolas Quintin,<sup>1</sup> Fabio Stefani,<sup>1,2</sup> Fabrice Wiotte,<sup>1</sup> Emilie Camisard,<sup>3</sup> Christian Chardonnet,<sup>1</sup> Giorgio Santarelli,<sup>4</sup> Anne Amy-Klein,<sup>1,2</sup> Paul-Eric Pottie,<sup>2</sup> Olivier Lopez<sup>1</sup>

<sup>1</sup>Laboratoire de Physique des Lasers, Université Paris 13, Sorbonne Paris Cité, CNRS, 99 Avenue Jean-Baptiste Clément, 93430 Villetaneuse, France

<sup>2</sup>Laboratoire National de Métrologie et d'Essais–Système de Références Temps-Espace, UMR 8630 Observatoire de Paris, CNRS, UPMC, 61 Avenue de l'Observatoire, 75014 Paris, France

<sup>3</sup>RENATER, 23-25 rue Daviel, 75013 Paris, France

<sup>4</sup>Laboratoire Photonique, Numérique et Nanosciences, UMR 5298 Université de Bordeaux, Institut d'Optique Graduate School and CNRS, 1, Rue F. Mitterand, 33400 Talence, France  
[amy@univ-paris13.fr](mailto:amy@univ-paris13.fr)



SENSEI

# Coexisting with data

Science

REPORTS

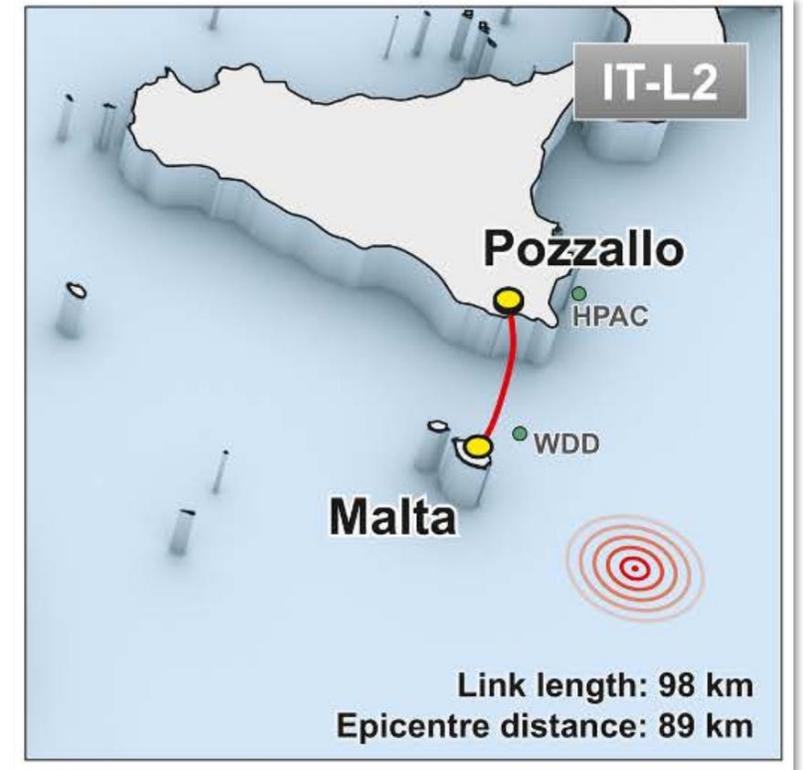
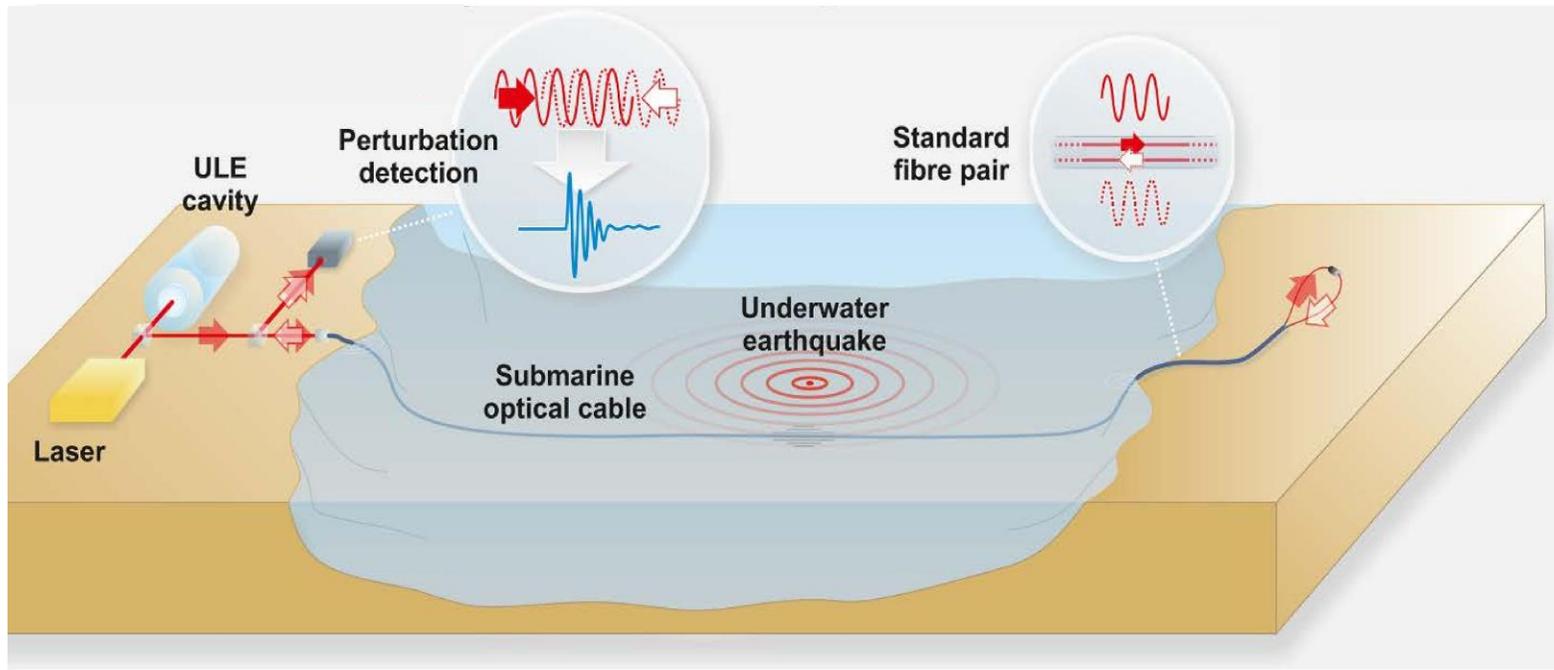
Cite as: G. Marra *et al.*, *Science* 10.1126/science.aat4458 (2018).

## Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables

Giuseppe Marra<sup>1\*</sup>, Cecilia Clivati<sup>2</sup>, Richard Lockett<sup>3</sup>, Anna Tampellini<sup>2,4</sup>, Jochen Kronjäger<sup>1</sup>, Louise Wright<sup>1</sup>, Alberto Mura<sup>2</sup>, Filippo Levi<sup>2</sup>, Stephen Robinson<sup>1</sup>, André Xuereb<sup>5</sup>, Brian Baptie<sup>3</sup>, Davide Calonico<sup>2</sup>

<sup>1</sup>National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK. <sup>2</sup>I.N.Ri.M., Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135 Turin, Italy.

<sup>3</sup>British Geological Survey, The Lyell Centre, Research Avenue South, Edinburgh, Scotland, UK, EH14 4AP. <sup>4</sup>Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy. <sup>5</sup>Department of Physics, University of Malta, Msida MSD 2080, Malta.



**NPL**  
National Physical Laboratory

**L-Università  
ta' Malta**

**INRiM**  
ISTITUTO NAZIONALE  
DI RICERCA METROLOGICA

**SENSEI**

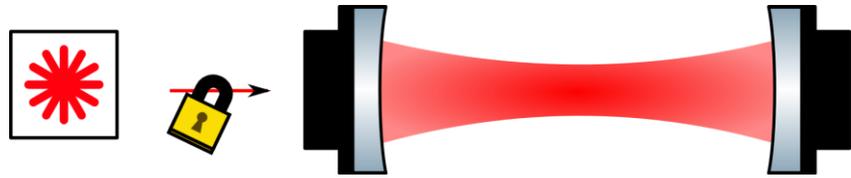
# Photonic sensing techniques

	Coherent interferometry	Distributed sensing
Localization	Not possible	10 m
Coexist with data traffic	Yes	Mostly not
On repeated links (unidir.)	Yes	Mostly not
Maximum reach	> 1000 km	<150 km
Size, weight & power	Very high	Medium

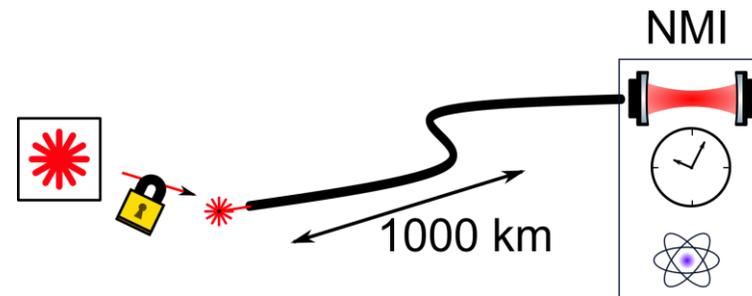
# Photonic sensing techniques

	Coherent interferometry	Distributed sensing
Localization	Not possible	10 m
Coexist with data traffic	Yes	Mostly not
On repeated links (unidir.)	Yes	Mostly not
Maximum reach	> 1000 km	<150 km
Size, weight & power	Very high	Medium

