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Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

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When Networks Sense: AI-enabled Optical Networks for Situational Awareness and Resilient Infrastructure

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Head of the Open Ireland National Research Infrastructure

Taighde Éireann Research Ireland
ADAPT Engaging Content Engaging People
European Commission

Content of this Keynote

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1. INTRODUCTION TO FIBRE SENSING TECHNOLOGY

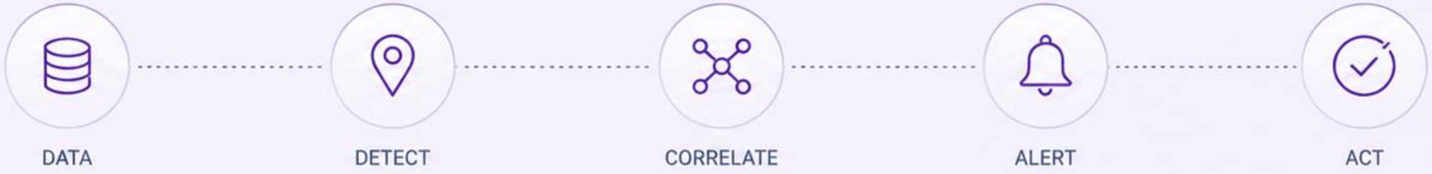
Light pulses travel through the fibre.
Interactions with the environment cause tiny changes in the backscattered light, measured continuously along the entire length.

2. SENSING APPLICATIONS

One technology.
Many critical applications.

3. NETWORK SENSING

From raw data to actionable intelligence,
fully integrated into network operations.



A world of fibre

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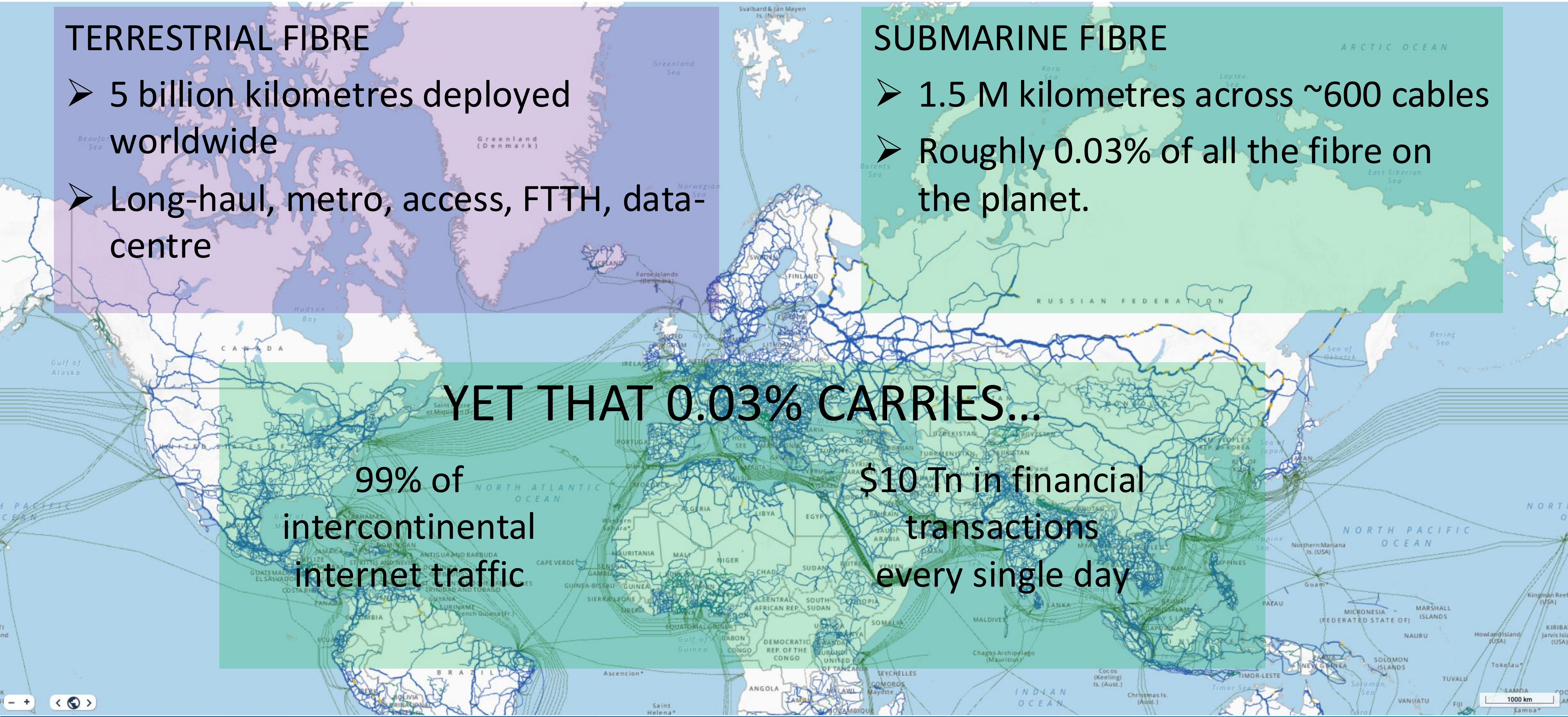

TERRESTRIAL FIBRE

- 5 billion kilometres deployed worldwide
- Long-haul, metro, access, FTTH, data-centre

SUBMARINE FIBRE

- 1.5 M kilometres across ~600 cables
- Roughly 0.03% of all the fibre on the planet.

YET THAT 0.03% CARRIES…

99% of intercontinental internet traffic

$10 Tn in financial transactions every single day

Do fibre cuts ever happen?

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TERRESTRIAL FIBRE

thousands nationally

estimated cuts per year (US alone)

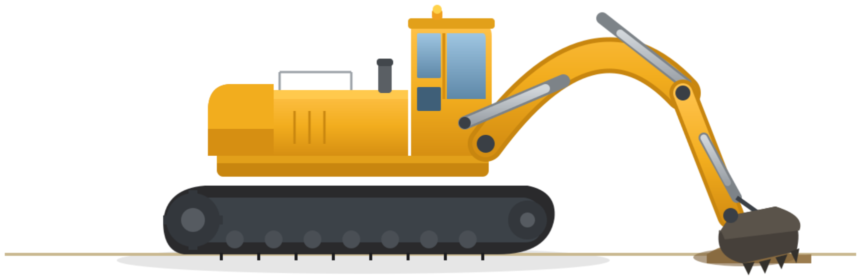
Metro rate	13 cuts / 1,000 mi / yr
Long-haul rate	3 cuts / 1,000 mi / yr
Operator impact	~1 cut every 4 days

SUBMARINE FIBRE

~150–200 globally

faults per year (global total)

Long-term average	199 / yr (2010-24)
Frequency	~4 per week
Avg. repair time 2023	40 days
Longest repair 2023	947 days



Would it not be nice if fibre could sense?

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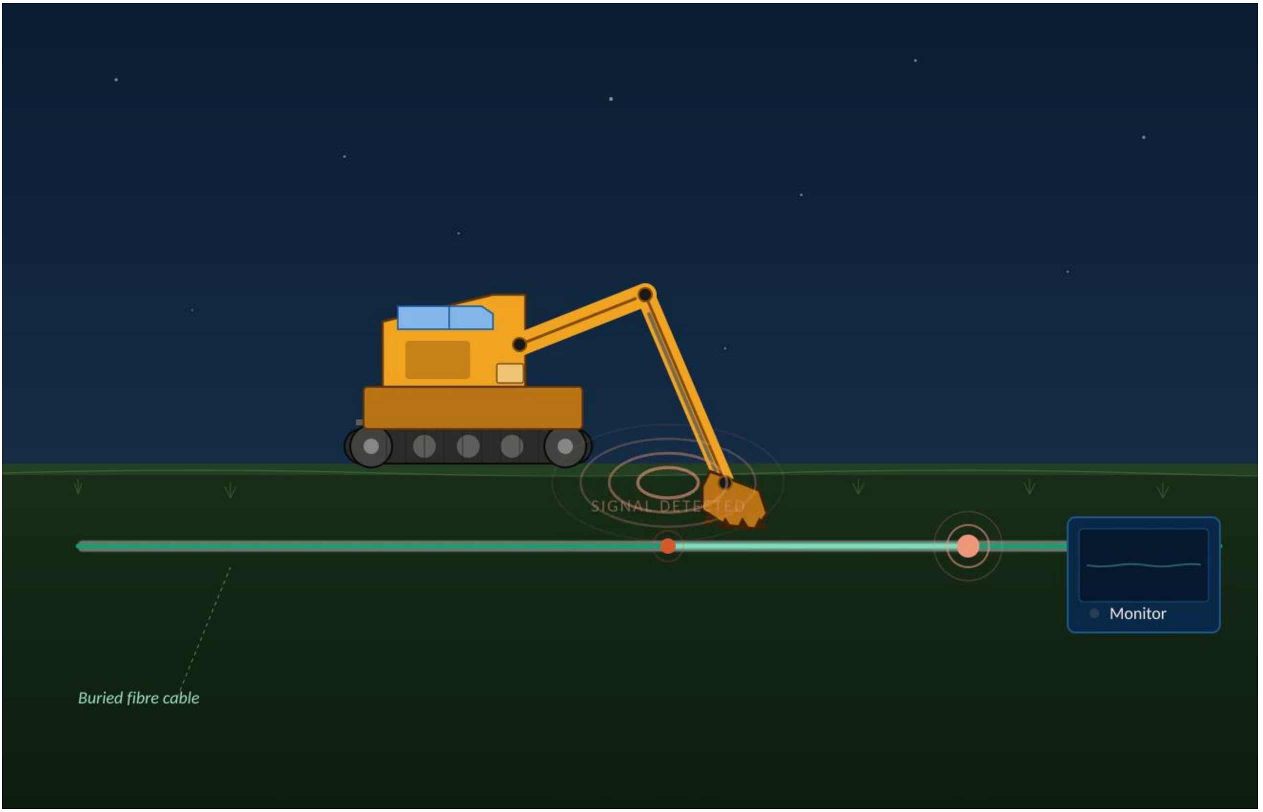
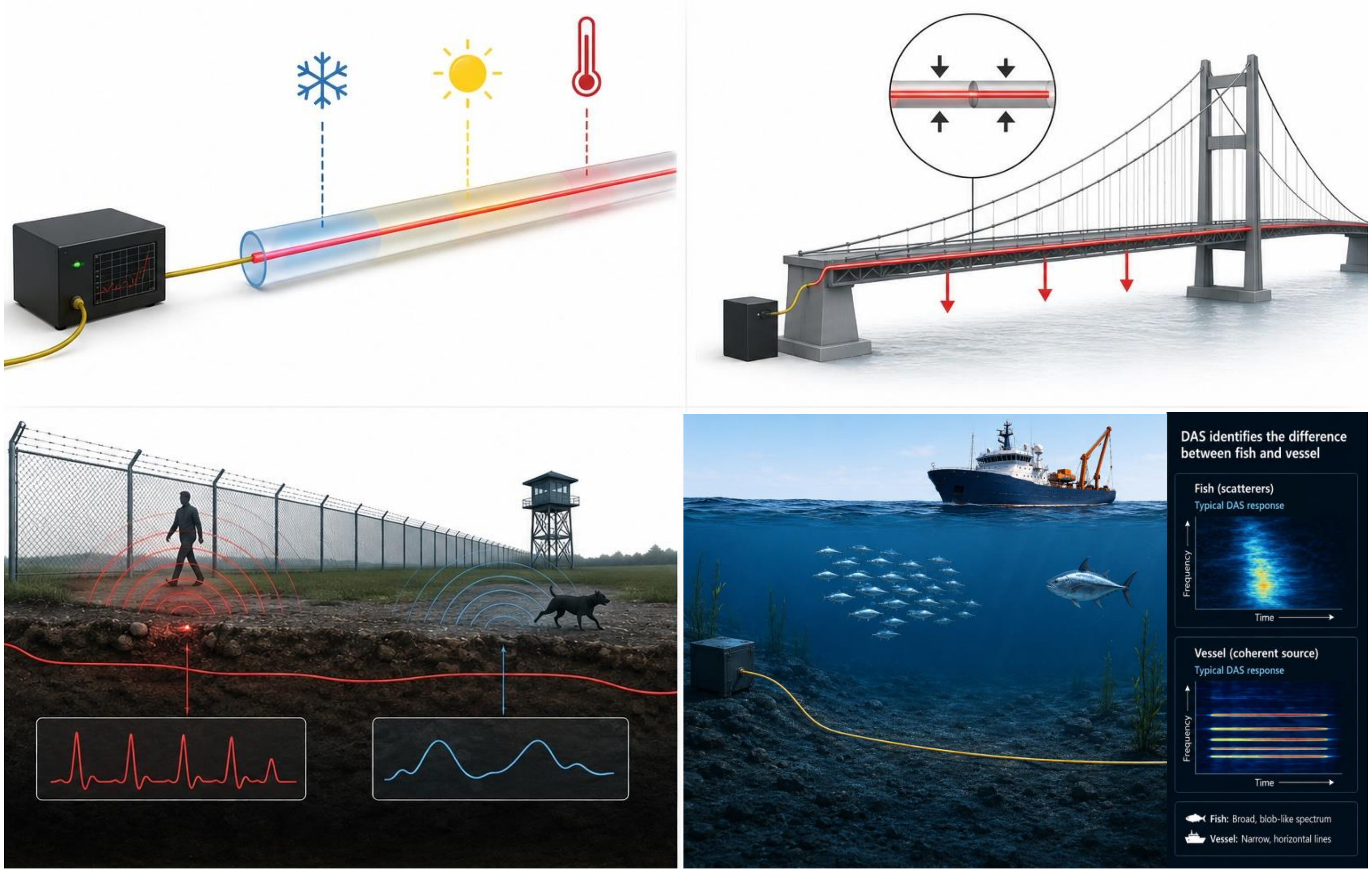


Spoiler alert…

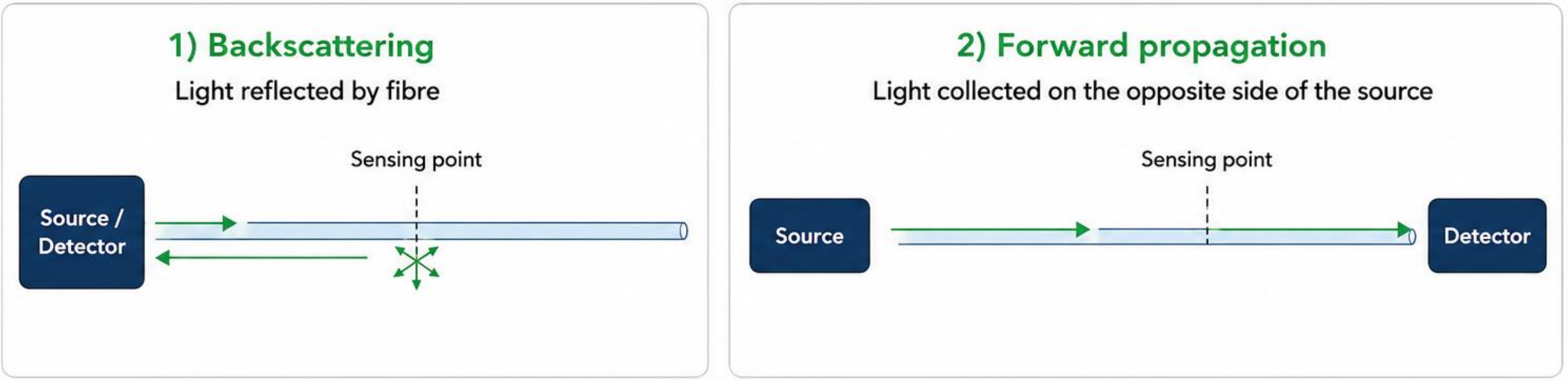
❖ **It can indeed and it has already been used in many applications… for over 20 years**



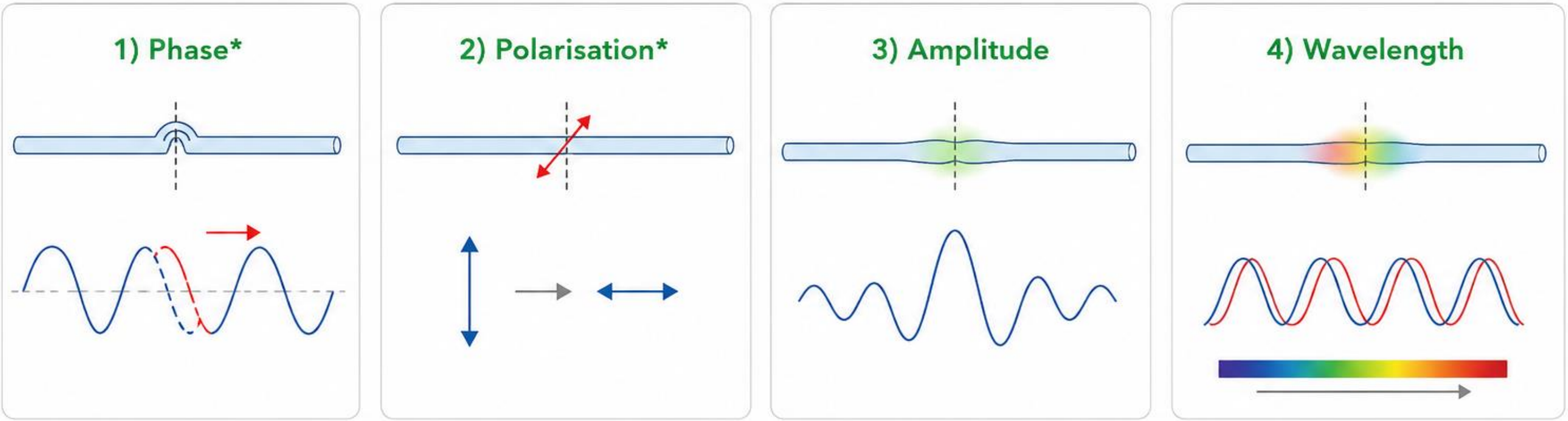
Strain, temperature, pressure on the fibre affect an optical signal propagating though it

Sensing techniques classification

❖ Depending on propagation direction:

