COHERENT LASER INTERFEROMETRY · LIVE TELECOM FIBER · IONIAN SEA

Characterising Coherent Laser Interferometry on a Long-Baseline Optical Fiber for Seismic-Wave Observations

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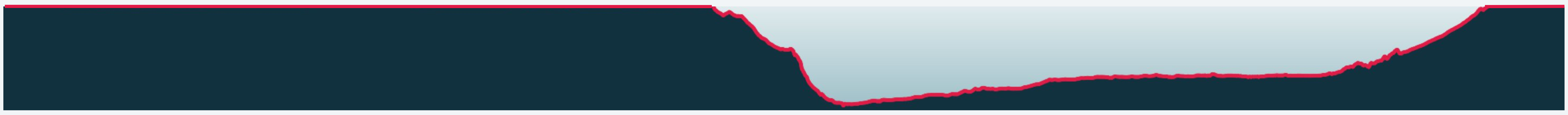


MALTA · 0 km max depth ≈ 4 km, Ionian abyssal plain CATANIA, SICILY · 260 km

01 Dense seismic coverage stops at the shoreline

The central Mediterranean's most active seismic sources, including the Malta Escarpment, the Sicily Channel Rift Zone, and the Calabrian arc lie offshore. These regions remain poorly sampled by permanent land-based stations, while ocean-bottom deployments are costly, sparse, and temporary. Telecom cables already cross these regions, providing an opportunity to extend seismic monitoring using existing infrastructure [1].

02 The measurement

An ultrastable laser is injected into one channel (Fig. 1) of the operational Malta–Catania fiber link and travels through the fiber in a round trip (Fig. 2). Vibrations, including those induced by ground motion, strain the fiber, inducing changes in the optical path length. We record the instantaneous frequency deviation of the returned light [2].

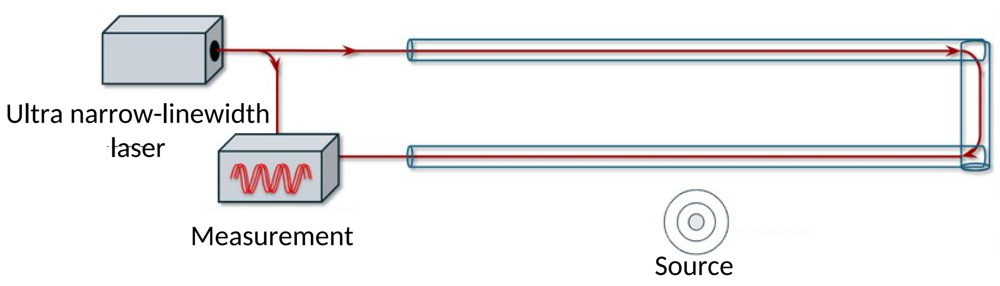


Fig. 1 — Schematic of the coherent-laser interferometry setup. A laser is wavelength-multiplexed into the fiber and undergoes deformation induced by an external source. The returned light is mixed with a reference laser to recover phase variation.

DISTINCTION FROM DAS

DAS relies on Rayleigh backscatter across thousands of channels, but signal attenuation limits its reach to a maximum of 300 km [3]. Coherent interferometry instead measures the phase of forward-transmitted light with no spatial resolution, but extending the sensing range and enabling compatibility with unidirectional components such as optical amplifiers.

03 The link

The sensing system uses a 260 km operational submarine telecom link between Malta and Sicily, spanning 260 km end-to-end and monitored continuously since September 2022.