### Ultrastable lasers

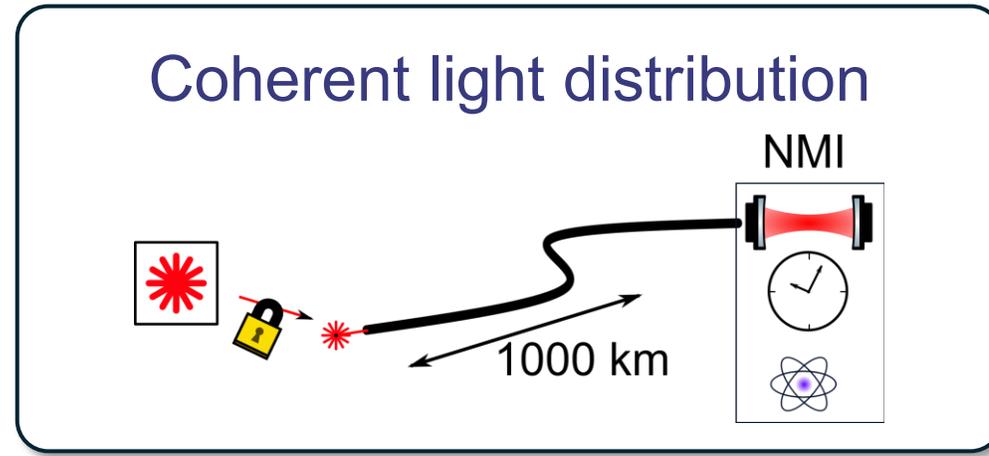
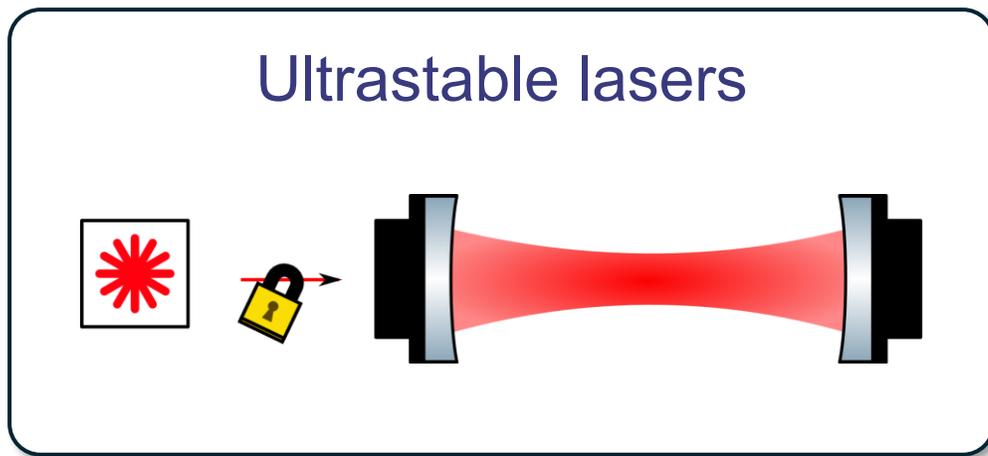


### Coherent light distribution



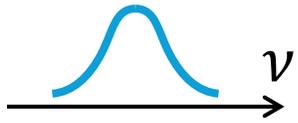
# Photonic sensing techniques

	Coherent interferometry	Distributed sensing
Localization	Not possible	10 m
Coexist with data traffic	Yes	Mostly not
On repeated links (unidir.)	Yes	Mostly not
Maximum reach	> 1000 km	<150 km
Size, weight & power	Very high	Medium



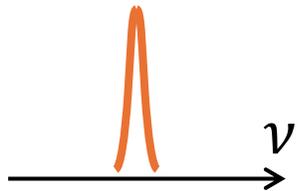
# How far can we go with ultrastable light?

Telecom-grade lasers



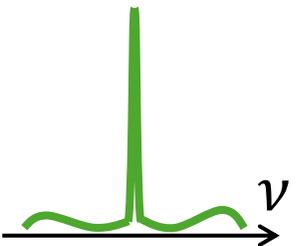
~50 km

Commercial “stable” lasers



~100 km

Ultrastable lasers



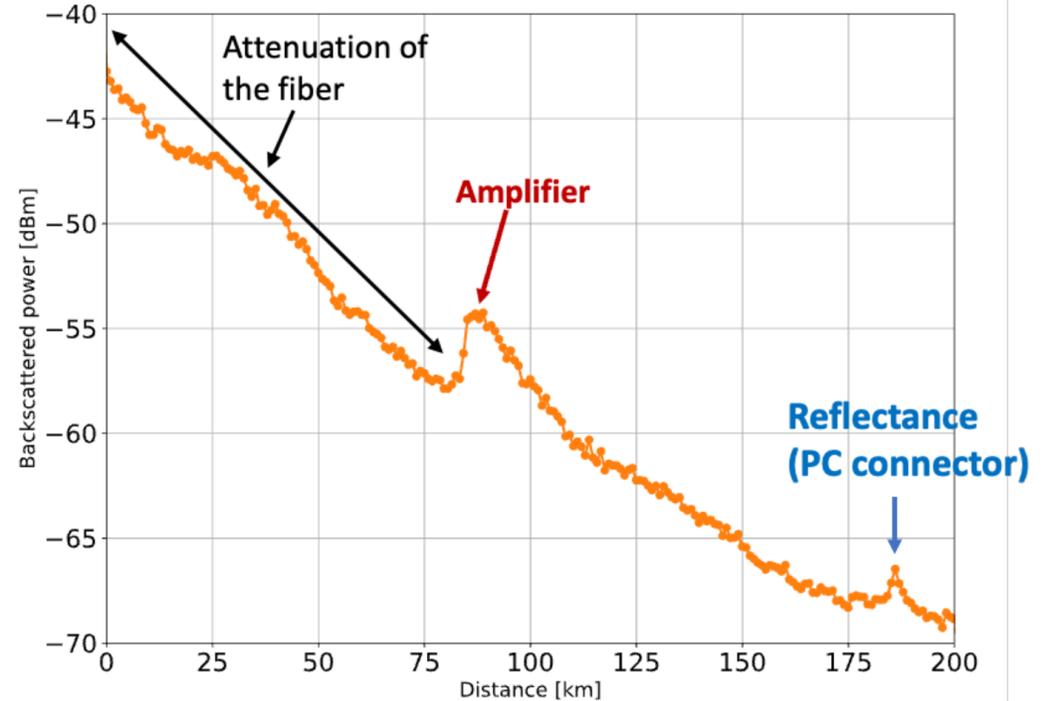
>> 150 km?

# How far can we go with ultrastable light?

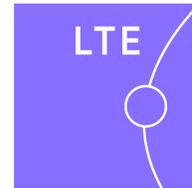
High precision fault location with frequency-domain reflectometry & ultrastable lasers



See Debanjan's poster!



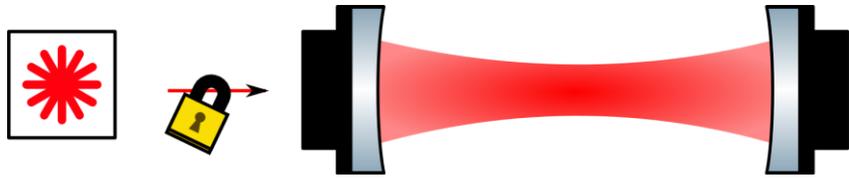
More to come...



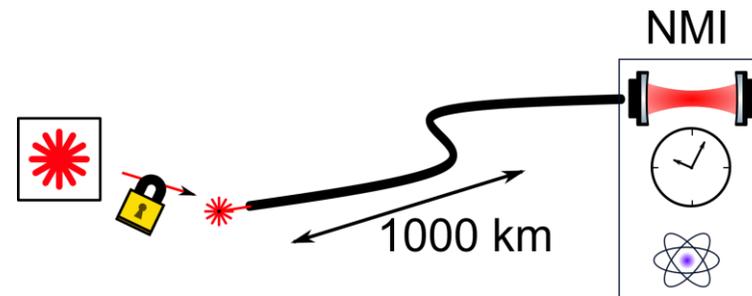
# Photonic sensing techniques

	Coherent interferometry	Distributed sensing
Localization	→ Not possible	10 m
Coexist with data traffic	Yes	Mostly not
On repeated links (unidir.)	Yes	Mostly not
Maximum reach	> 1000 km	<150 km
Size, weight & power	Very high	Medium