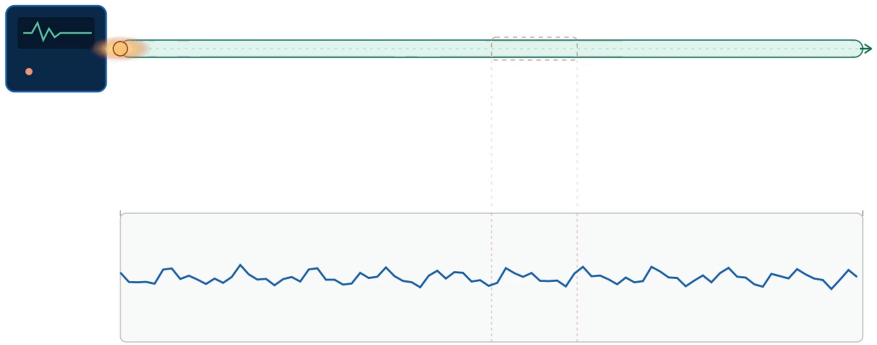


❖ Depending on feature sensed:



Fibre sensing mechansisms

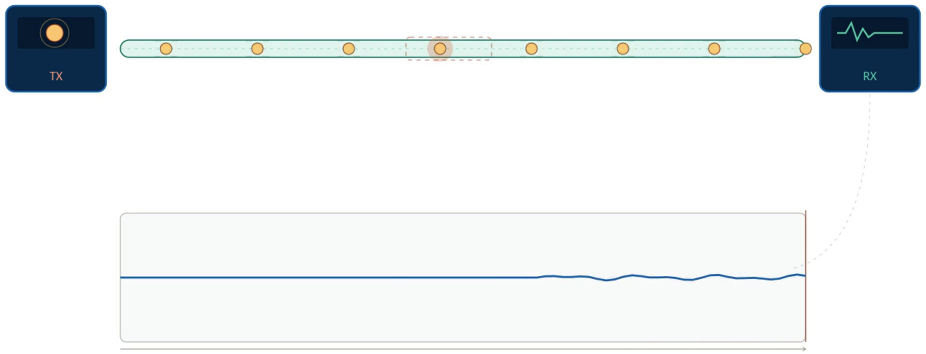
Based on signal backscattering:



❖ **Pros:**
- Accurate localization
- Source and receiver at same location

❖ **Cons:**
- High sensitivity receiver: 0.0001% of incident light is received back
- Does not work with amplified networks
- Sampling rate determined by fibre length

Based on forward propagation:

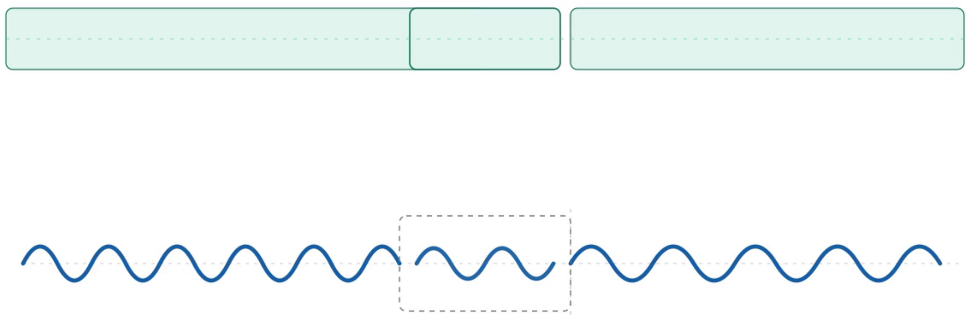


❖ **Pros:**
- Can use data channels as source
- High sampling rates are possible

❖ **Cons:**
- Localisation not provided natively
- Noise accumulates over whole link

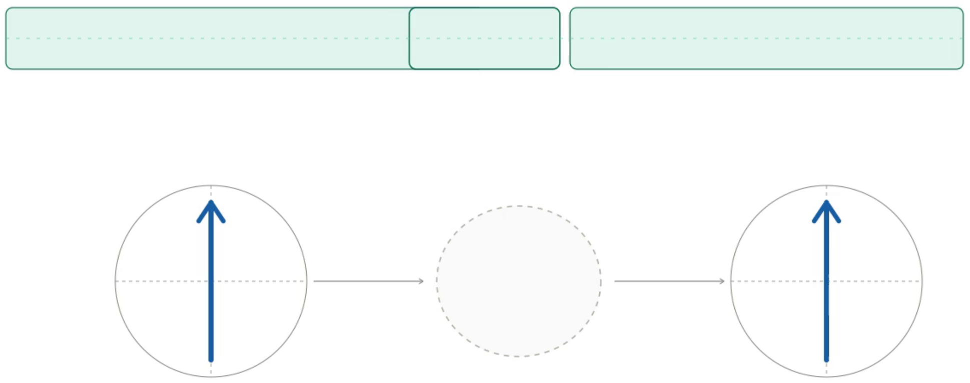
Features that can be sensed

Phase



- **Pros:**
  - Phase is very sensitive, tens picometers accuracy
- **Cons:**
  - More complex coherent receiver required
  - Signal saturates when phase difference > 2π

Polarisation



- **Pros:**
  - Low cost receiver, can be part of data channels
- **Cons:**
  - Much less sensitive than phase

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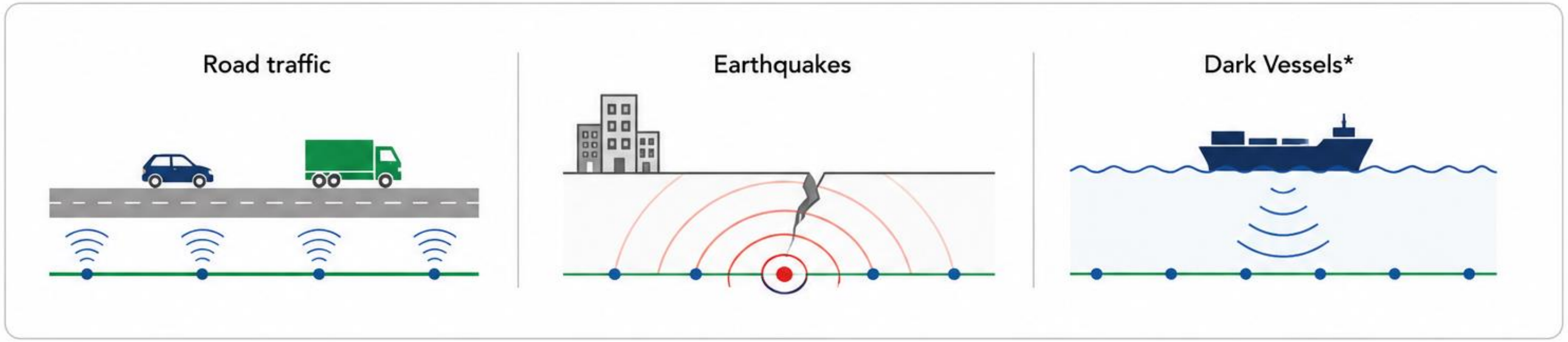
Sensing Applications

❖ Localised (point) sensing:

- Can provide higher precision for specific locations
- High variety of sensors

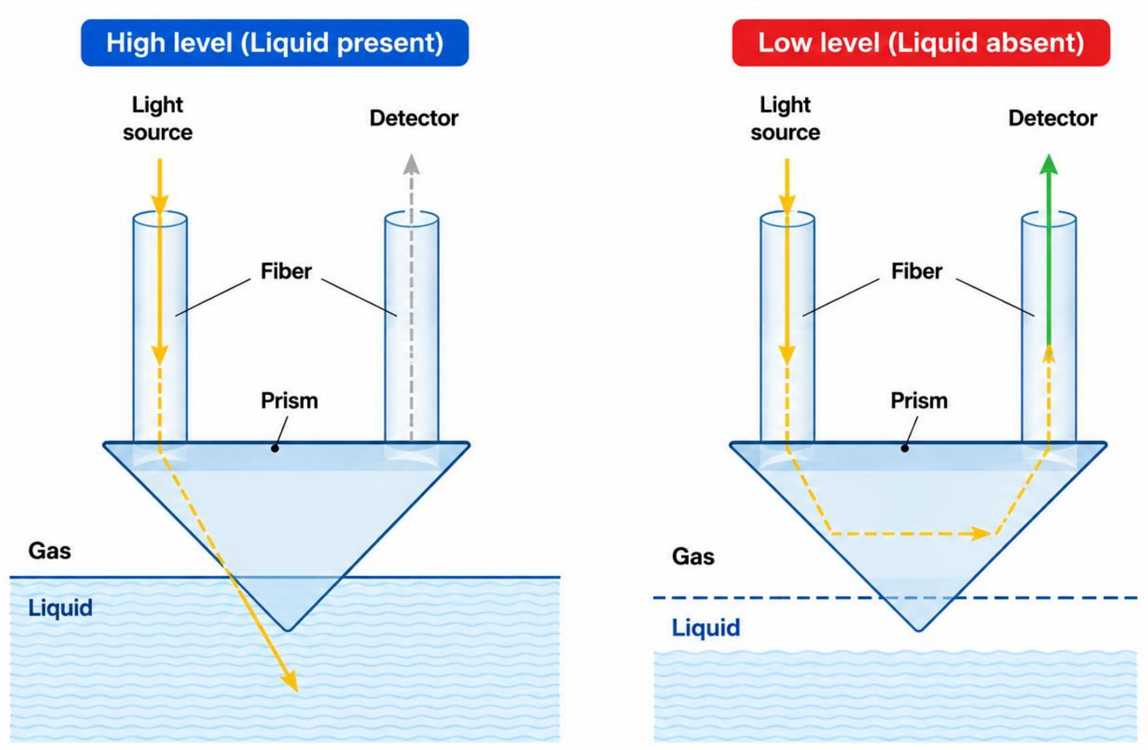
❖ Distributed sensing:

- Tens of thousand of points across entire length of fibre
- Can be applied to existing telecoms fibre

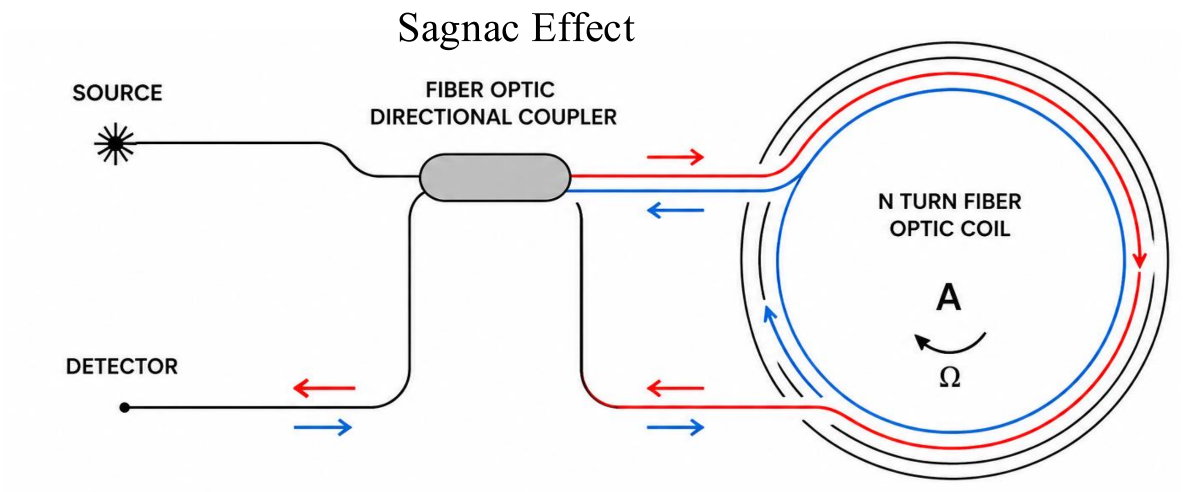


Point sensing applications

Gauge level



Optical Gyroscope



Pros: no electrical parts, chemically inert,…

Pros: no moving parts, high dynamic range,…

Chemical and biological sensinng

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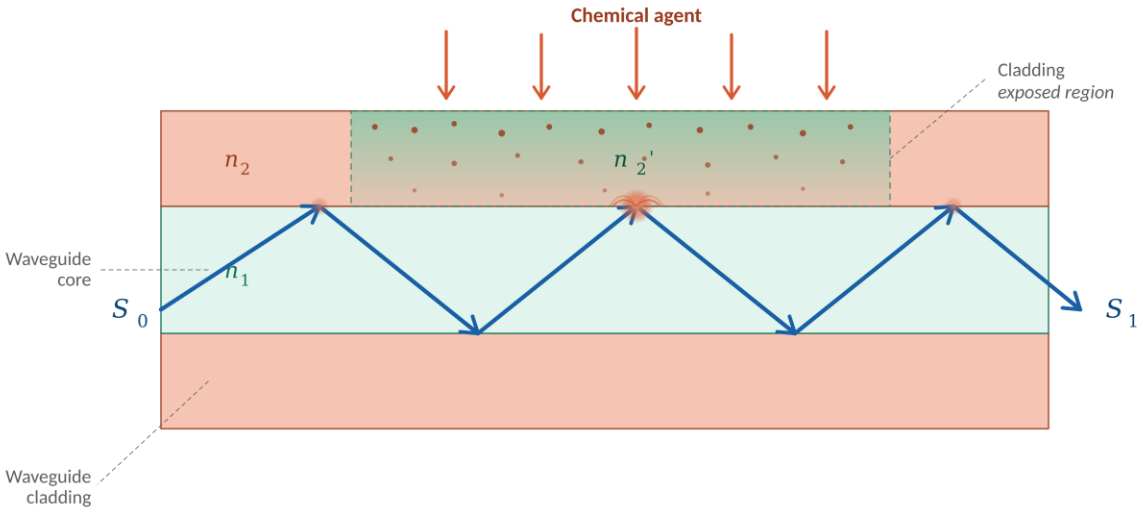
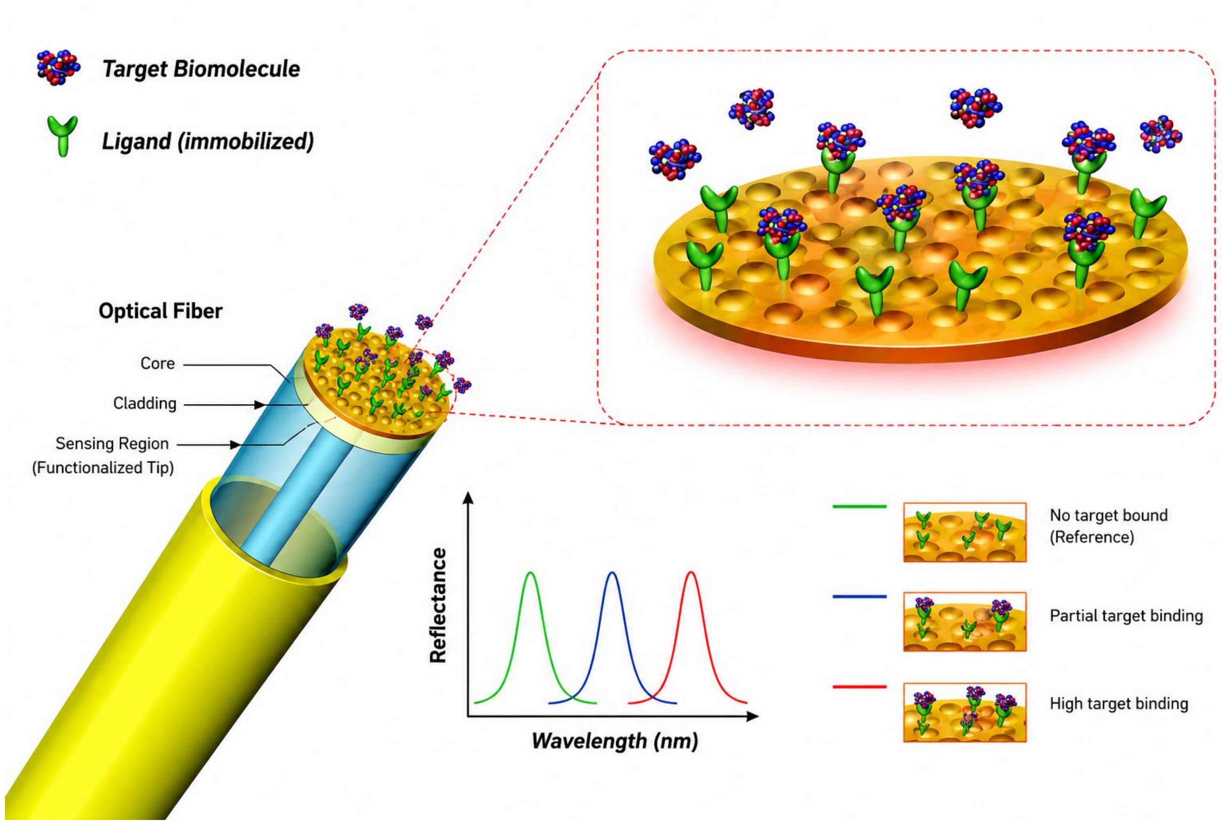
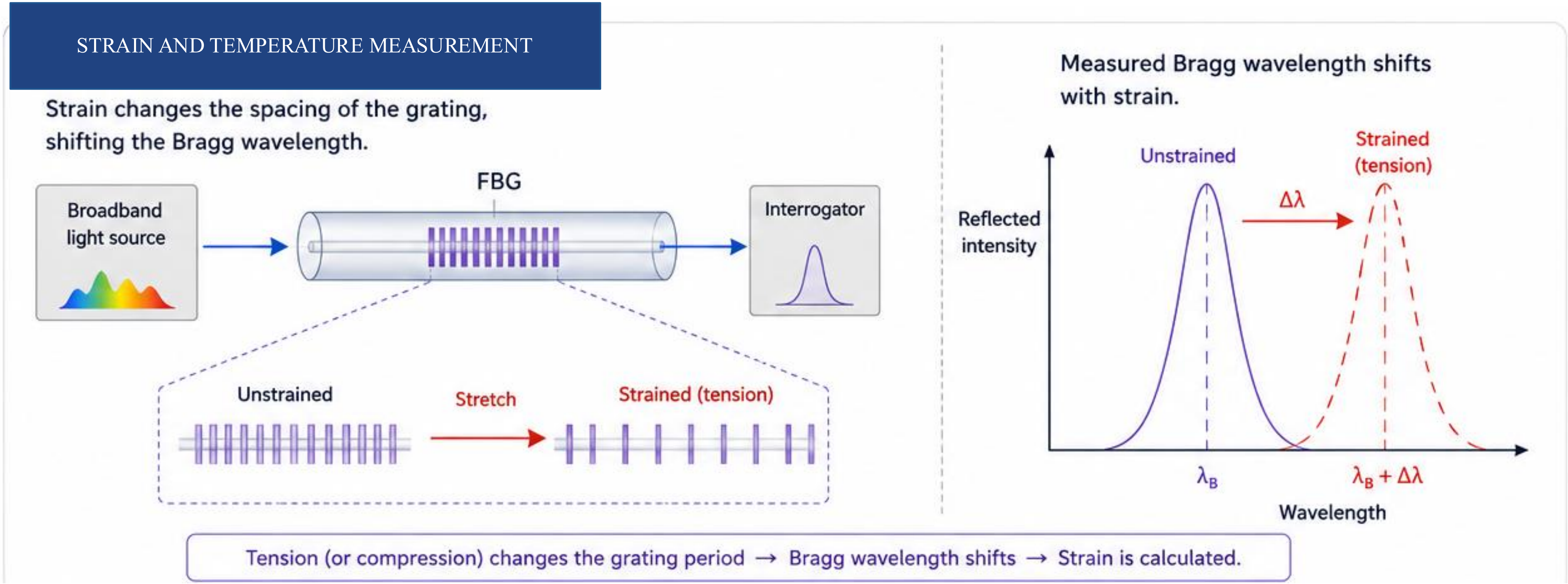
Measuring the presence and concentration of given chemical agent