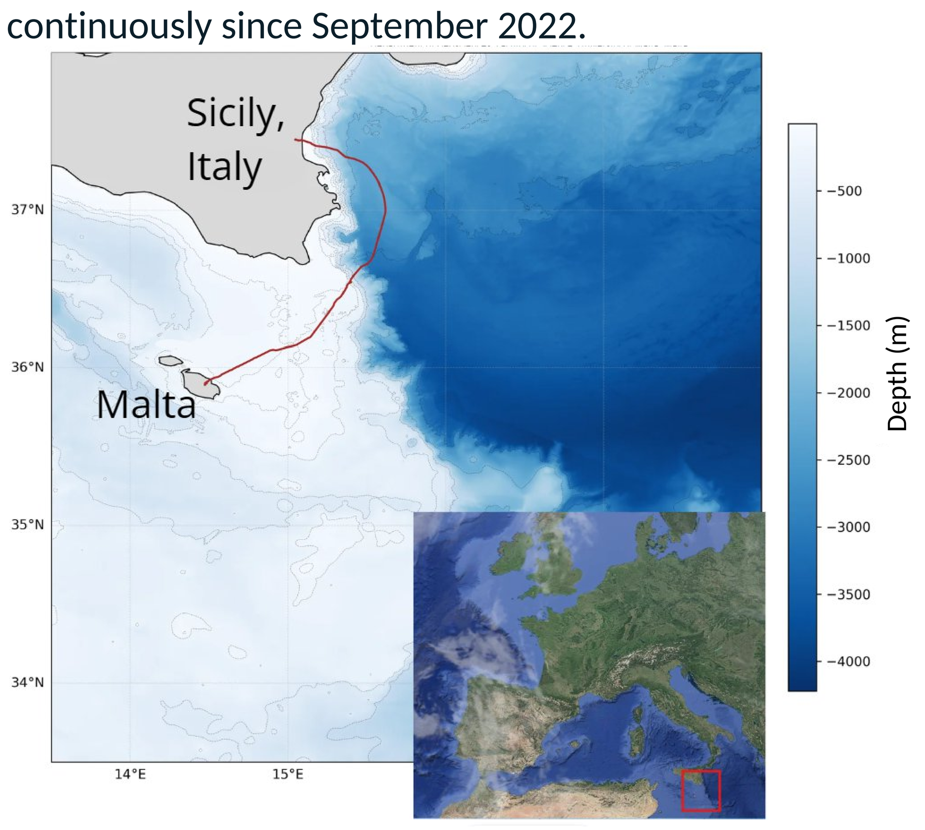


Fig. 2 — Map showing the bathymetry and location of testbed between Malta and Sicily. Inset shows the location on a regional map.

04 Observations of distinct seismic phases

Frequency deviations for ~1500 catalogued events by INGV were inspected against predicted arrival times and against nearby land seismic stations. Fig. 3 shows examples of regional and teleseismic earthquake waveforms.

2.3–8.8 magnitude range observed

3–9000 km epicentral distance

≈35% robustly identifiable (categories A–C)