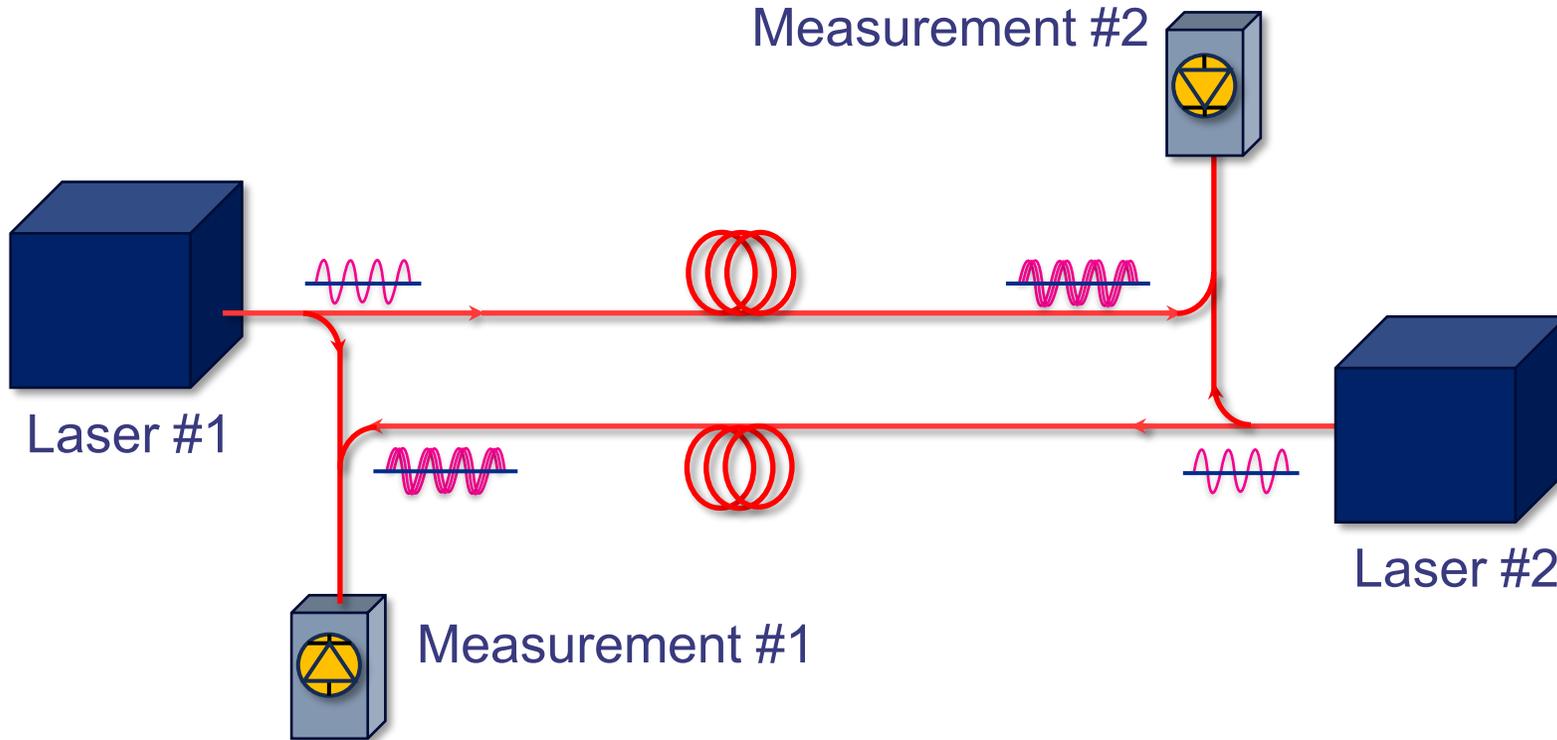
### Ultrastable lasers



### Coherent light distribution

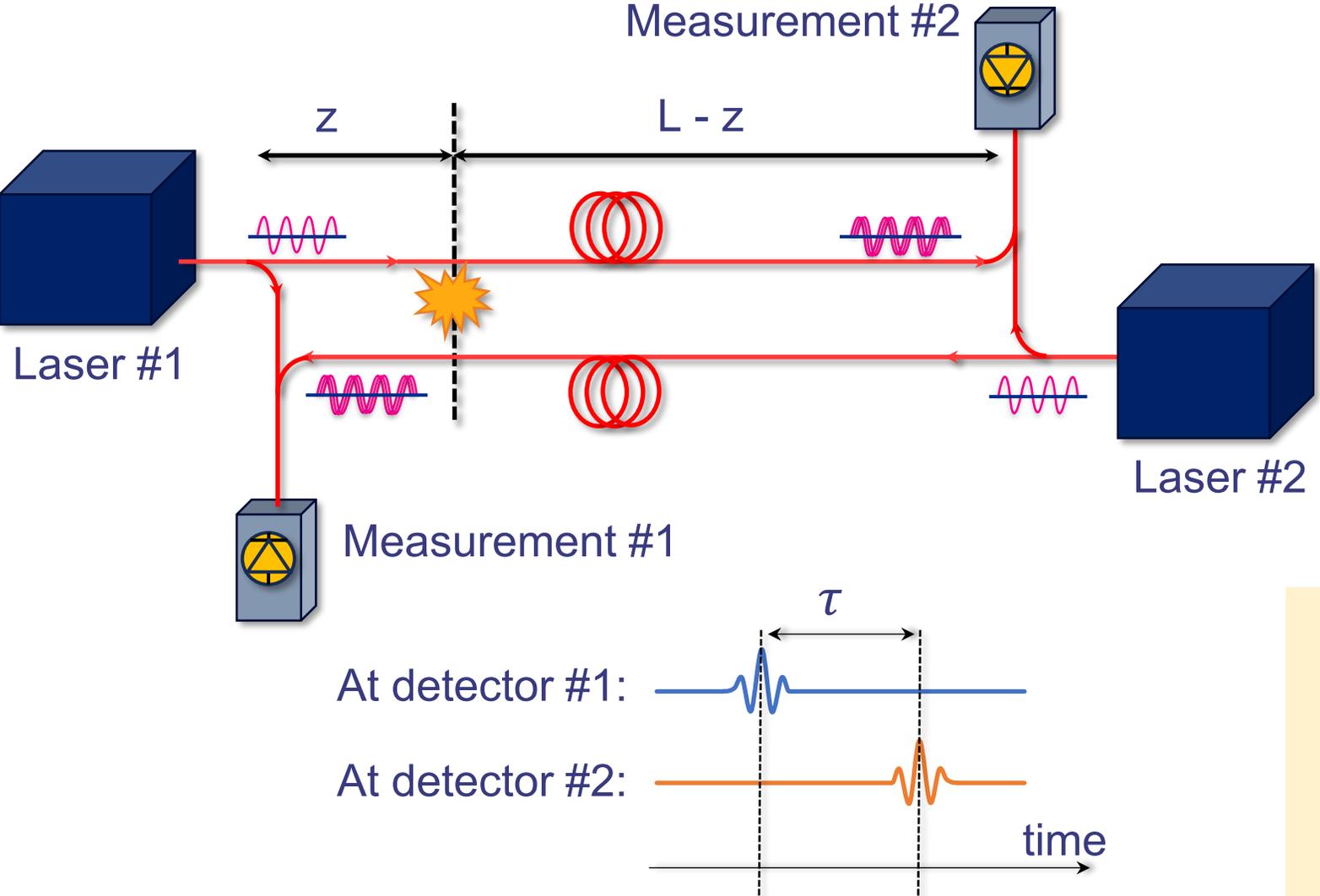


# Event localization along cable



- Counterpropagating signals
- Coherent detection against local laser

# Event localization along cable

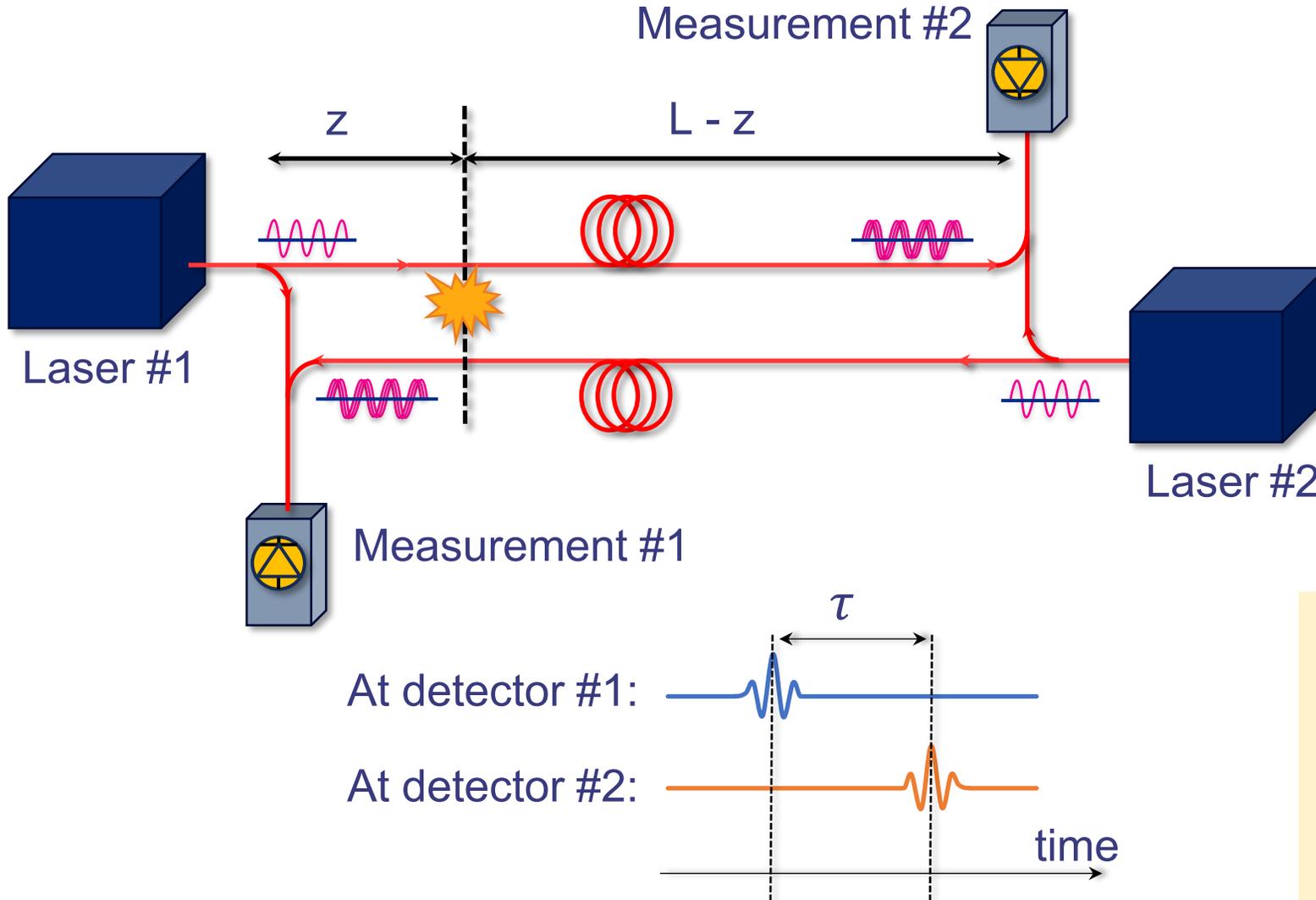


- Counterpropagating signals
- Coherent detection against local laser
- Synchronized acquisition for time-delay extraction

$$\text{distance} = \frac{\tau \times c}{2}$$

$c = 2 \times 10^8 \text{ m/s}$   
 $1 \text{ km} \Leftrightarrow 10 \mu\text{s}$