Pros: real-time, continuous monitoring, non invasive,…

Localised strain and temperature measurement



<u>Pros</u>: no electrical parts, high precision, remote reading,…

Applications based on distributed sensing

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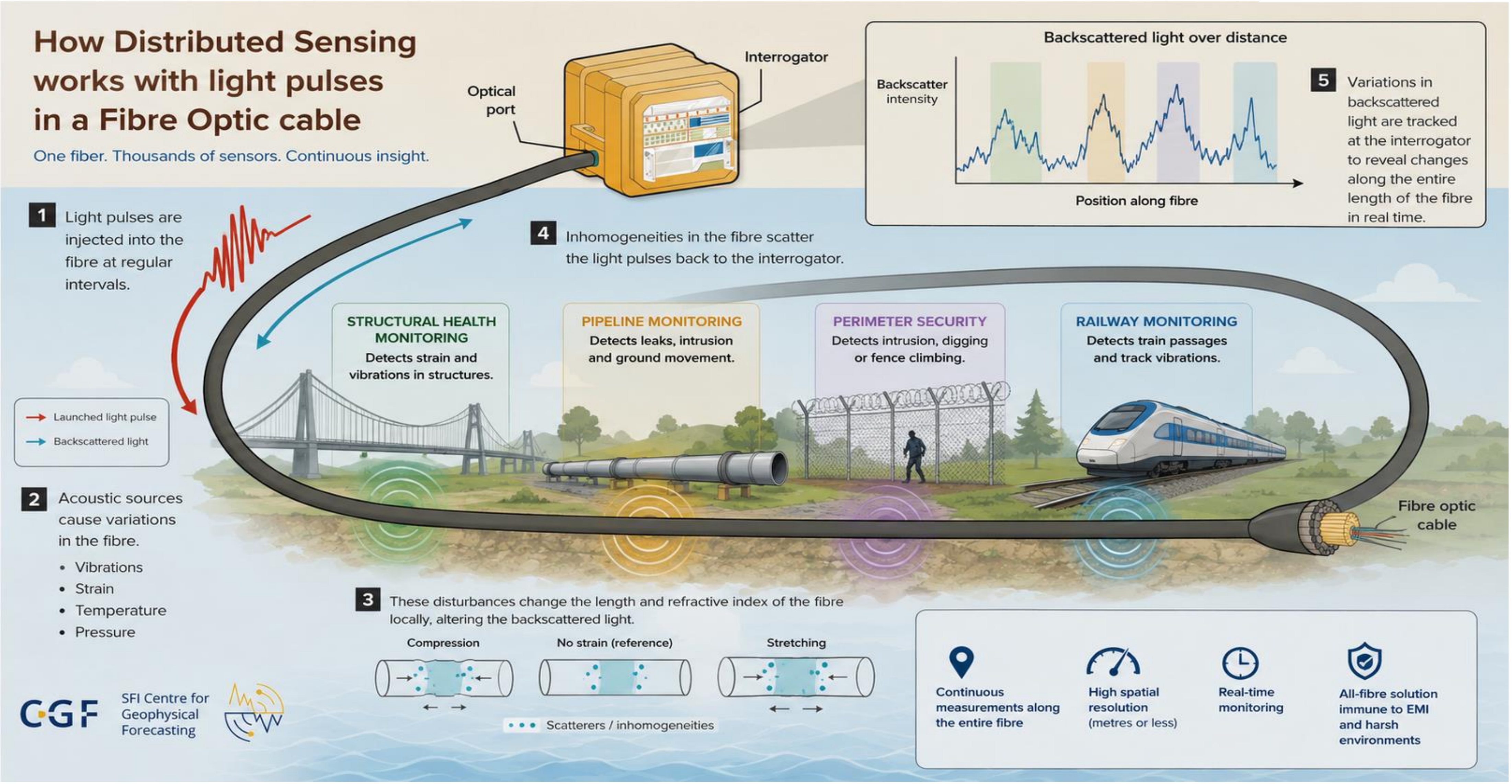
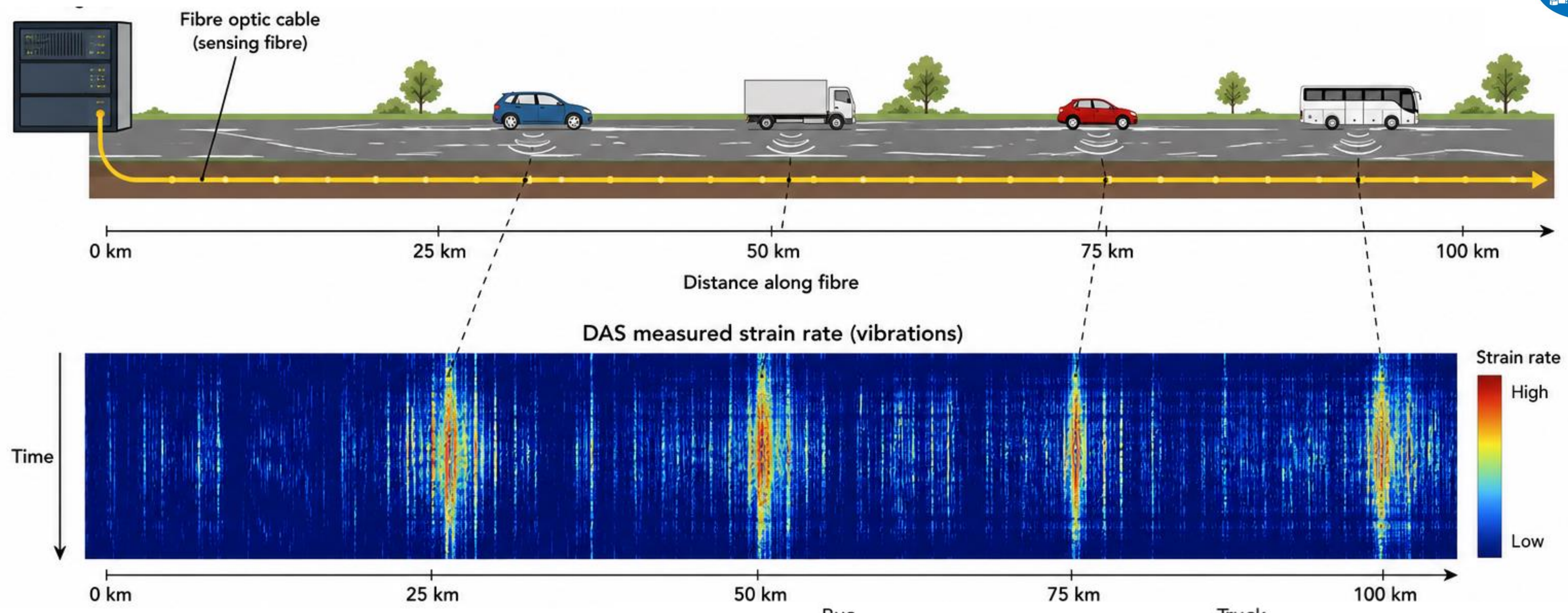
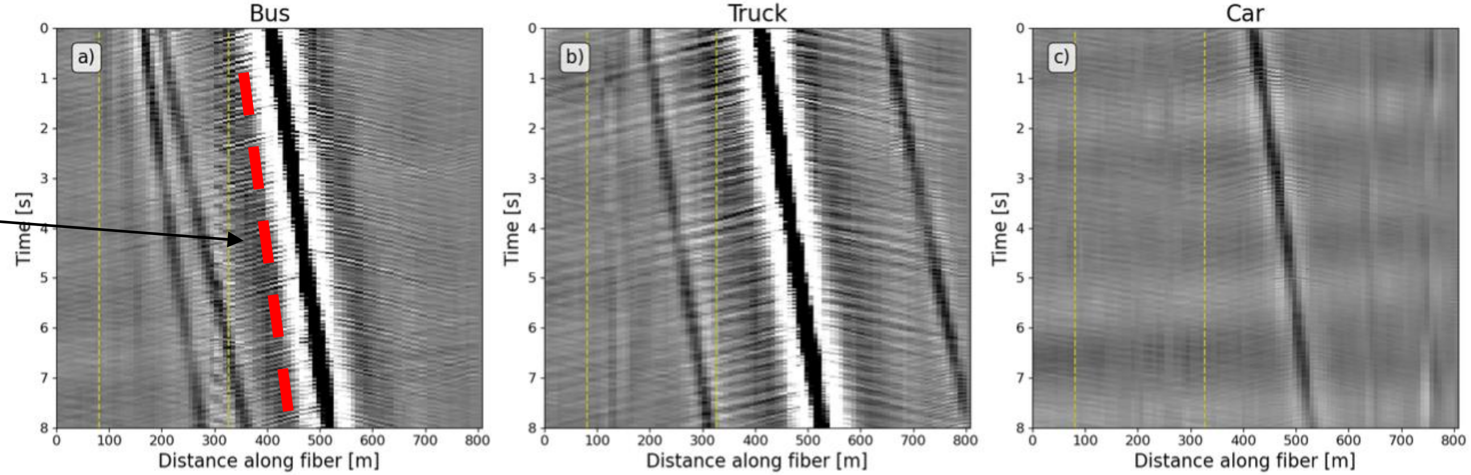


Traffic Sensing

DAS

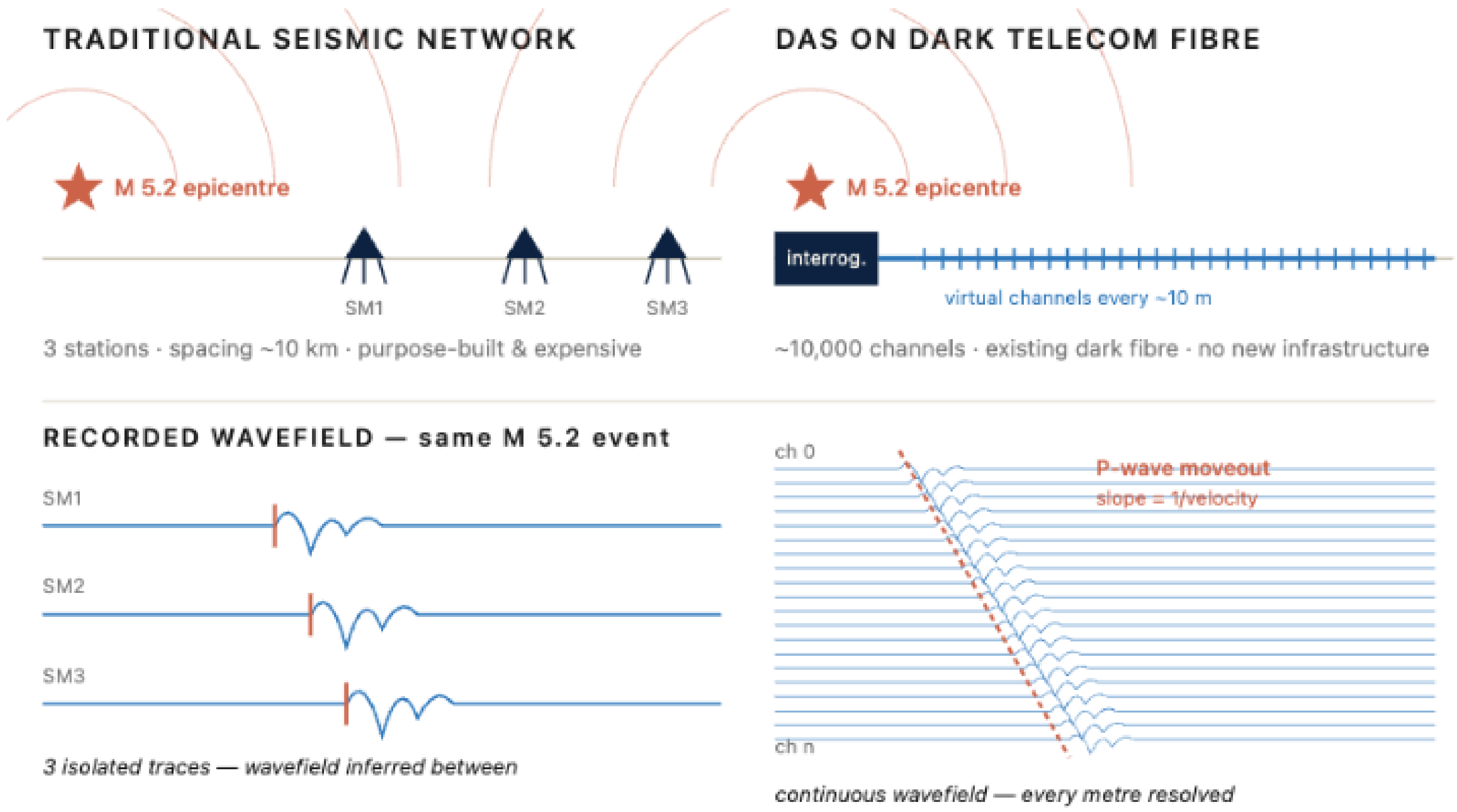


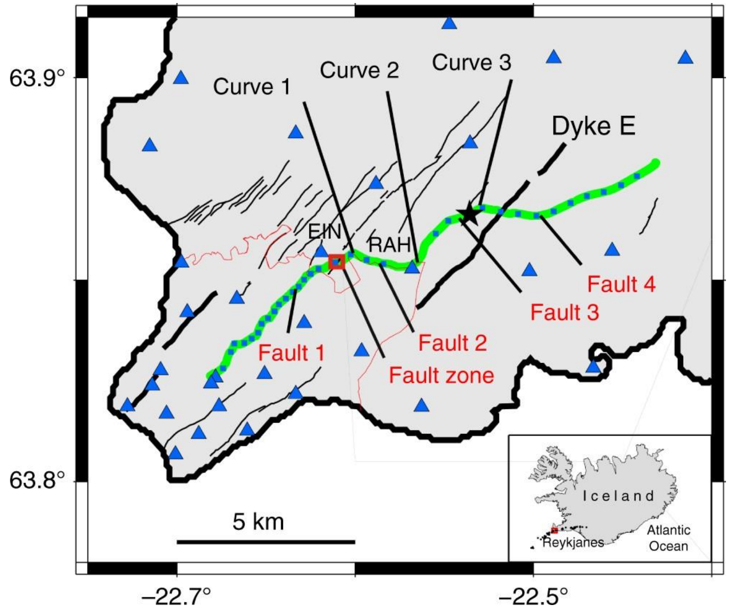
Vehicle speed

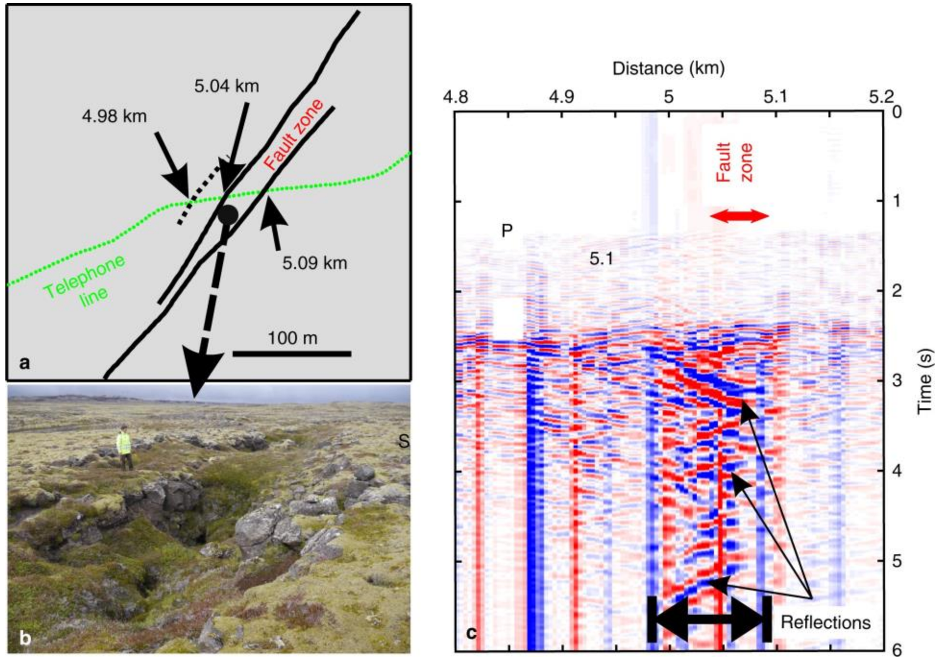


B. Biondi and H. Li, "Future SMART Cities Enabled by Fiber Sensing," *2025 Optical Fiber Communications Conference and Exhibition (OFC)*, San Francisco, CA, USA, 2025

Earthquake sensing

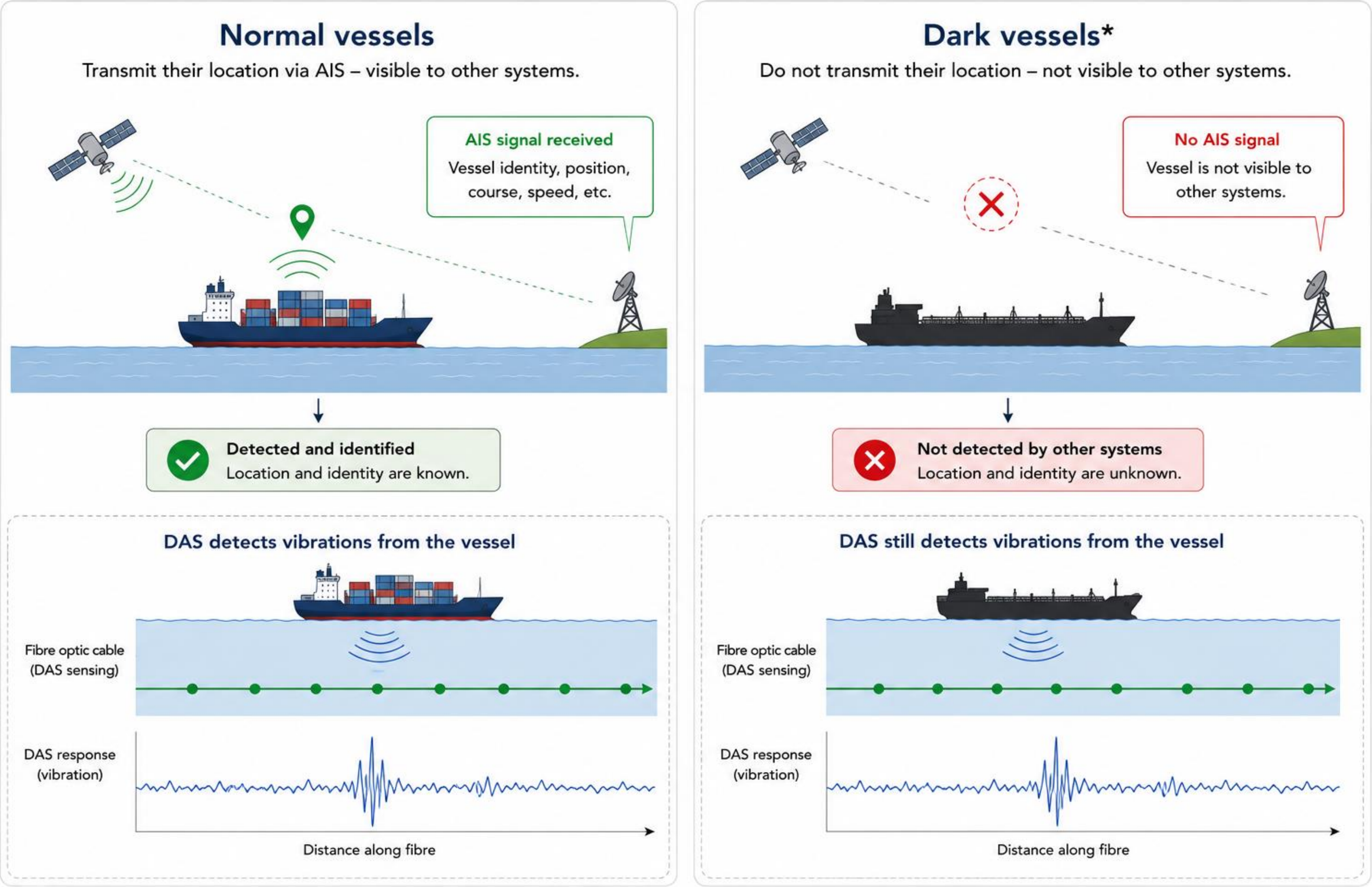






Jousset, P., Reinsch, T., Ryberg, T. *et al.* Dynamic strain determination using fibre-optic cables allows imaging of seismological and structural features. *Nat Commun* **9**, 2509 (2018). https://doi.org/10.1038/s41467-018-04860-y

Sea-Scan*: Solving the issue of dark vessels



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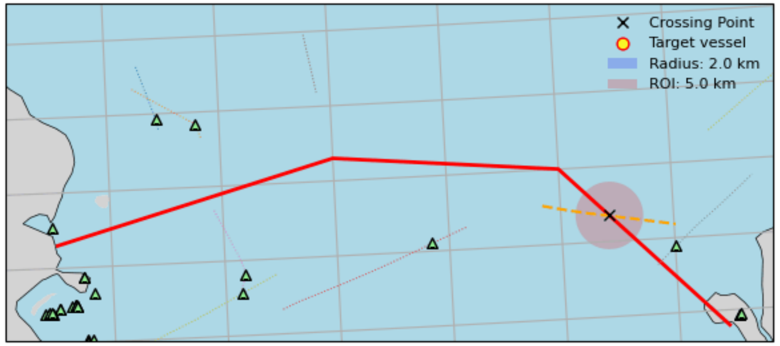

Data Collection of Vessels signatures

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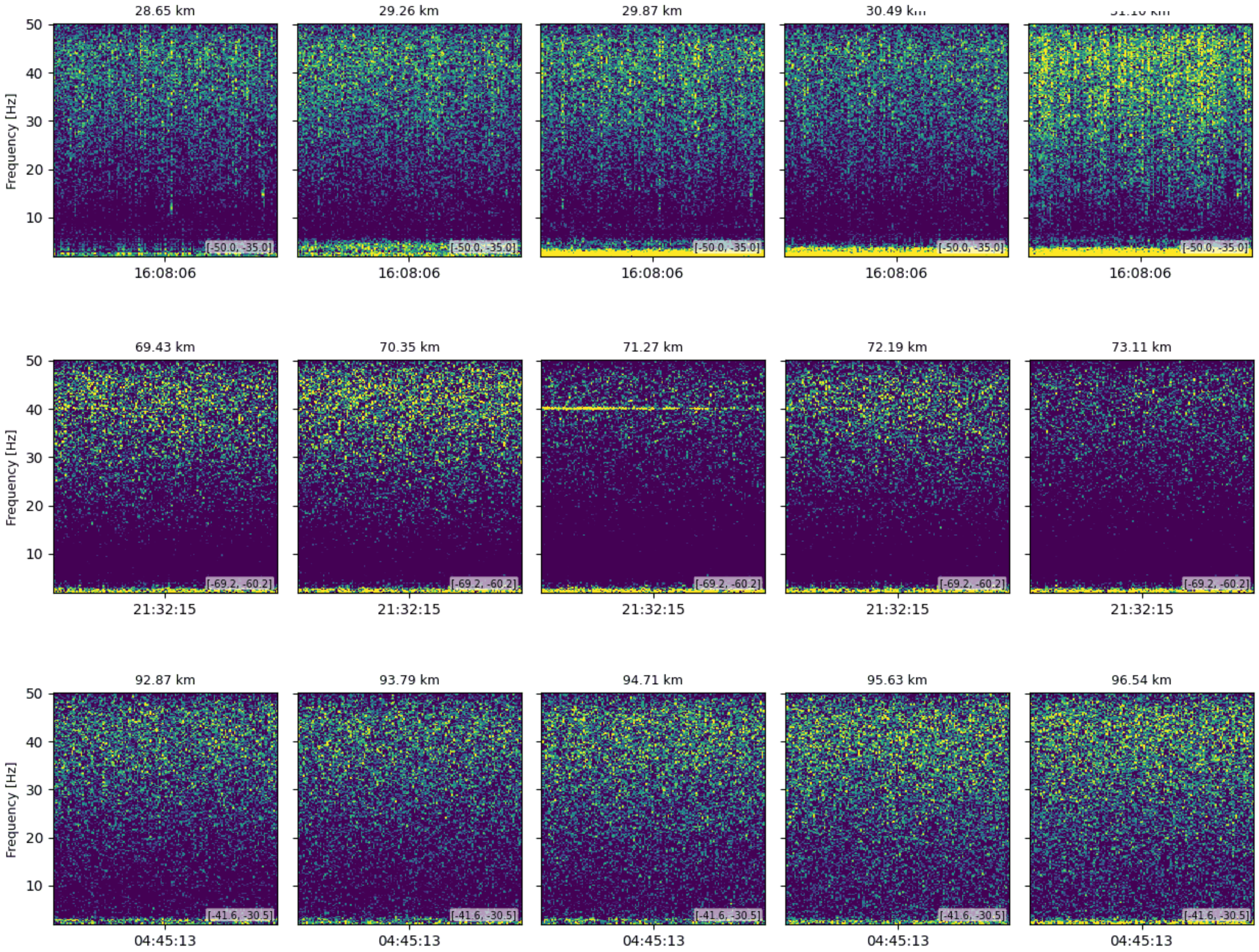
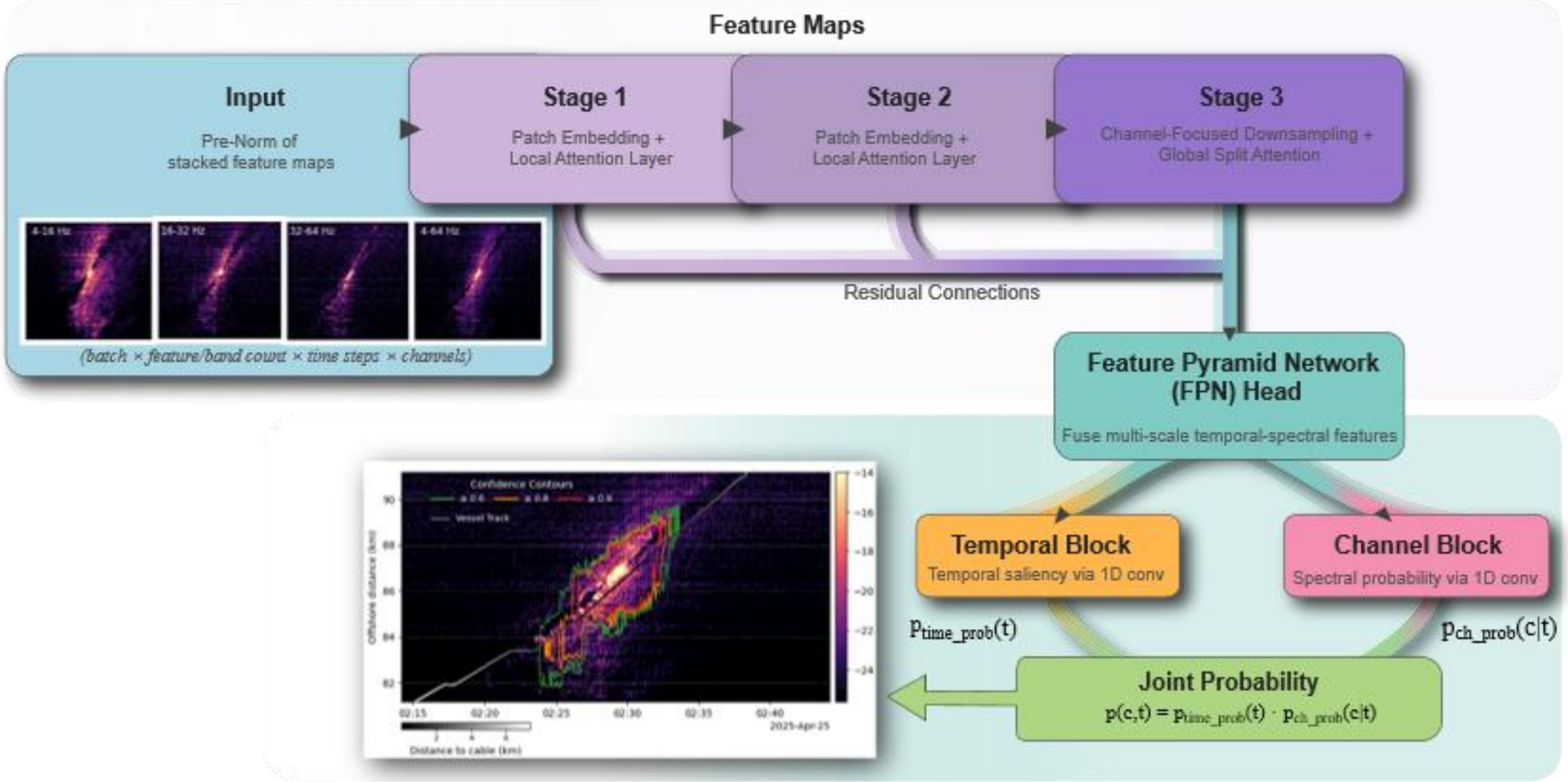
HANNAH J Trawler: Length 20.0 m, Width: 8.0 m, Tonnage: 103

BORE SONG Cargo Ship, Length 195.0 m, Width: 26.0 m, Tonnage: 25,586

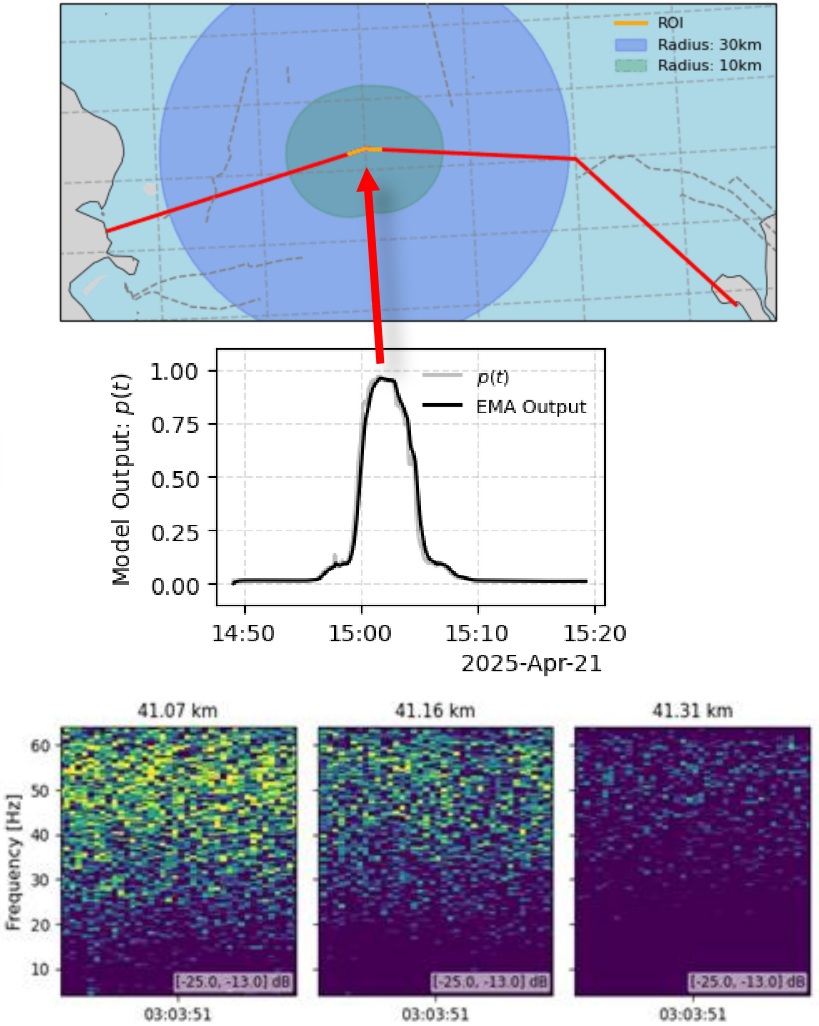
STENA ESTRID Passenger Ship, Length 215.0 m, Width: 28.0 m, Tonnage: 41,671



AI for dark vessel detection and classification



41 Dark vessels detected in 35 days



Vessel detection accuracy: 98.7%

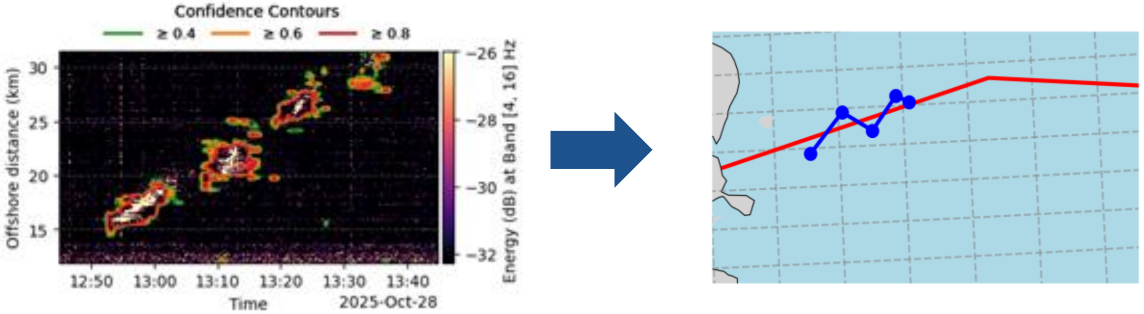
Vessel tonnage classification accuracy: 86.2%

Detecting specific events

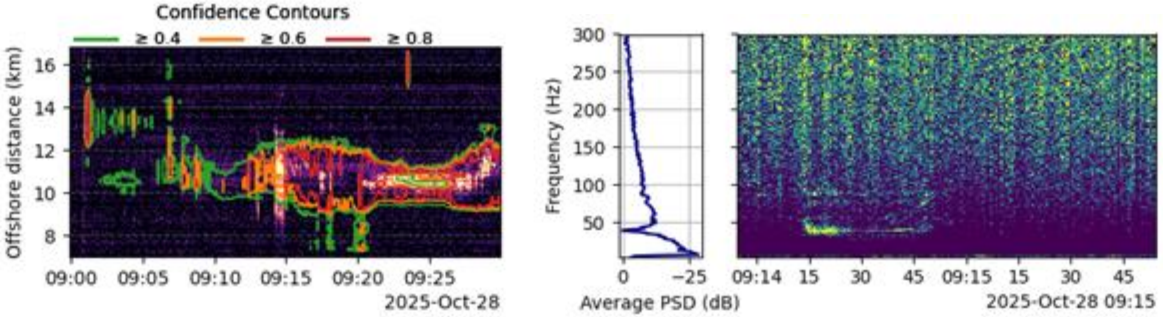
WB YEATS Irish navy vessel

Length	90.0m
Beam	14m
Main Engines	2 x Wärtsilä diesel engines and Power Take In
Tonnage	2,256
Crew	44 (6 Officers)