# Event localization along cable



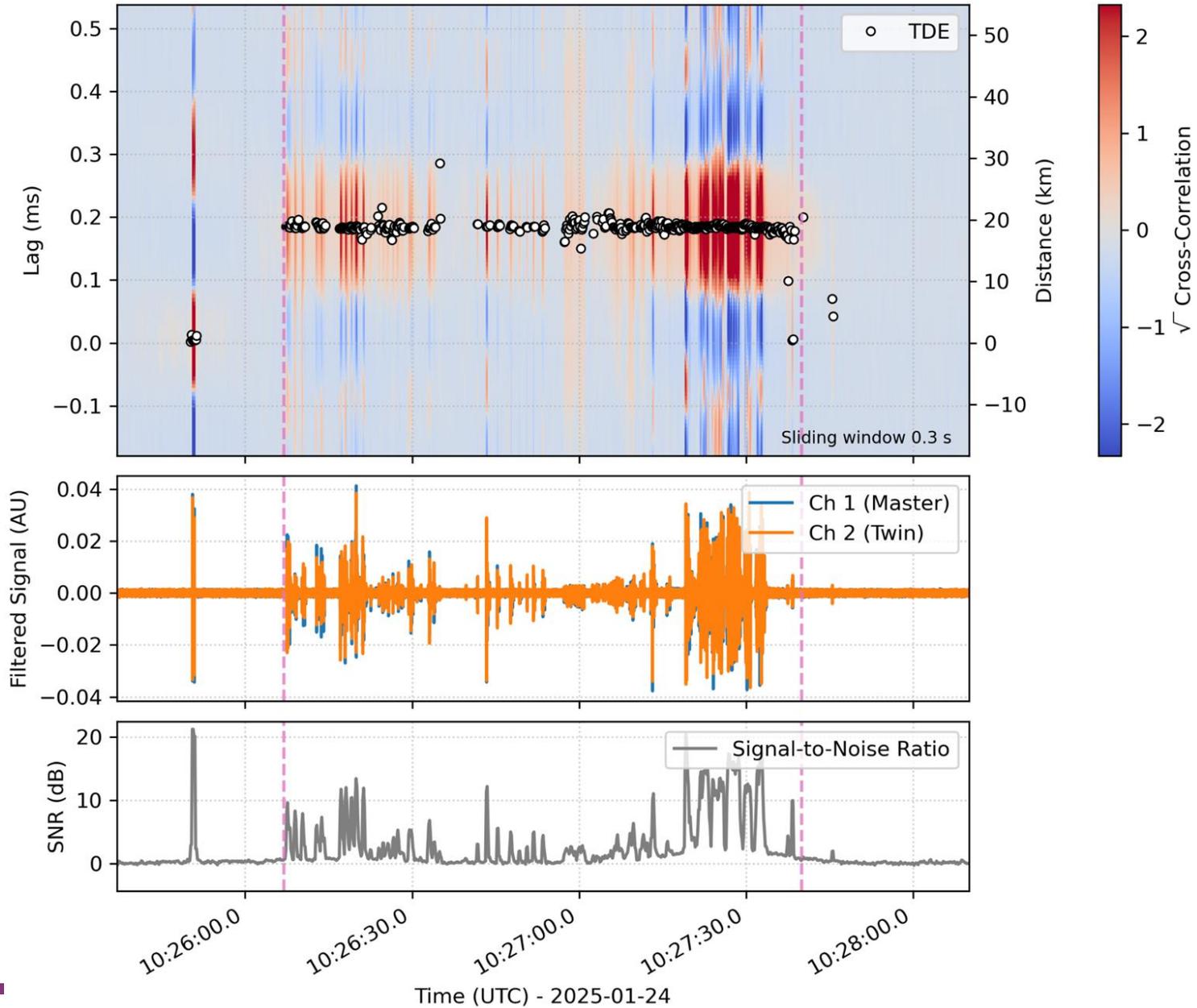
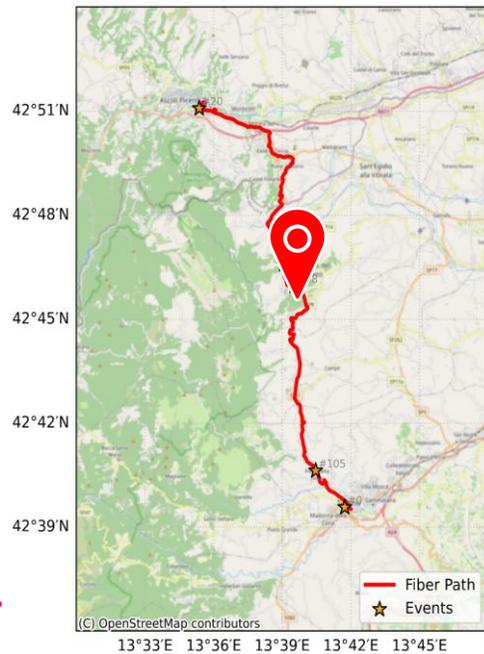
- Counterpropagating signals
- Coherent detection against local laser
- Synchronized acquisition for time-delay extraction
- Hardware-sync ( $\sim 3 \mu\text{s}$ )
- WR PTP ?

$$\text{distance} = \frac{\tau \times c}{2}$$

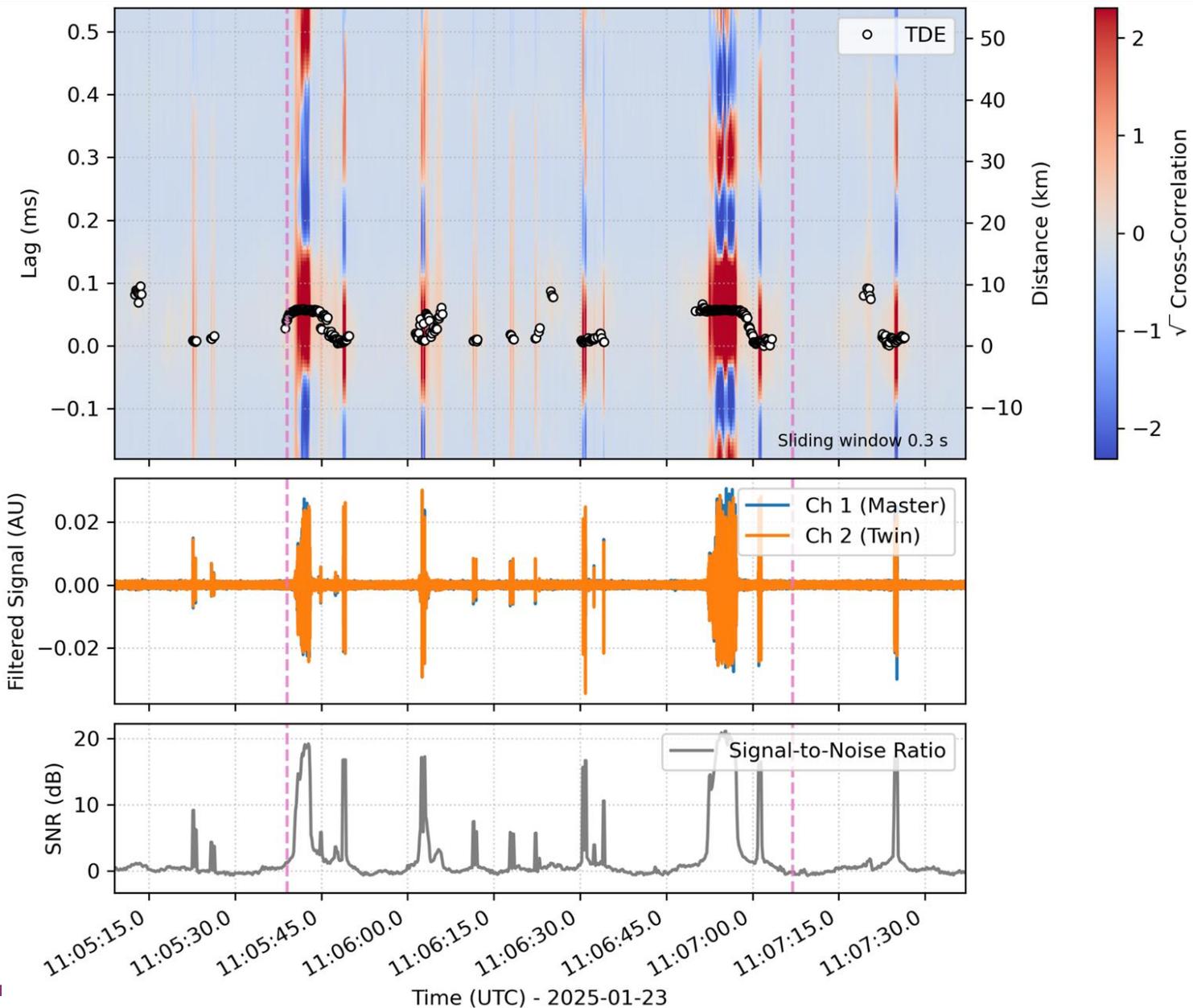
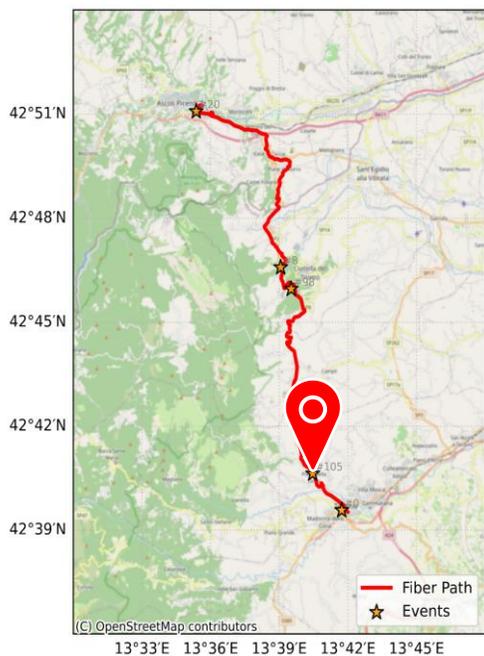
$$c = 2 \times 10^8 \text{ m/s}$$

$$1 \text{ km} \Leftrightarrow 10 \mu\text{s}$$

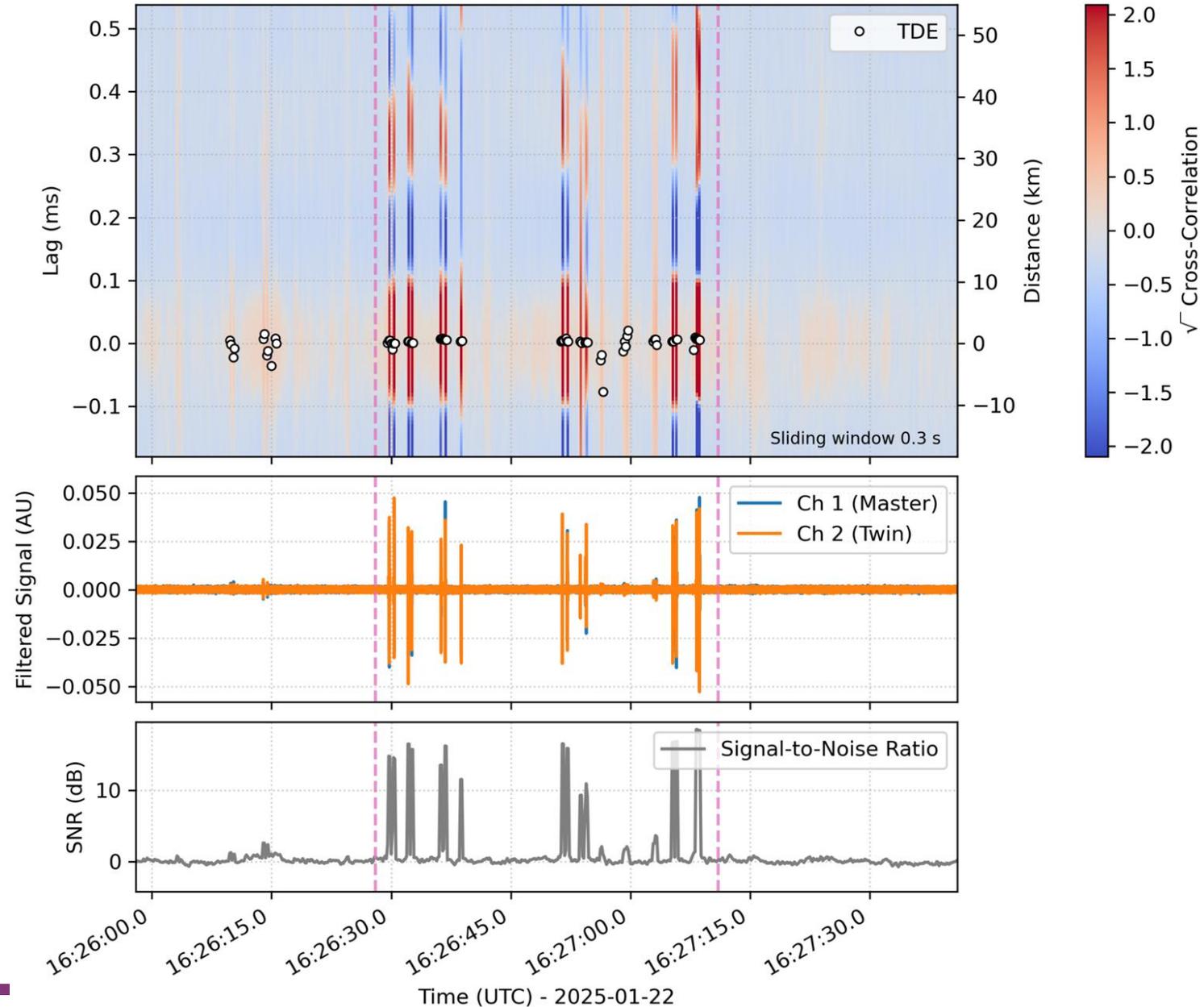
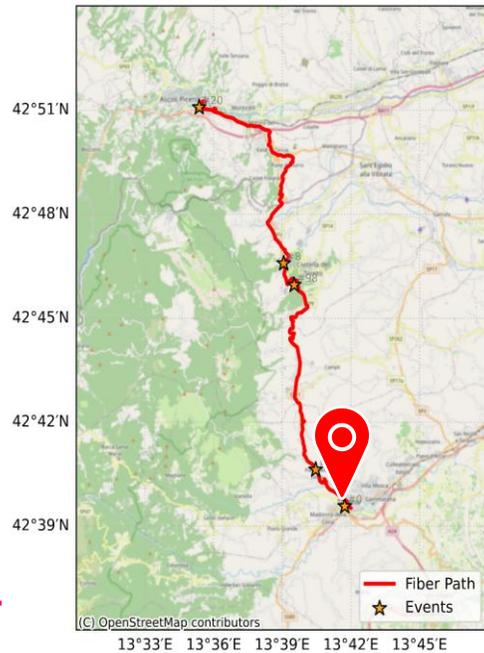
# Tapping fiber joint (km 19)



# Real signals: roadworks (km 6)



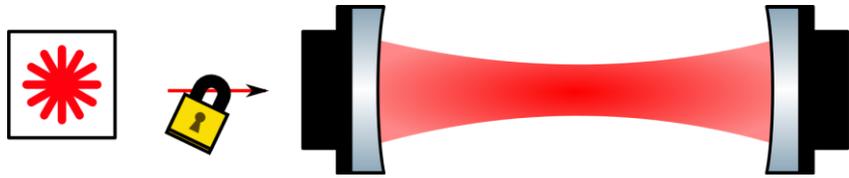
# Real signals: degraded pavement (km 0.5)



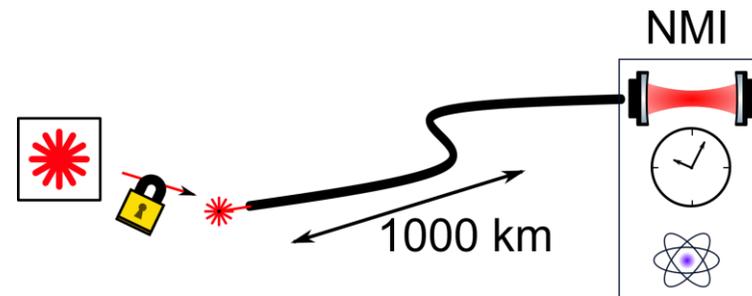
# Photonic sensing techniques

	Coherent interferometry	Distributed sensing
Localization	Not possible	10 m
Coexist with data traffic	Yes	Mostly not
On repeated links (unidir.)	Yes	Mostly not
Maximum reach	> 1000 km	<150 km
Size, weight & power →	Very high	Medium