1. Dark Vessel: estimated speed within 1 knot

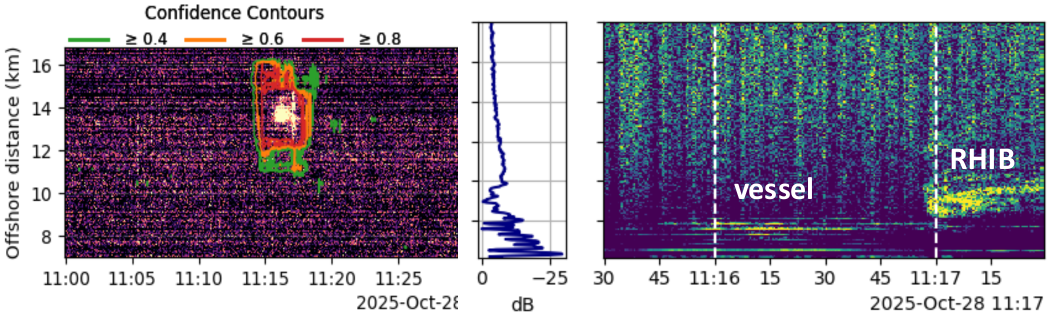


2. Anchor down near the cable

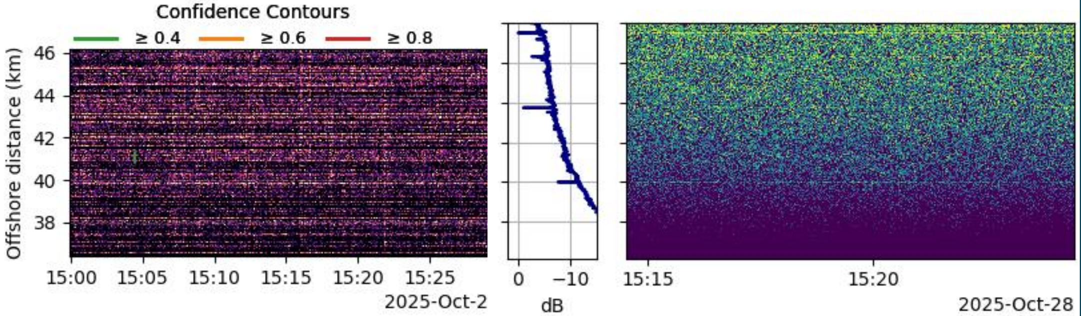


Importance of spectral analysis

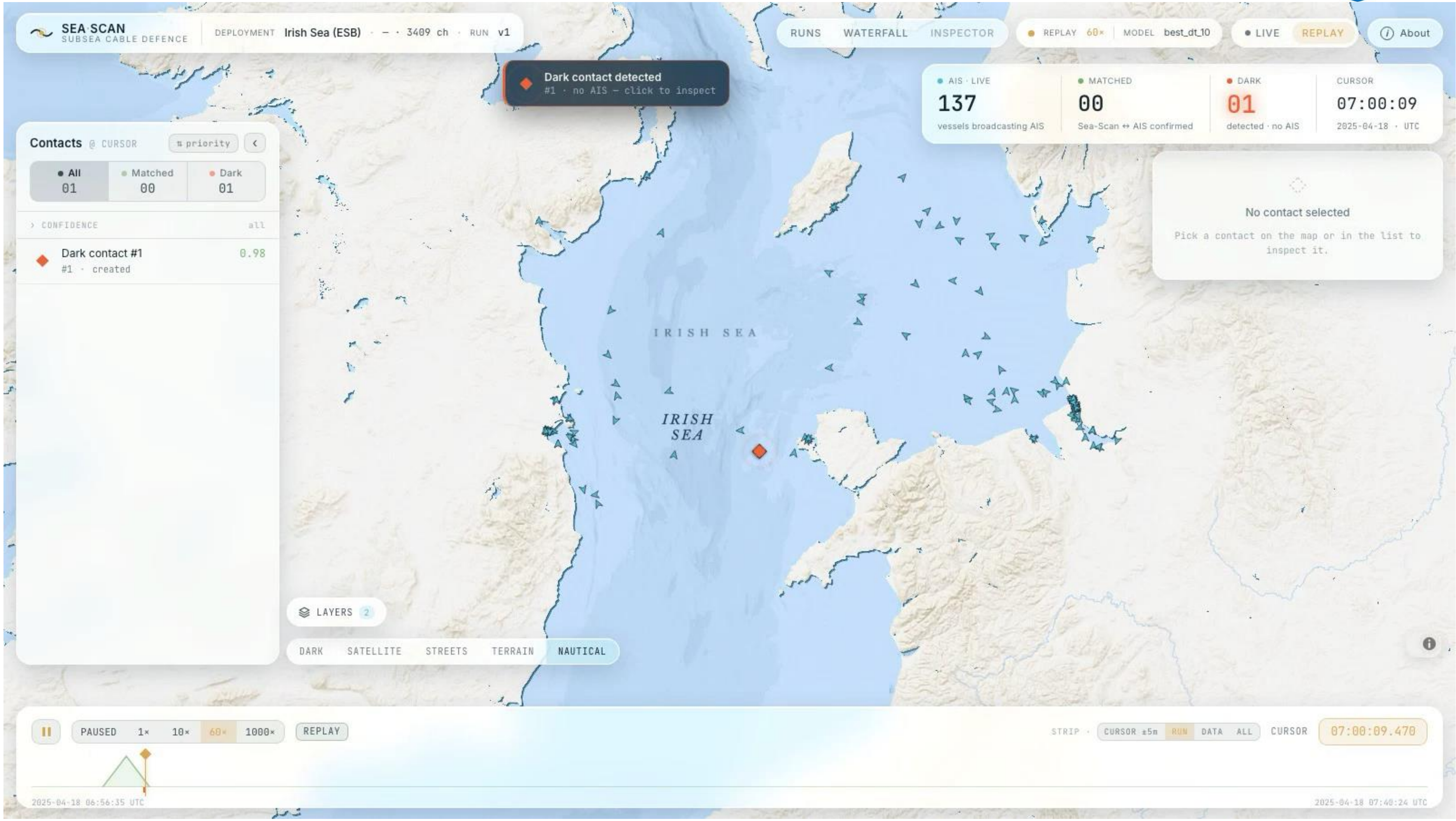
3. RHIB hiding its signature behind large vessel



4. Detection of (stealth) electric engine



Sea-Scan for real time dark vessel detection



Sea-Scan: what's next?

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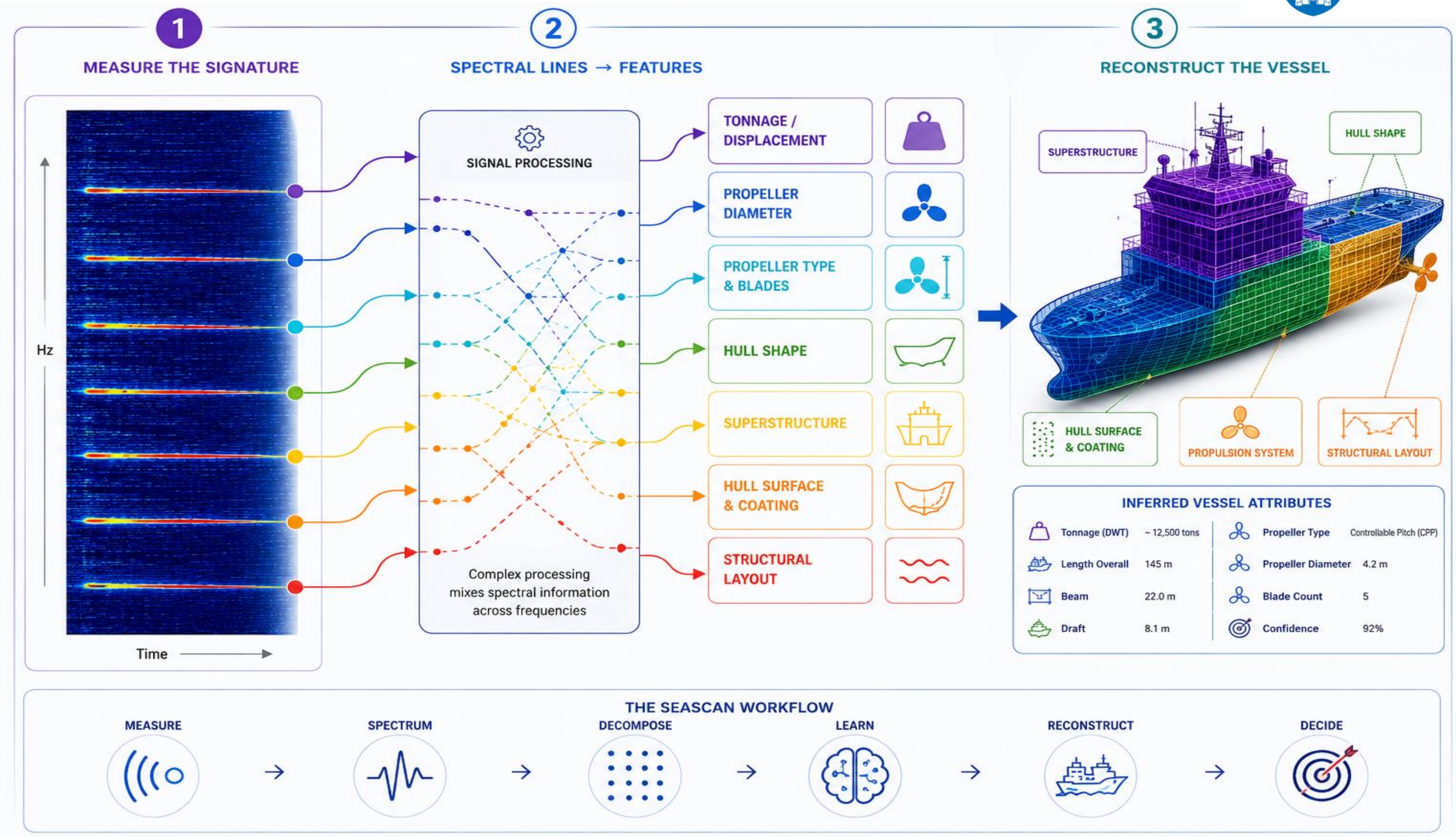

Polarisation sensing for eavesdropping detection

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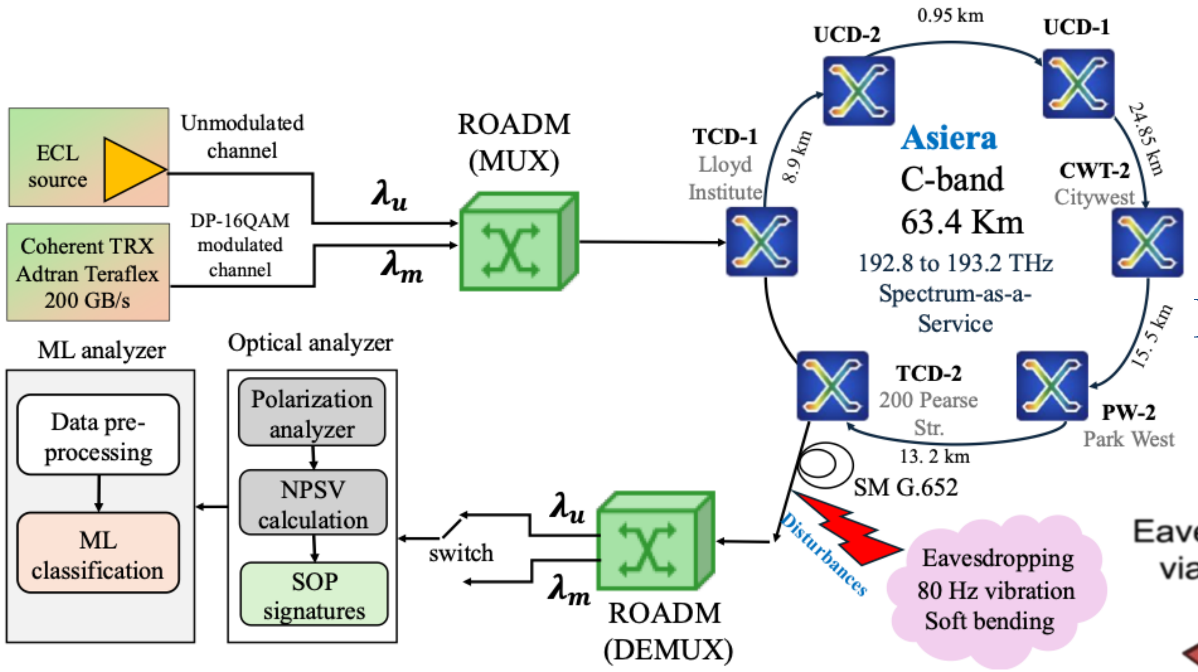

Commercial metropolitan Dublin network

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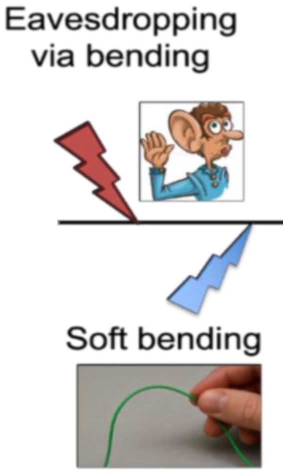


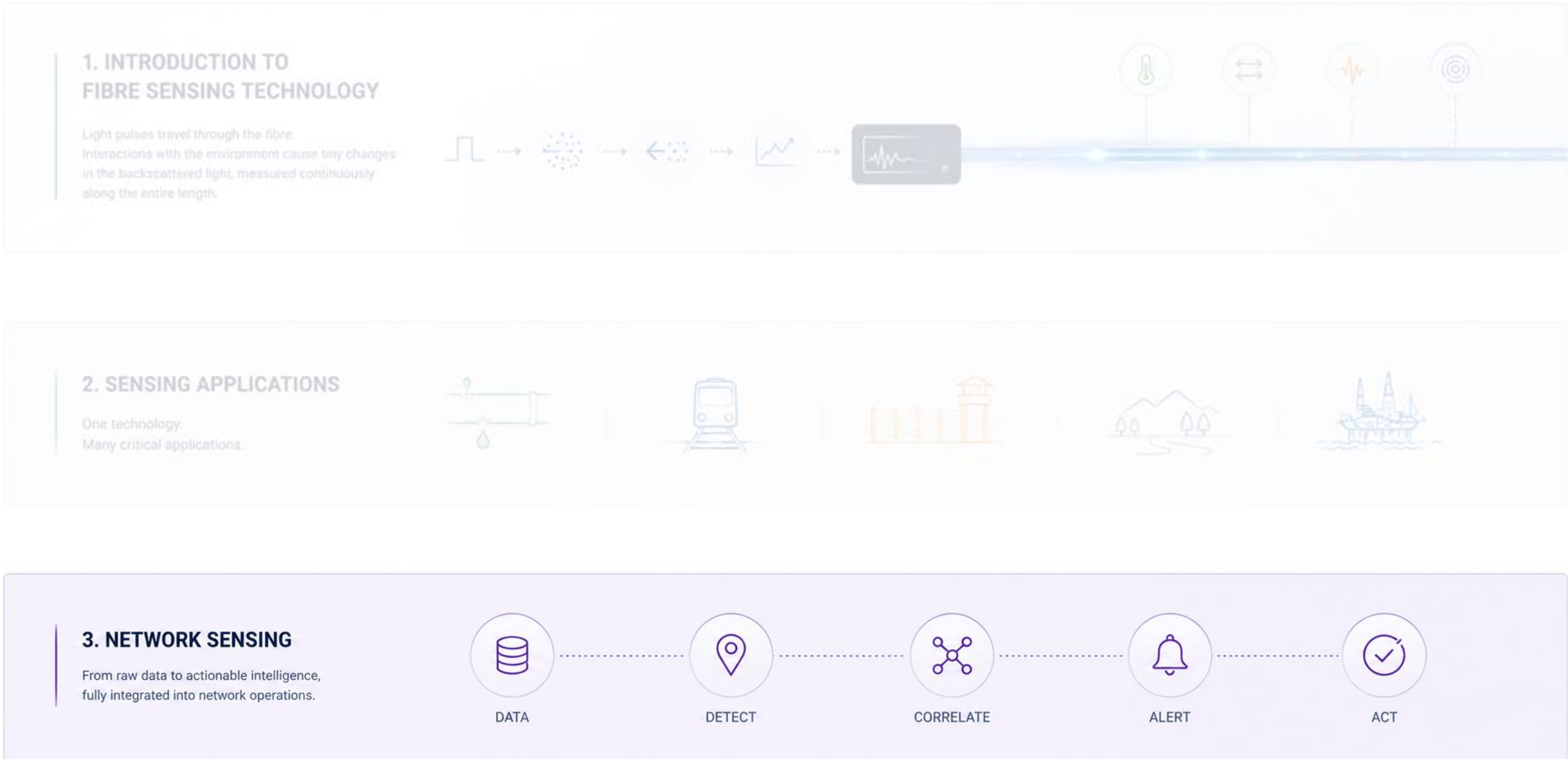
Confusion Matrix

True label \ Predicted label	rlx	eav	sbd	80vb
rlx	98.8%	0.0%	1.2%	0.0%
eav	0.7%	99.0%	0.3%	0.1%
sbd	2.2%	0.6%	95.6%	1.6%
80vb	0.1%	0.1%	1.4%	98.4%