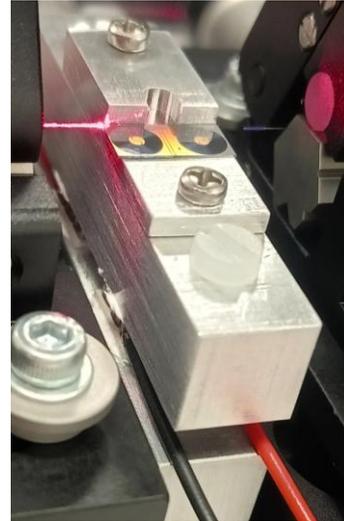
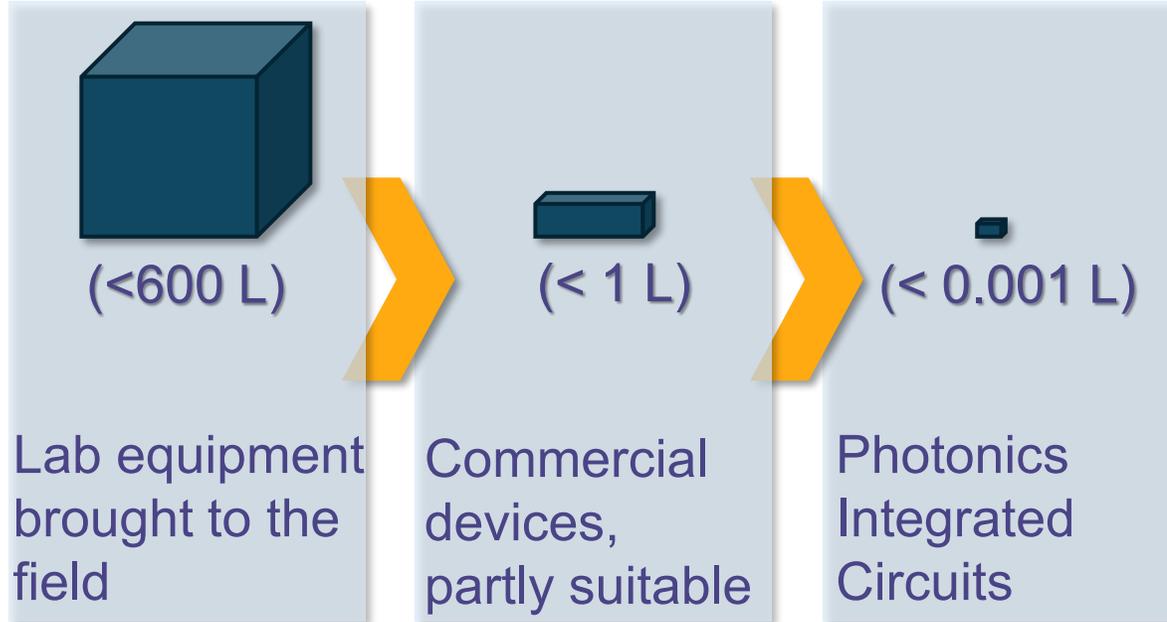
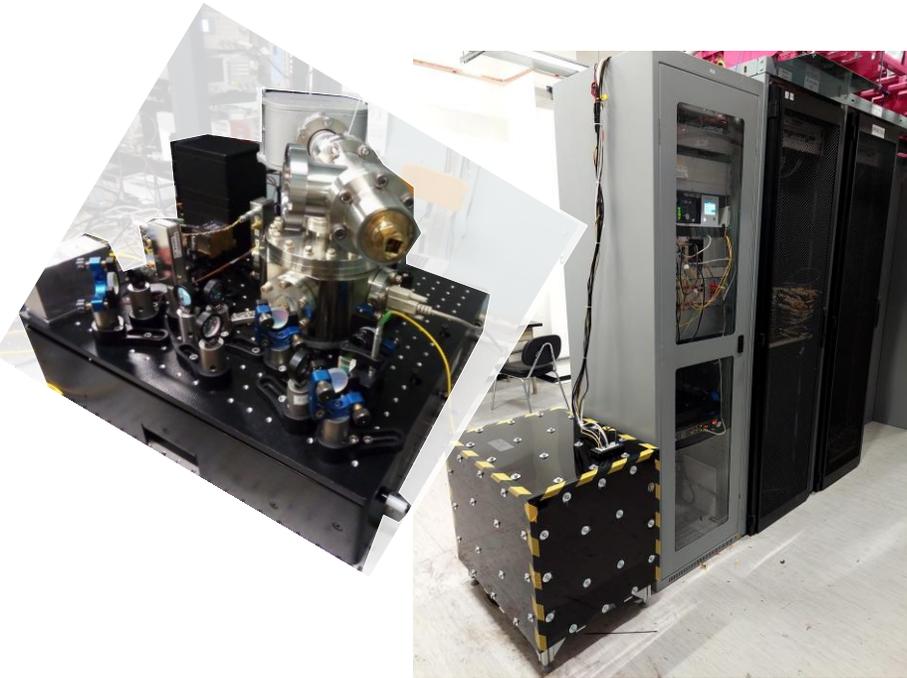
### Ultrastable lasers



### Coherent light distribution



# Toward integrated laser interrogators



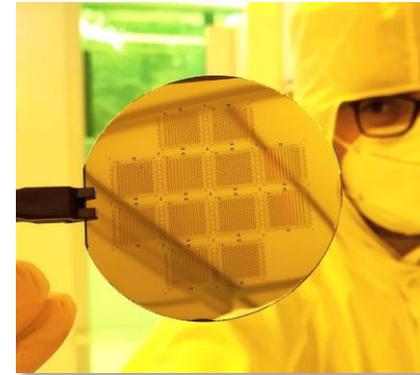
Low(er) cost  
Quick deployability  
Scalability

# Toward integrated laser interrogators

Upgrade RLS with sensing capability



Stable, chip-integrated lasers at INRIM nanofab



Low(er) cost  
Quick deployability  
Scalability

# In-field tests

---



Extended data collection & storage



Compare fiber data to conventional sensors (DAS, seismometers...)



Automated AI/ML analytics



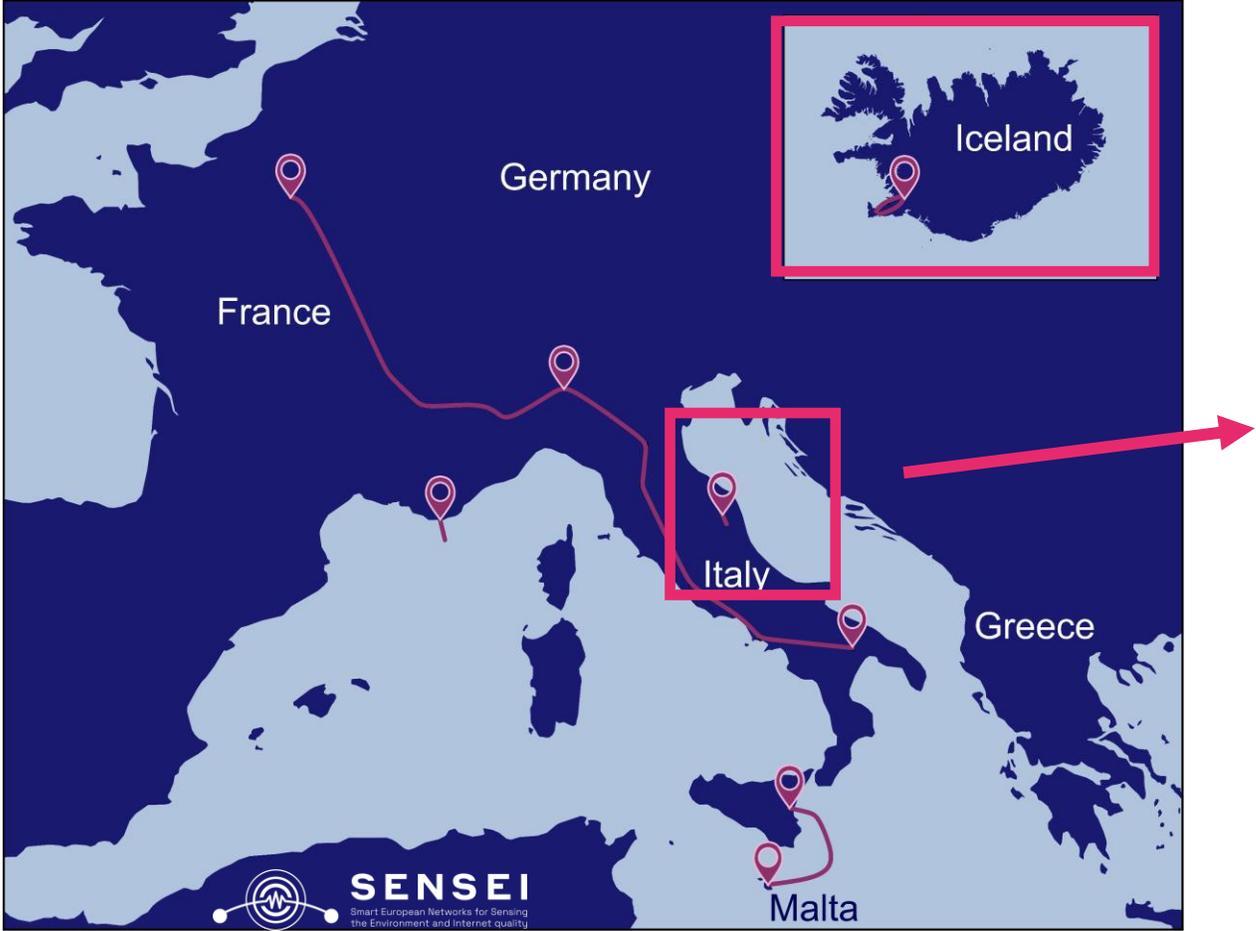
Extract quantitative information

# In-field tests on the EU fiber network

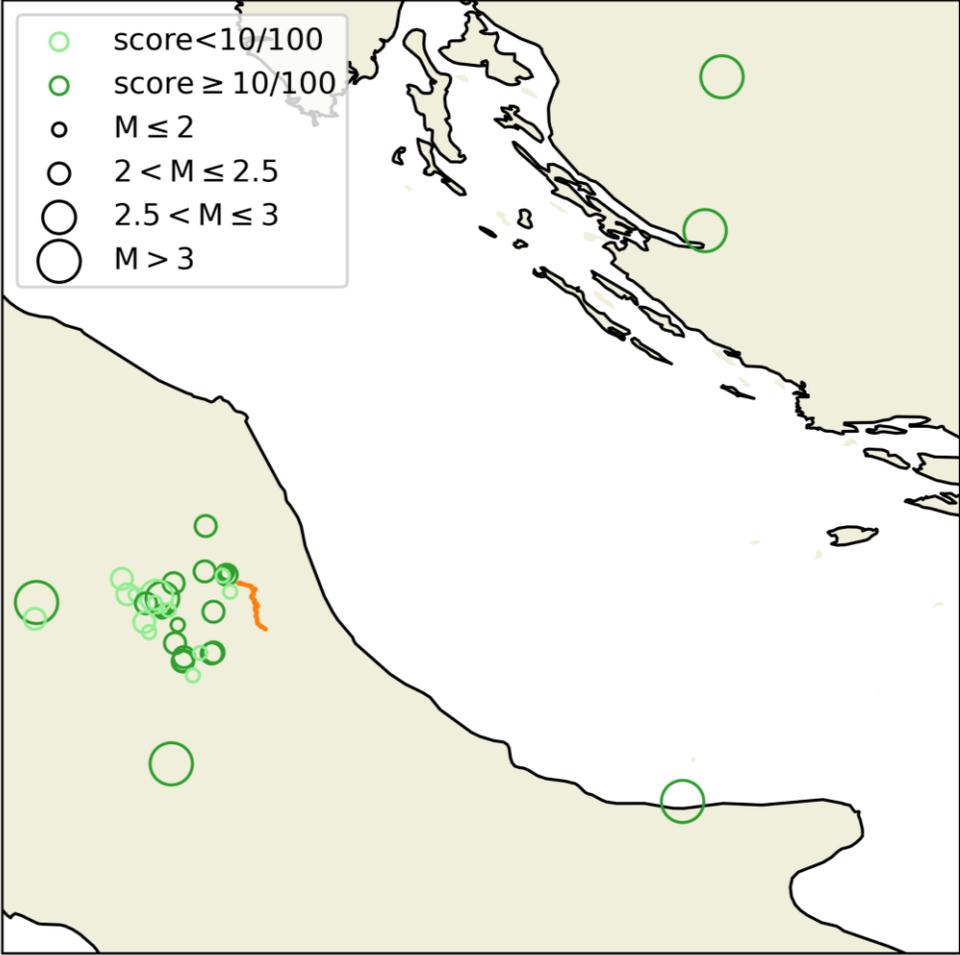


- REFIMEVE and IQB
- Ultrastable laser radiation at any endpoint
- Testing freedom & flexibility, not possible with production networks
- ‘Activation’ of ad-hoc spans