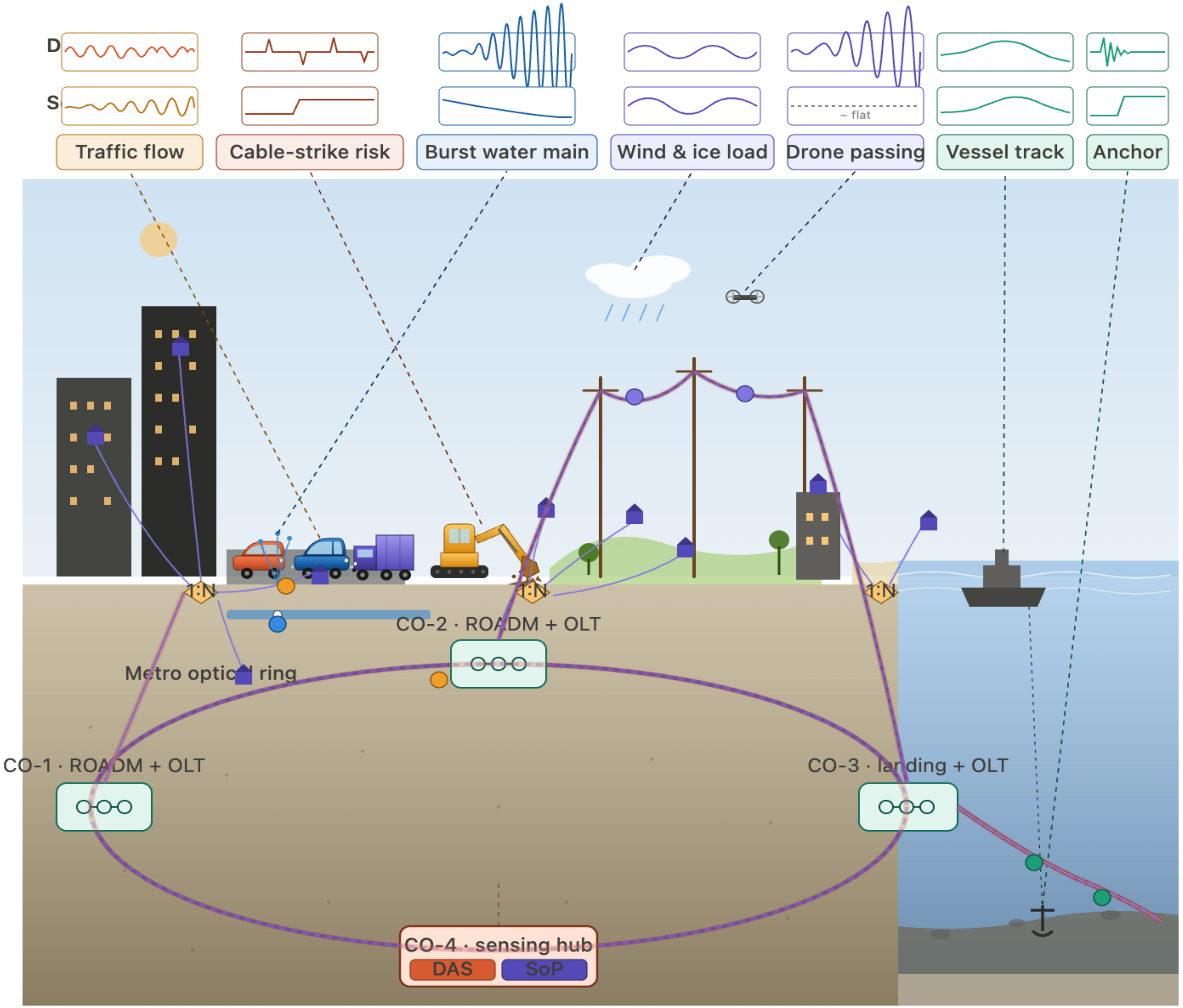
❖ **Able to distinguish between:**

- **No event (rlx)**
- **Eavesdropping (hard bend)**
- **Casual impact (soft bending)**
- **Digger noise at 80Hz (80vb)**

Content of this Keynote



A full scale sensing network

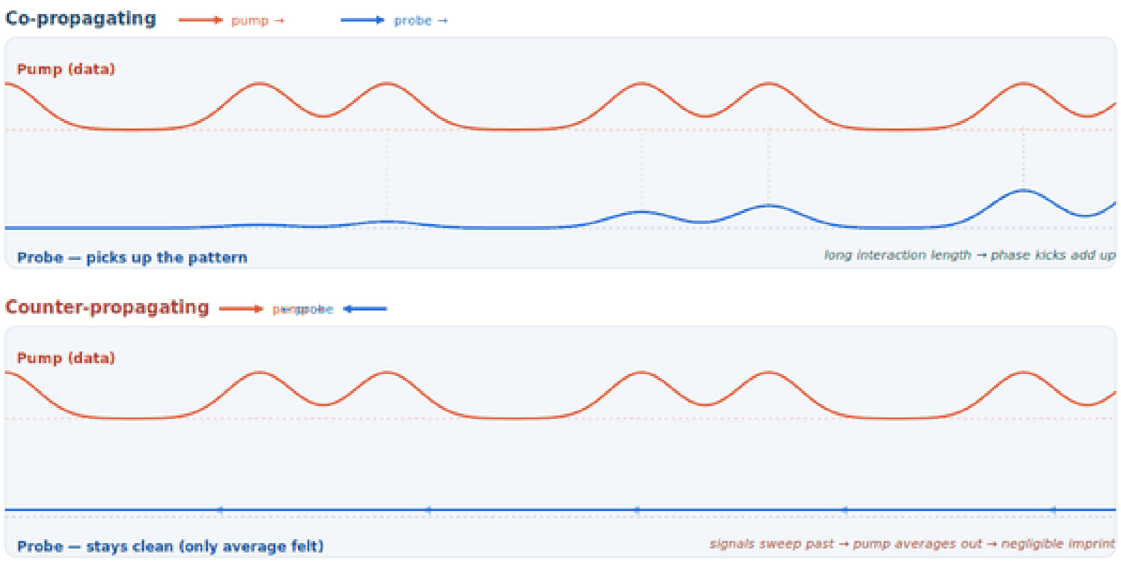


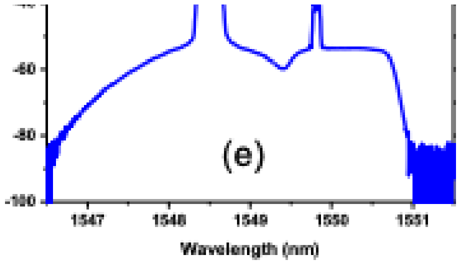
- **Pros:**
  - Share costly sensing devices
  - Ubiquitous sensing
- **Open Issues:**
  - Interference sensing/data channels
  - Environmental noise leads to low SNR
  - Distance/coupling of fibre with event
  - Do I need more diverse data?

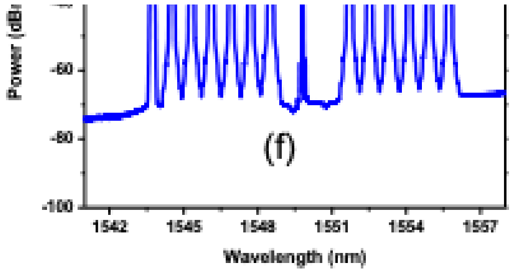
➔ Key question: which fibre/s route to use for a given sensing event

Interference issue: How DAS affects other transmission channels

❖ **Fibre nonlinearity causes cross-talk among channels**



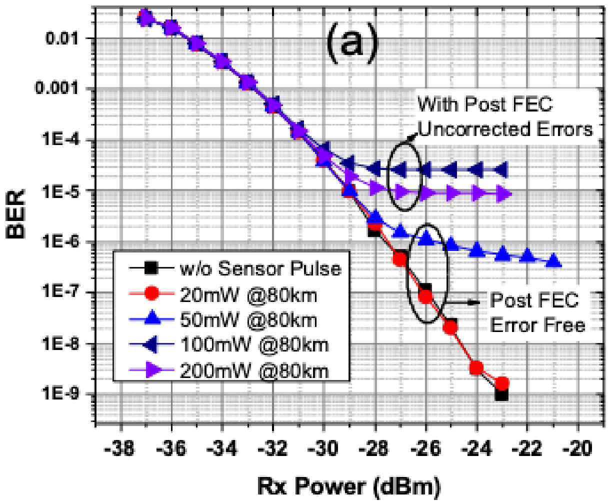




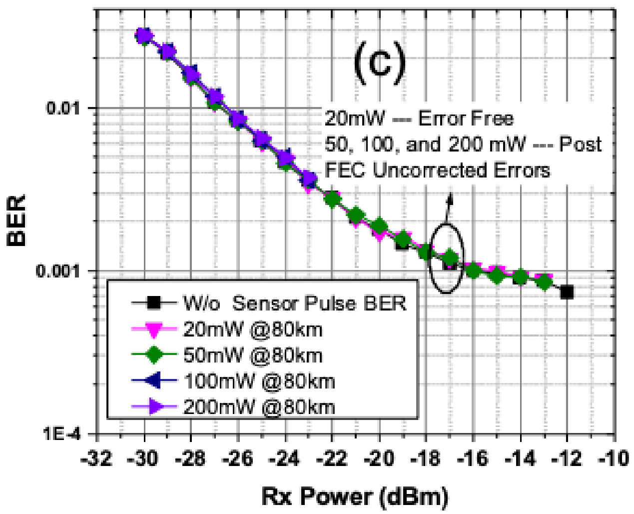
❖ **DAS pulses have high power, triggering nonlinear effects**

- Issue occurs when DAS and data are co-propagating

Co-propagating



Counter-propagating



Z. Jia, L. A. Campos, M. Xu, H. Zhang, M. Gonzalez-Herraez, H. F. Martins, and Z. Zhan, "Experimental Coexistence Investigation of Distributed Acoustic Sensing and Coherent Communication Systems," OFC 2021

Fibre coupling with ground changes event detection

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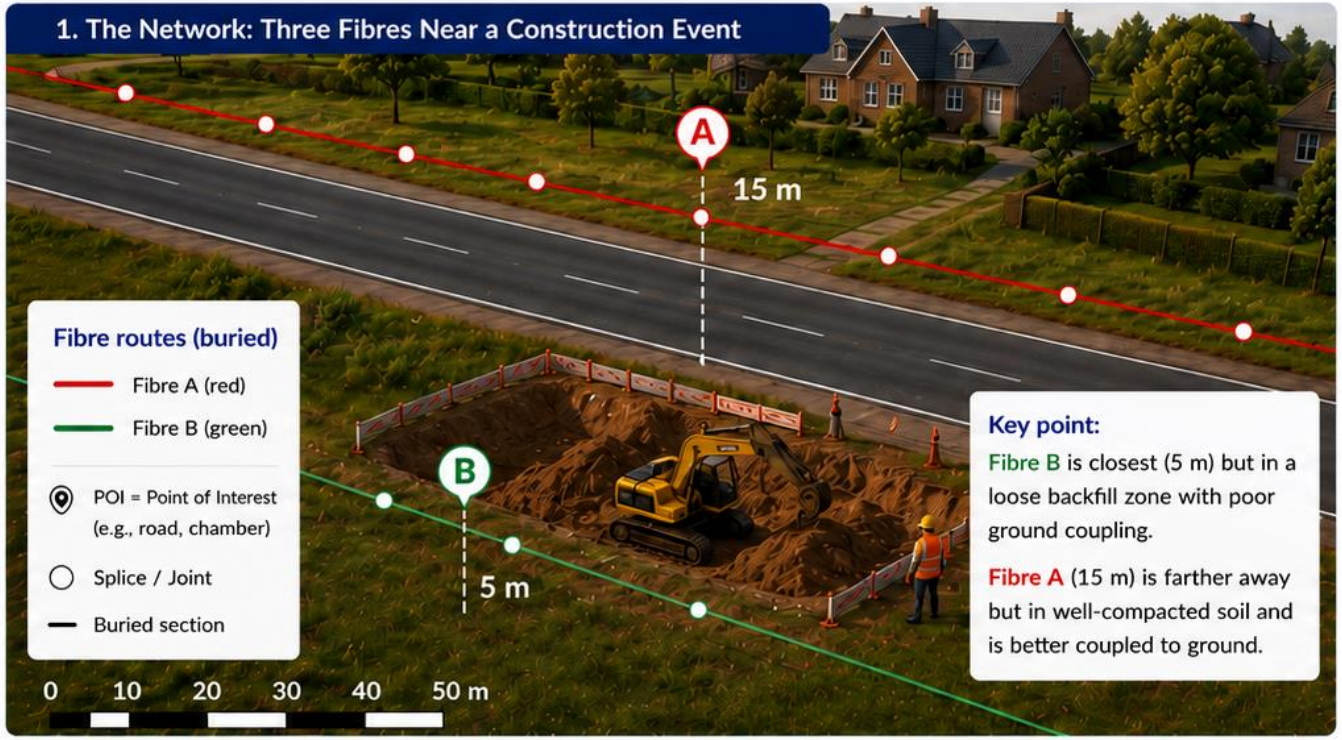
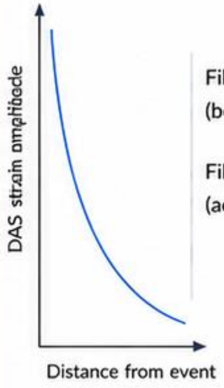
1. The Network: Three Fibres Near a Construction Event



2. What Determines How Much Each Fibre "Feels" the Event?

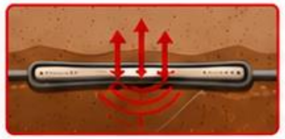
Distance to the Event

Signal amplitude decays with distance

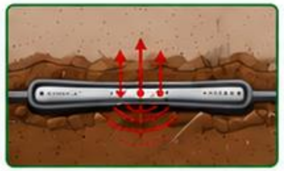


Fibre–Ground Coupling

Stronger coupling → more ground motion transferred into the fibre



Fibre A (15 m)
Strong coupling
Well-compacted soil
(direct burial)



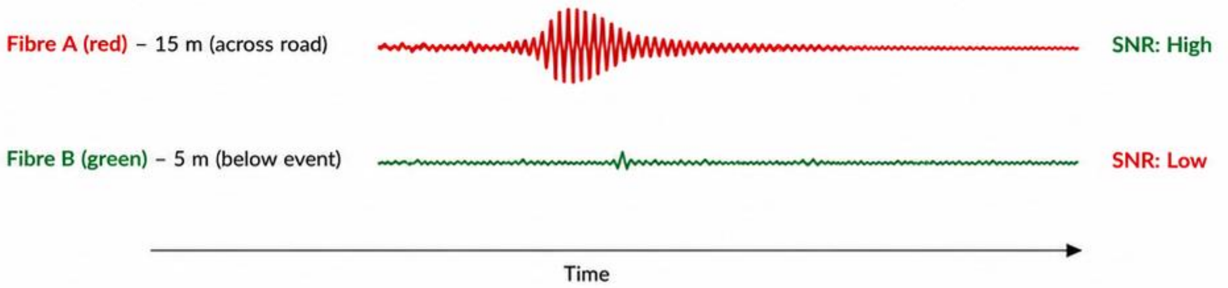
Fibre B (5 m)
Weak coupling
Loose backfill / soft soil
(poor contact)

3. Relative DAS Response of Each Fibre to the Event

Fibre	Distance to Event	Fibre–Ground Coupling (qualitative)	Expected DAS Amplitude	Detectability (with DAS)
Fibre A (red)	15 m (across road)	Strong (well-compacted soil)	High	✔
Fibre B (green)	5 m (below event)	Weak (loose backfill)	Low	!

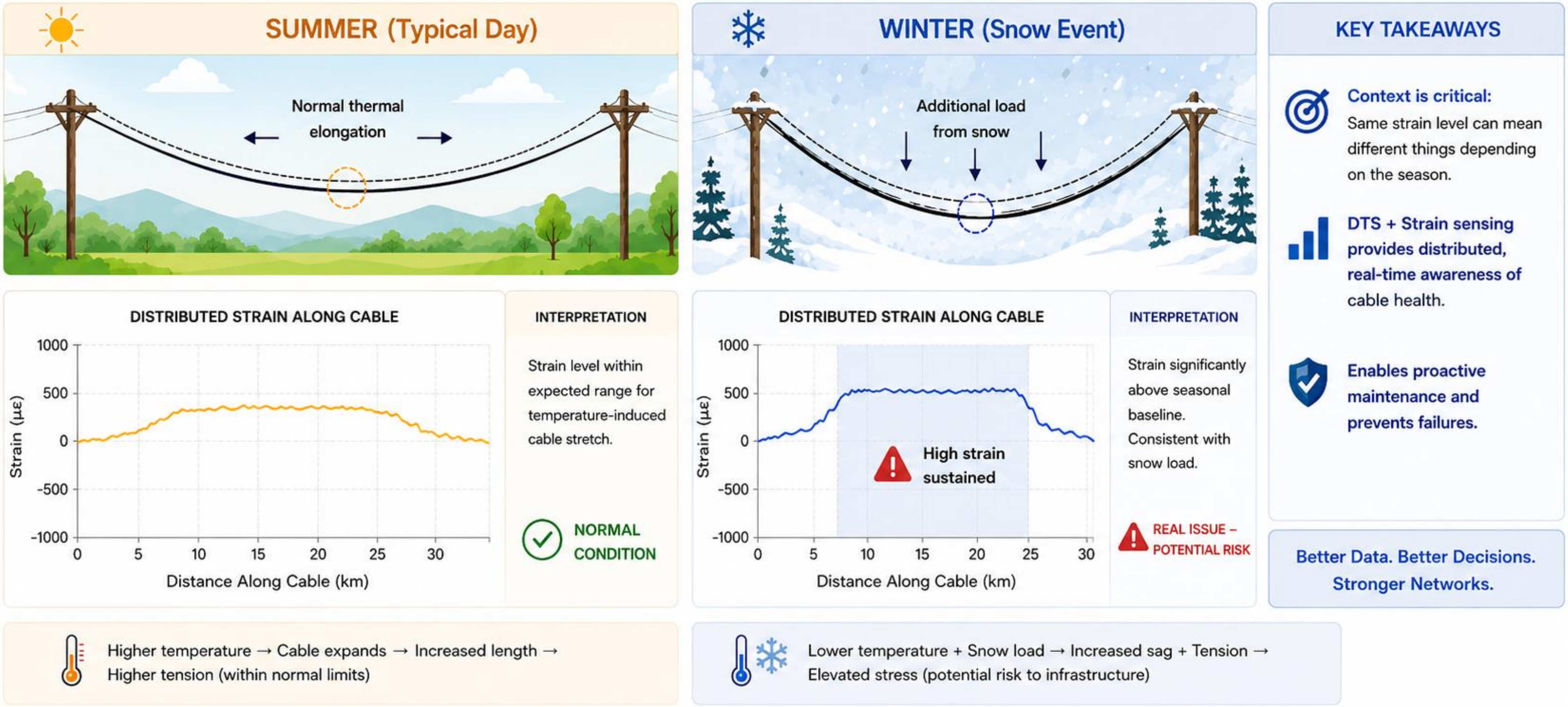
✔ Reliable detection   ! Unreliable / marginal   ✖ Likely not detected

4. Example DAS Comparison (Same Event)

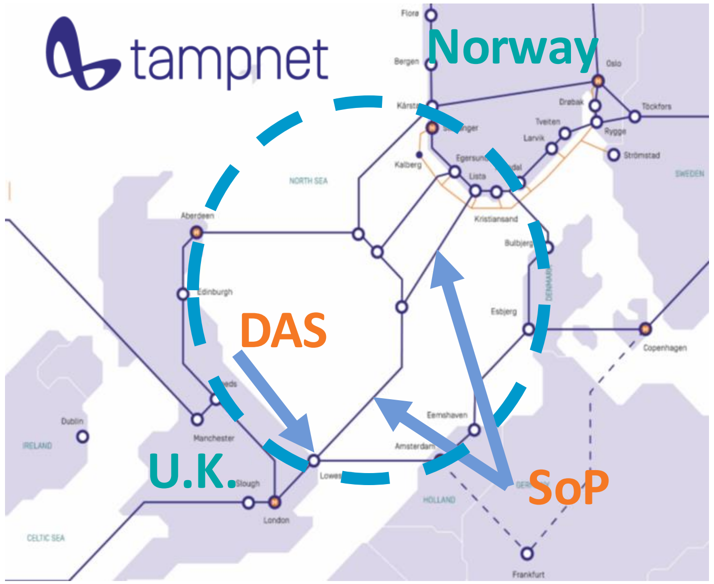


Overhead cable protection: do I need more diverse data?

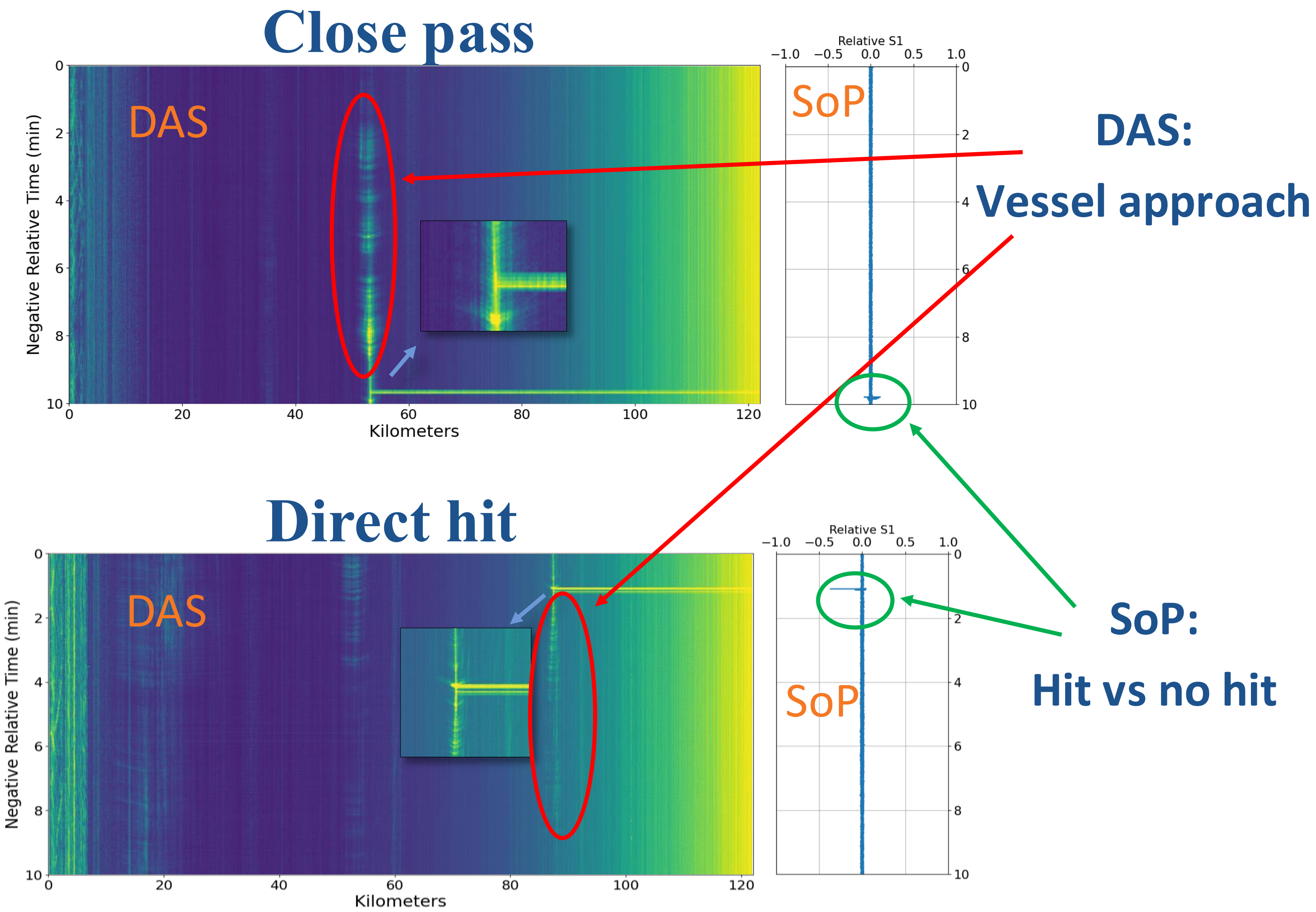
❖ **Should the operator act on strain alert or not?**



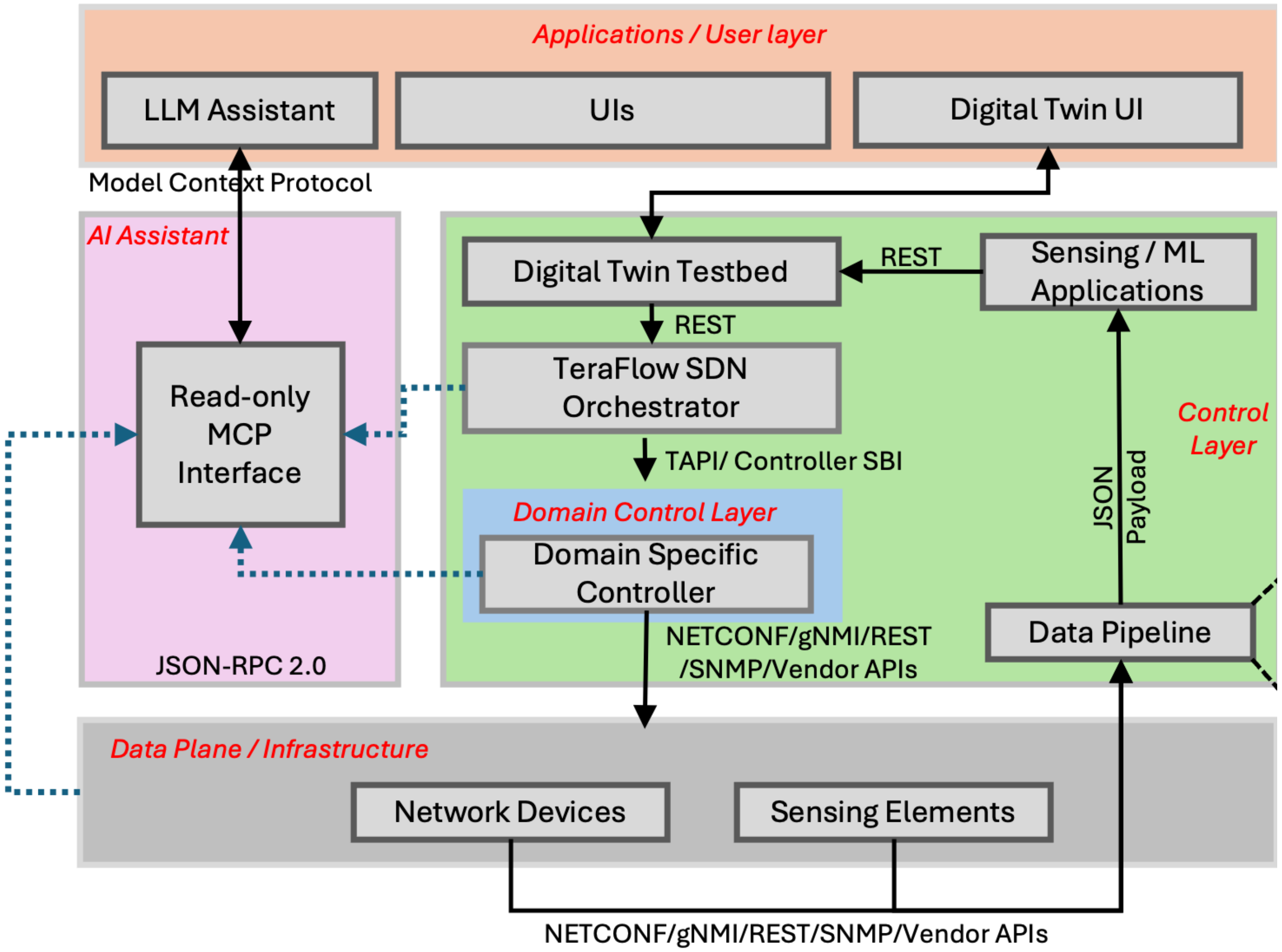
Overhead cable protection: do I need more diverse data?



Courtesy of Steinar Bjørnstad, Tampnet



Solution: Intent based network architecture



- **Intent-based control plane, deciding**
  - Route selection
  - Type of sensing probe
  - Integrate with SDN telecoms infrastructure
- **Build context awareness for sensing applications**
  - Multi-modal data
  - AI-based data fusion

Content of this Keynote

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

1. INTRODUCTION TO FIBRE SENSING TECHNOLOGY

Light pulses travel through the fibre.
Interactions with the environment cause tiny changes in the backscattered light, measured continuously along the entire length.

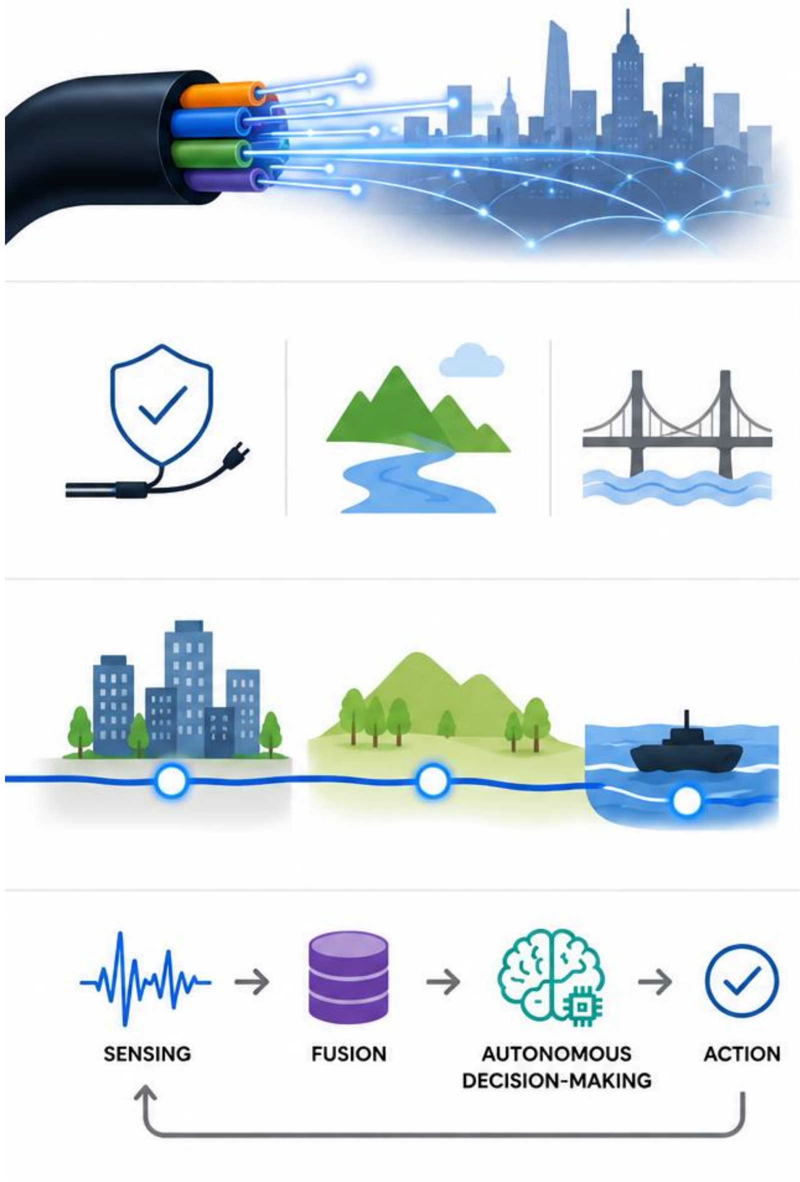
2. SENSING APPLICATIONS

One technology.
Many critical applications.

3. NETWORK SENSING

From raw data to actionable intelligence, fully integrated into network operations.

Conclusions



❖ **Fibre sensing technology developing rapidly**

❖ **Growing range of applications is emerging**

❖ **Coexistence with telecoms enables ubiquitous sensing**

❖ **Use of AI very promising**

… BUT…

The scalability problem

❖ **DAS produces 1TB of data/day (for 100km)**

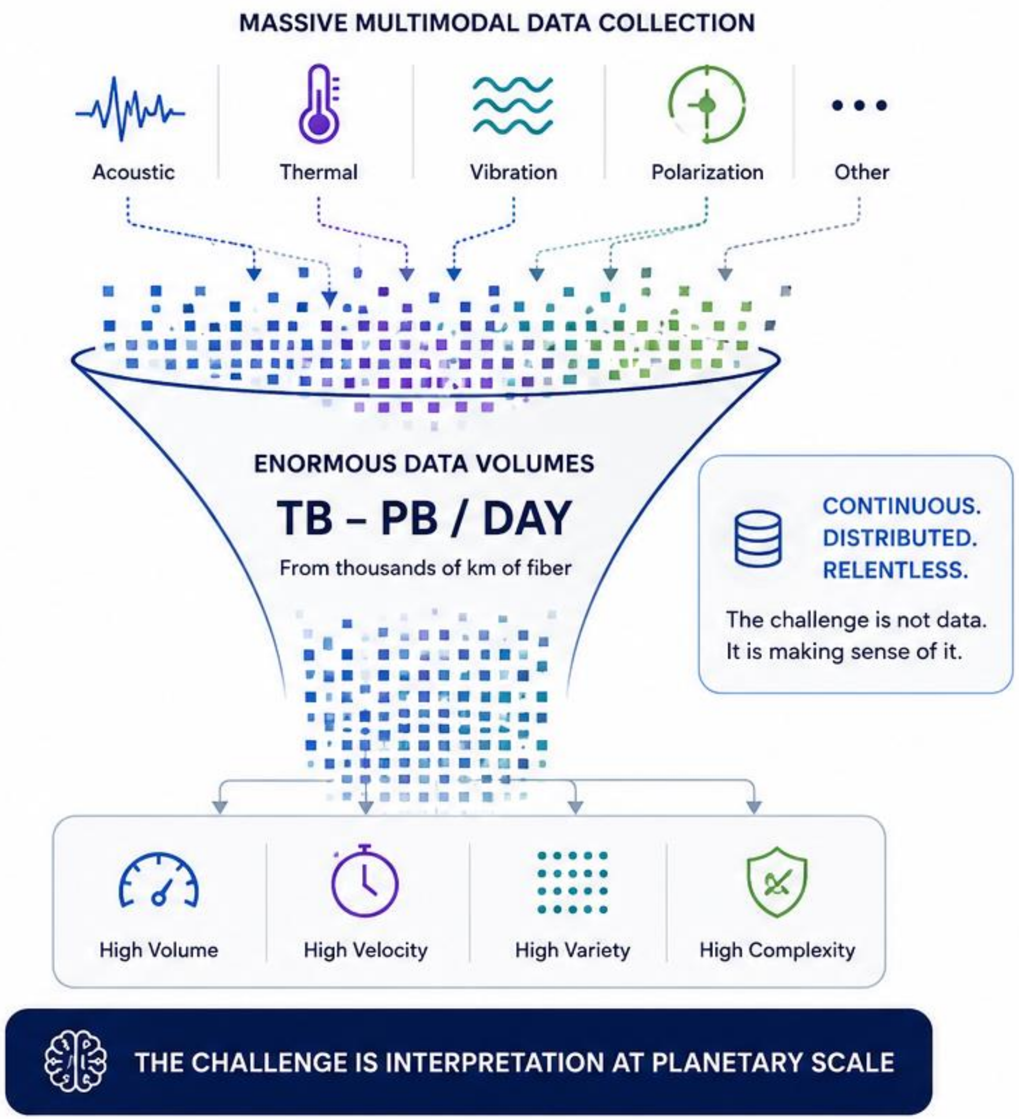
If applied to 1bn km (20% of fibre worldwide):