# In-field tests



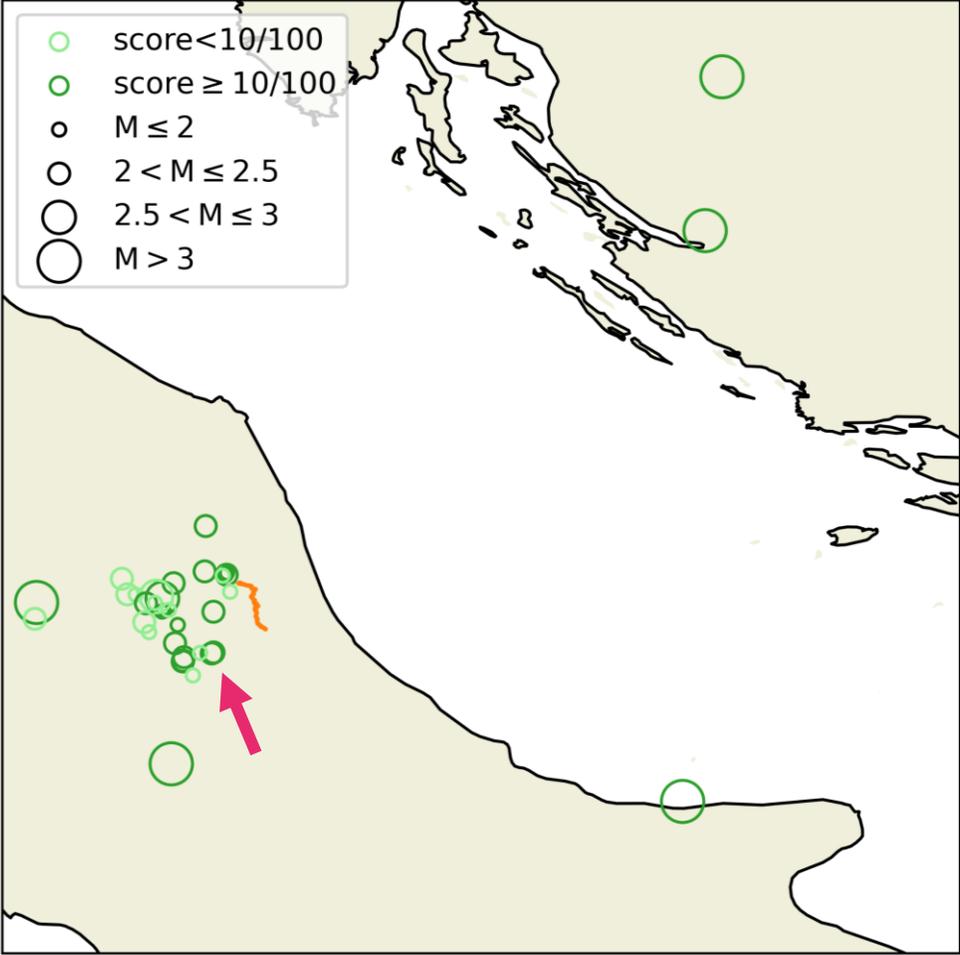
## Earthquakes recorded within SENSEI



# In-field tests



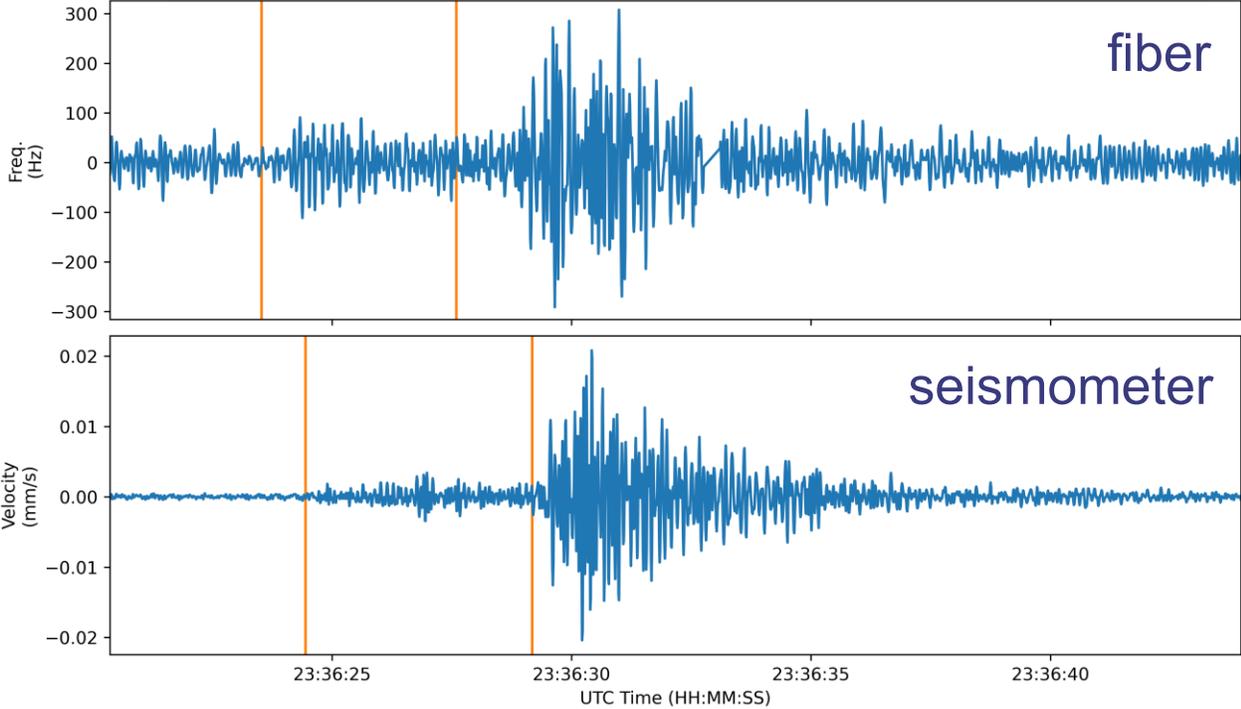
## Earthquakes recorded within SENSEI



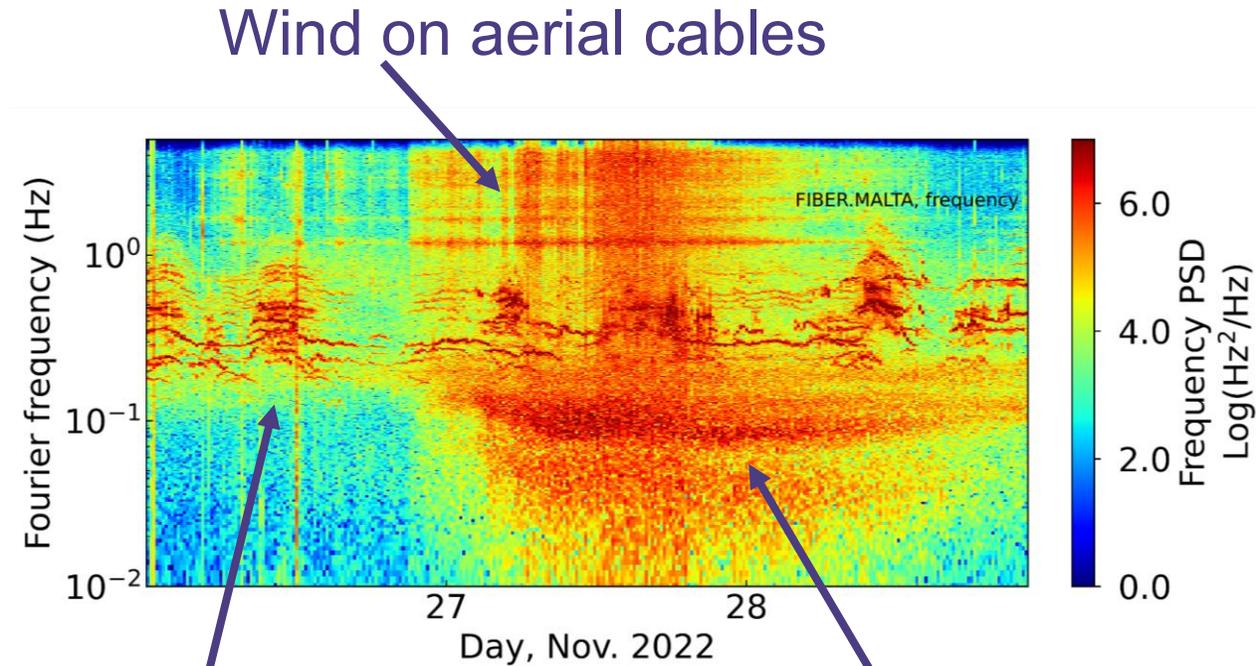
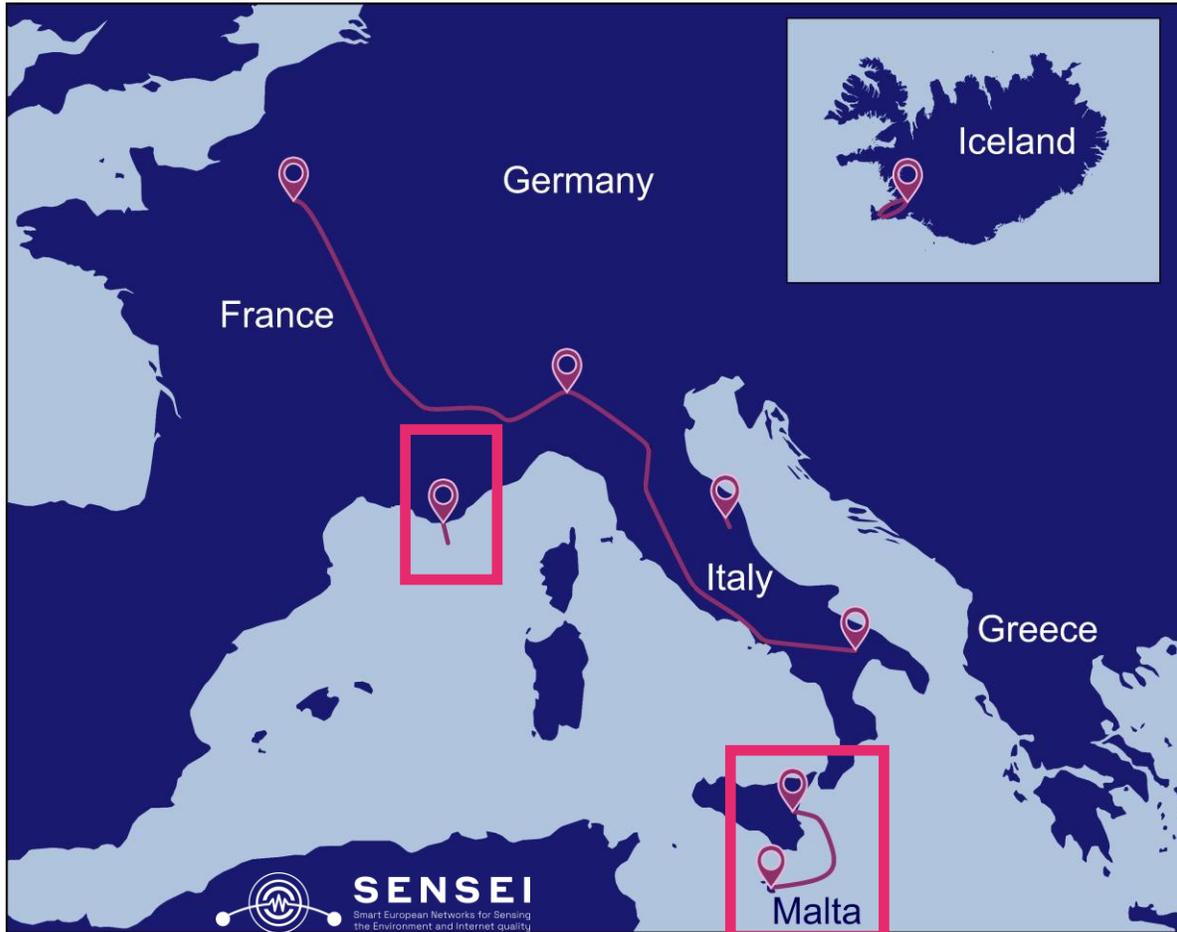
# In-field tests



M=2.2, distance = 32.5 km (25/03/2025)



# In-field tests

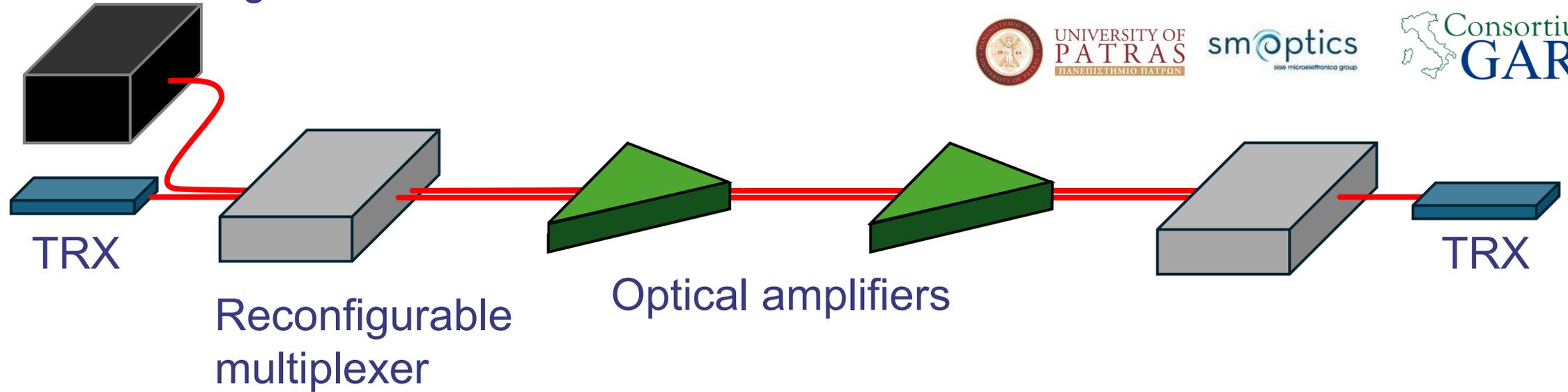


Currents shaking submarine fiber

Microseismicity

# Sensing *within* the telecom network

'Alien' sensing device



Politecnico di Torino

FONDAZIONE  
**Links**  
PASSION FOR INNOVATION

coriant



UNIVERSITY OF  
**PATRAS**  
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

sm@optics  
siae microelettronica group

Consortium  
**GARR**

Alien devices for  
high-resolution distributed sensing

+

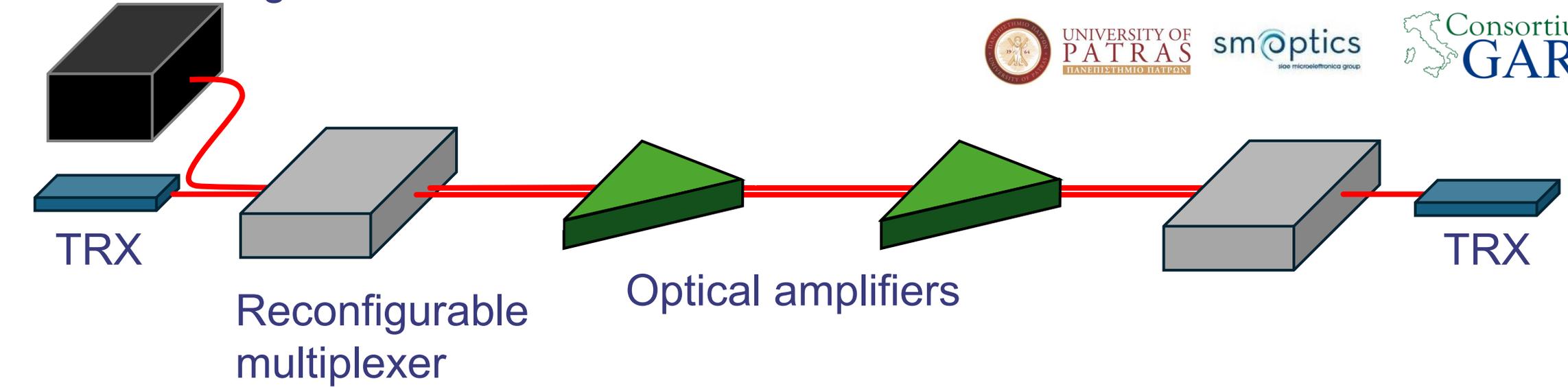
Conventional network elements  
for localised / distributed sensing



**SENSEI**

# Sensing *within* the telecom network

'Alien' sensing device



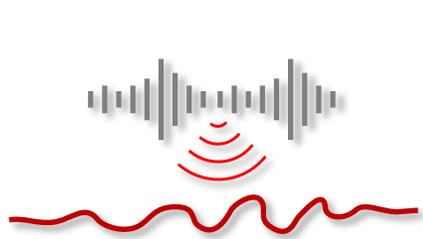
Politecnico di Torino



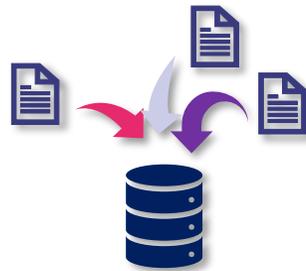
coriant



UNIVERSITY OF PATRAS  
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ



Detection



Collection



Interpretation



Action

# Case studies



## Resource optimization & cable integrity supervision

- Automatic collection and processing of telemetry data
- Lowest-energy control
- Assess response to soft / hard failures



## Integrating fiber sensing into seismic surveillance system

- Continuous transmission, low latency
- Contribute to event identification, localization and magnitude estimation.



## Localizing earthquakes in remote areas

- European fiber network as a training ground, toward future application to remote areas (e.g. transoceanic cables)



# Toward a scientific research infrastructure

---



**Time and Frequency**

**Quantum technologies**

**Sensing**

# Toward a scientific research infrastructure

---

- Leverage T/F tools
- Multi-functional, interoperable infrastructures
- Open facilities for testing & research
- Open Science approach

**Time and Frequency**

**Quantum technologies**

**Sensing**



**SENSEI**

# Thank you for your attention!



## SENSEI

Smart European Networks for Sensing the Environment and Internet quality



Funded by the European Union

Views and opinions expressed are those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.



LABORATOIRE de RECHERCHE TERRE - OCÉAN - ESPACE



Politecnico di Torino



L-Università ta' Malta



UNIVERSITY OF PATRAS

open fiber



coriant

exail