- 1,000,000 x

- Week x Internet traffic

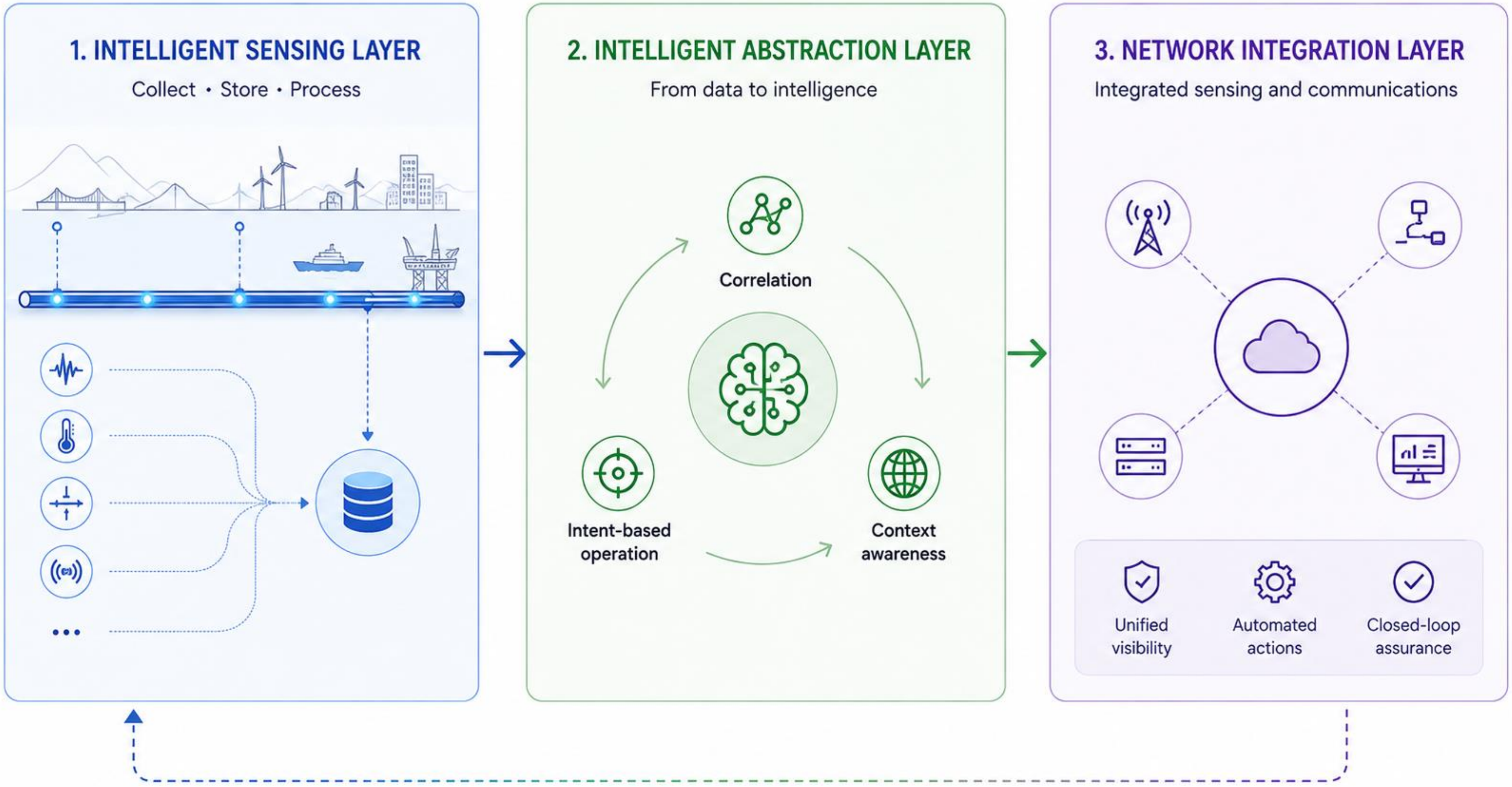
- 10,000 x

➔ **To be stored, organised, processed,…**



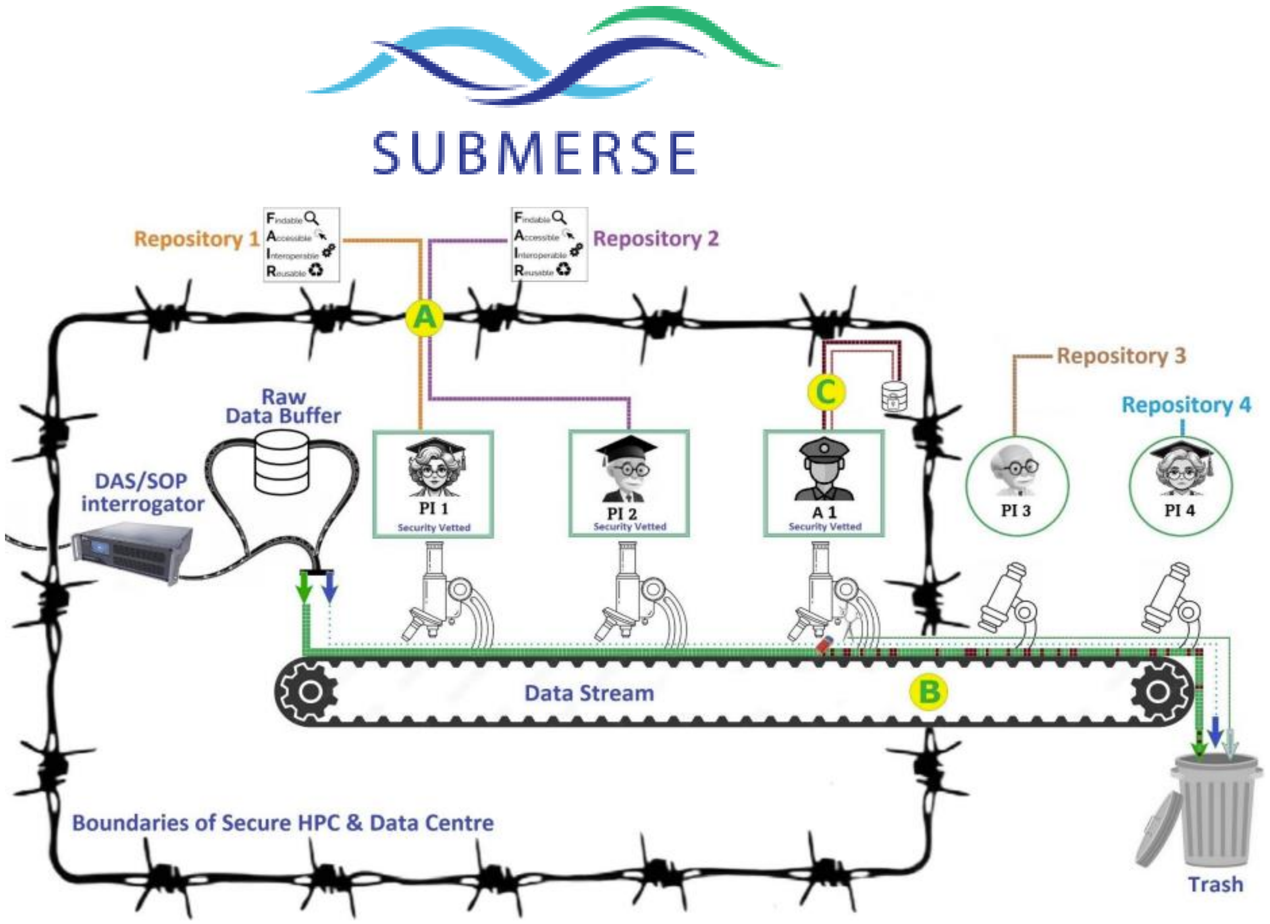
The Integration Problem

Integrate sensing intelligent with network operations



The Governance Problem

Who should access, interpret and benefit from sensing data?



How do we solve these problems?

European Commission | HORIZON EUROPE 2021-2027

FOREST

- ❖ New ESFRI on European fibre infra for time synch, sensing and quantum

ICON

- ❖ Embedding sensing into optical network architectures

ECO eNET

- ❖ Feeding real-world sensing data into AI/ML pipelines for network automation.

SUBMERSE

- ❖ Turn European submarine cables into continental-scale scientific observatory

SENSEI

- ❖ Photonic techniques and network architectures for sensing

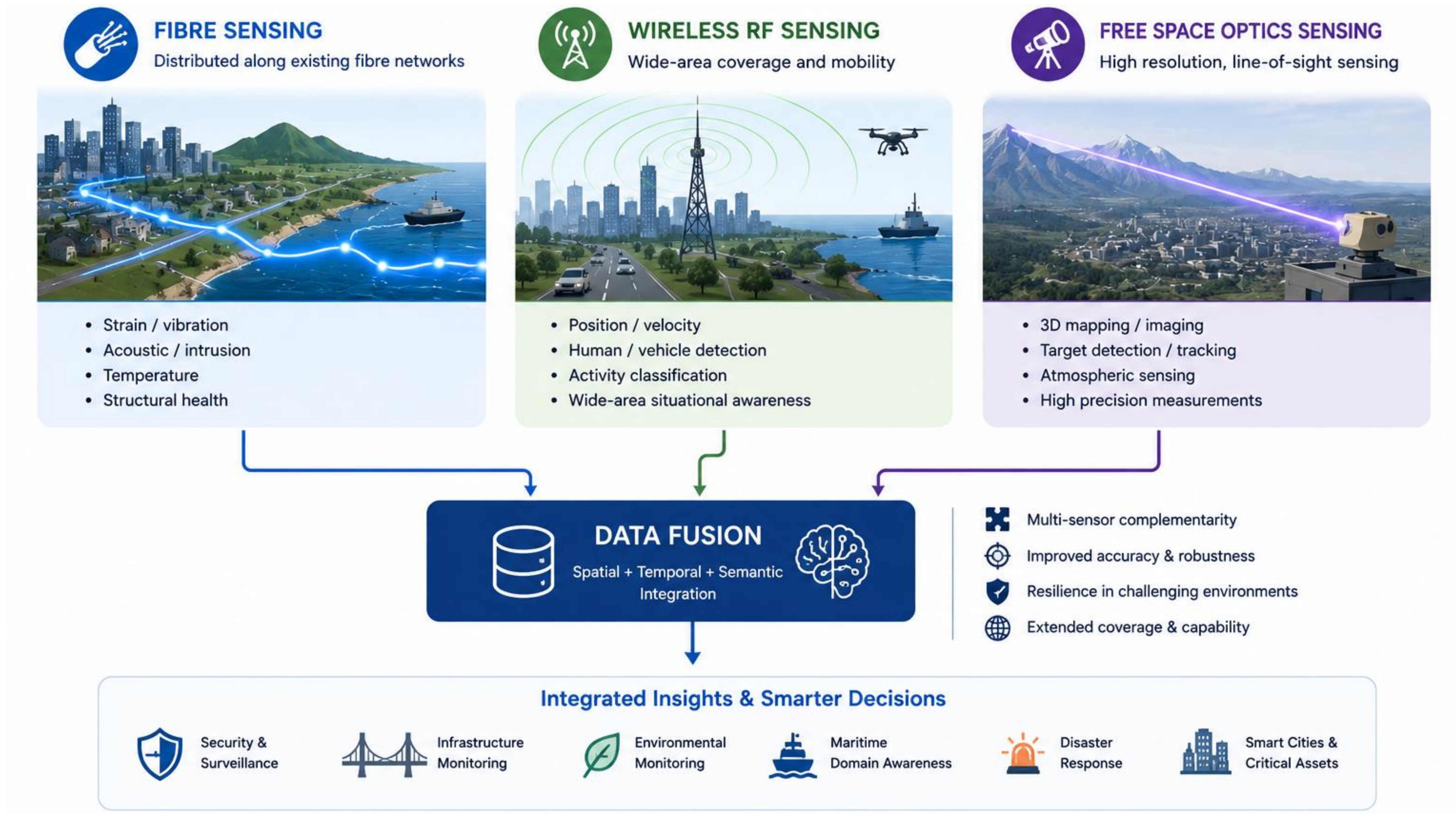
ECSTATIC

- ❖ Joint communication and sensing over live telecom networks

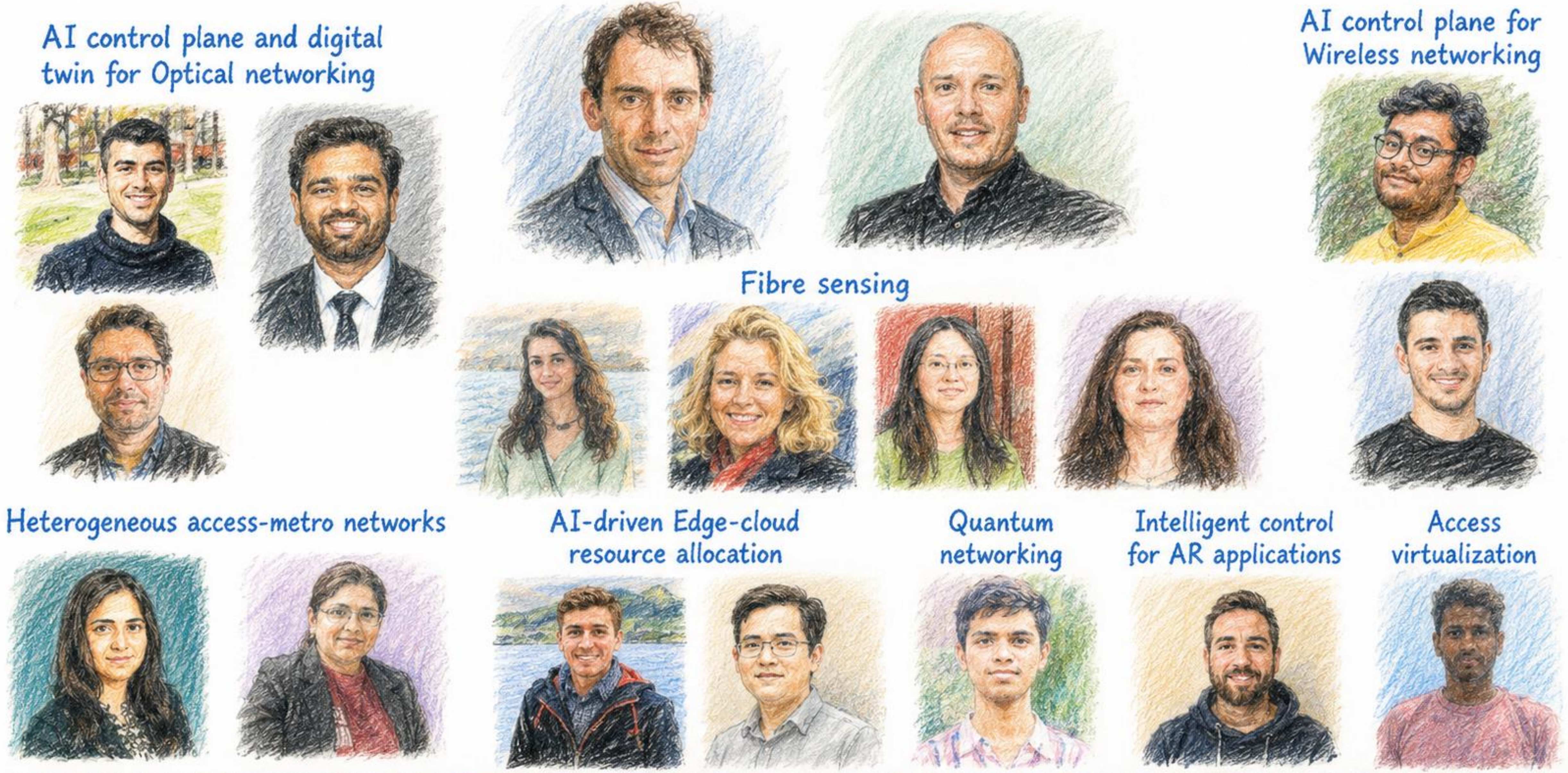
6GSNS

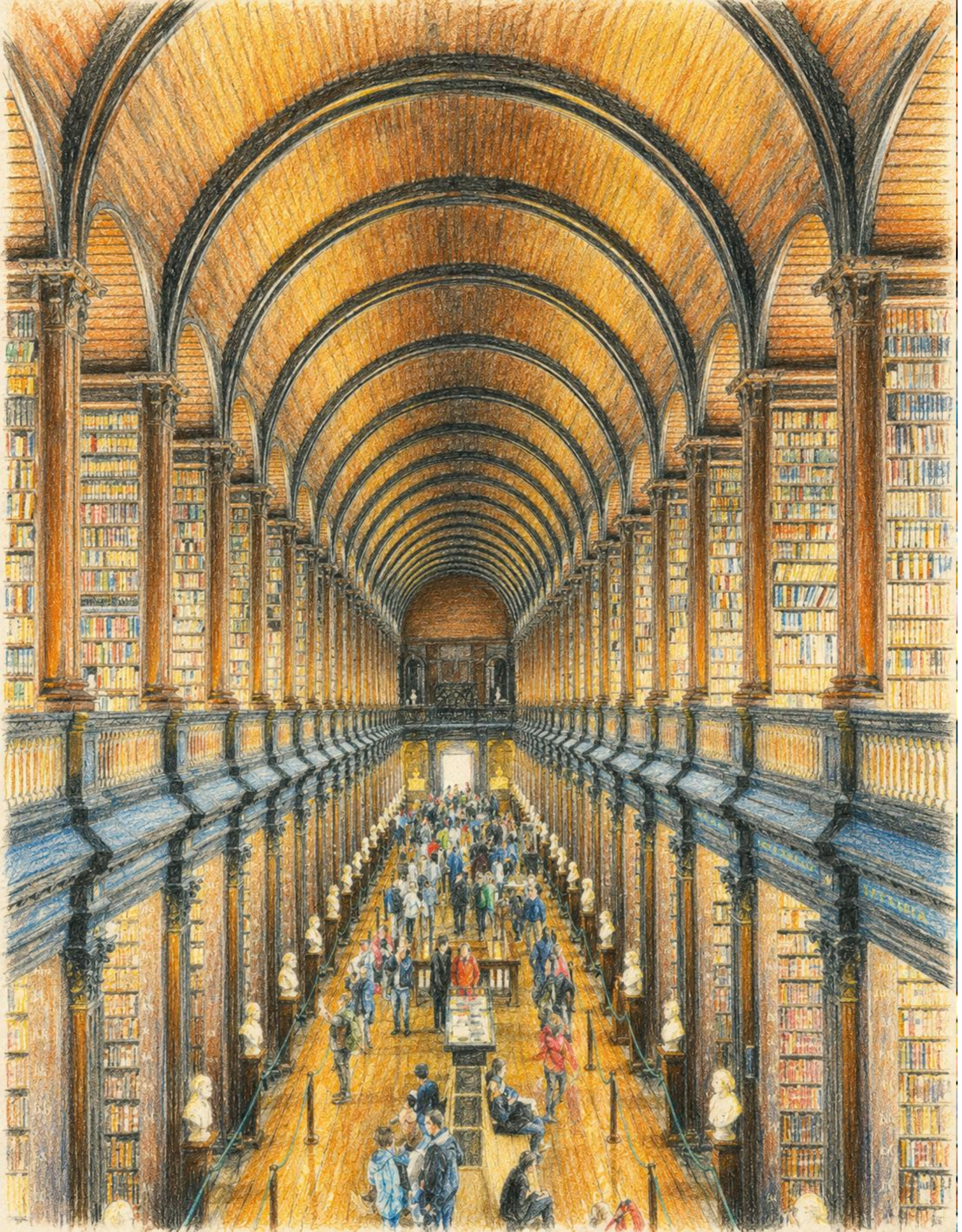
Keep fibre sensing in ISAC in the work programme!

The next frontier: fusion of fibre, wireless RF and FSO sensing



IRIS: The Network AI and Sensing Research Group





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EUCNC | 6G Summit
Málaga, Spain ▪ 2-5 June 2026

Thank you

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Taighde Éireann
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