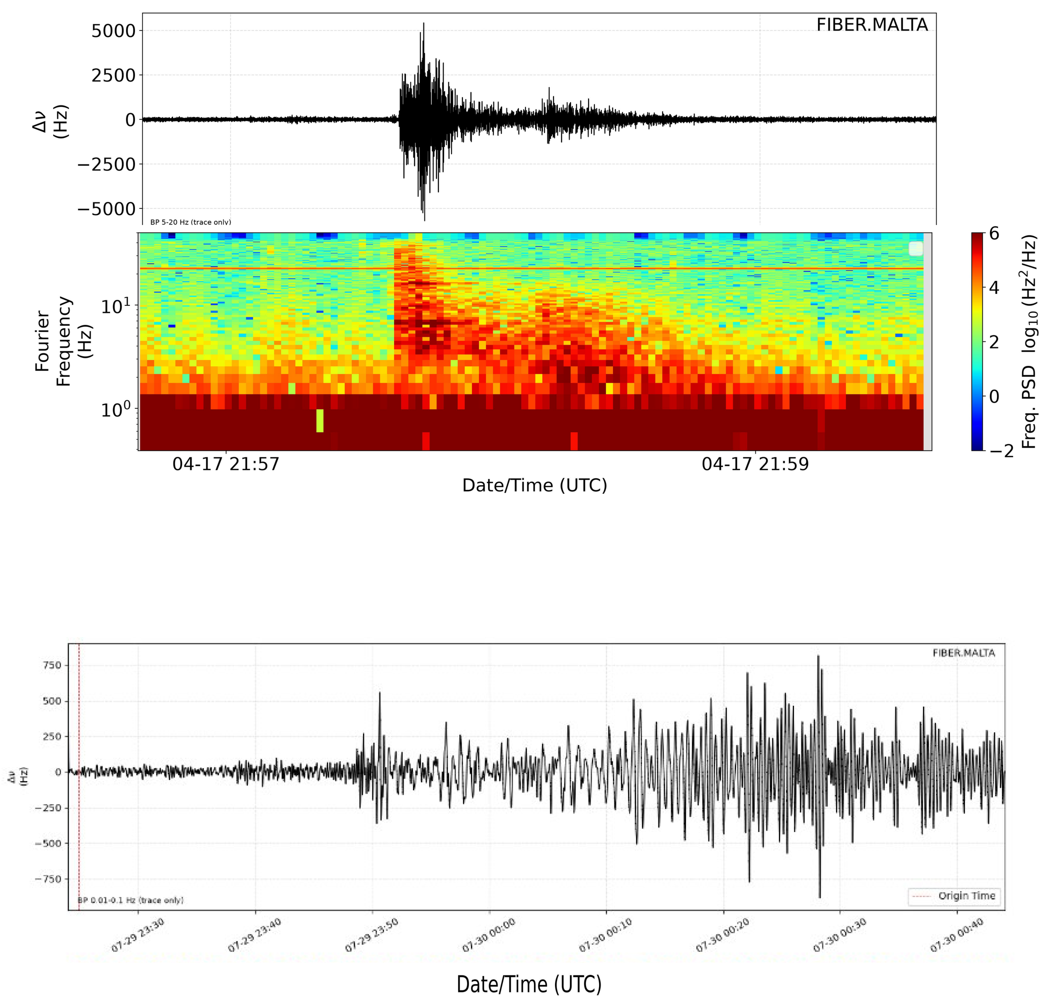
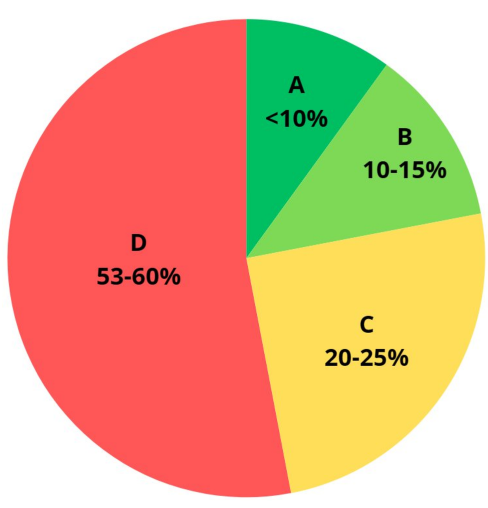


Fig. 3 — Seismic observations of earthquakes located at regional and teleseismic distances. **Top**: Time-domain fiber and corresponding spectrogram showing the response to an offshore *M*3.5 earthquake (17 April 2025) at approximately 120 km from the fiber. **Bottom**: Time-domain observation of surface waves from the M8.8 2025 Kamchatka, Russia earthquake (29 July 2025) at a teleseismic distance of around 9000 km.

05 Characterisation of magnitude-distance sensitivity

Each event was categorised according to detection quality, with the assessment based on the observability of body-wave arrivals (Fig. 4). The resulting distribution is consistent with the expected magnitude-distance dependence and provides a working detection threshold for the telecommunication link (Fig. 5).



Quality	Description
A	Clearly identifiable waveforms, detectable by STA/LTA
B	Identifiable waveforms with occasional STA/LTA false positives
C	Ambiguous signal but potentially recoverable with focused analysis near predicted arrival time
D	Not Detected

Fig. 4 — Distribution of events across classification categories. Approximately 25% of waveforms are classified as quality A or B, while quality D are predominantly low-magnitude, distant, or both.

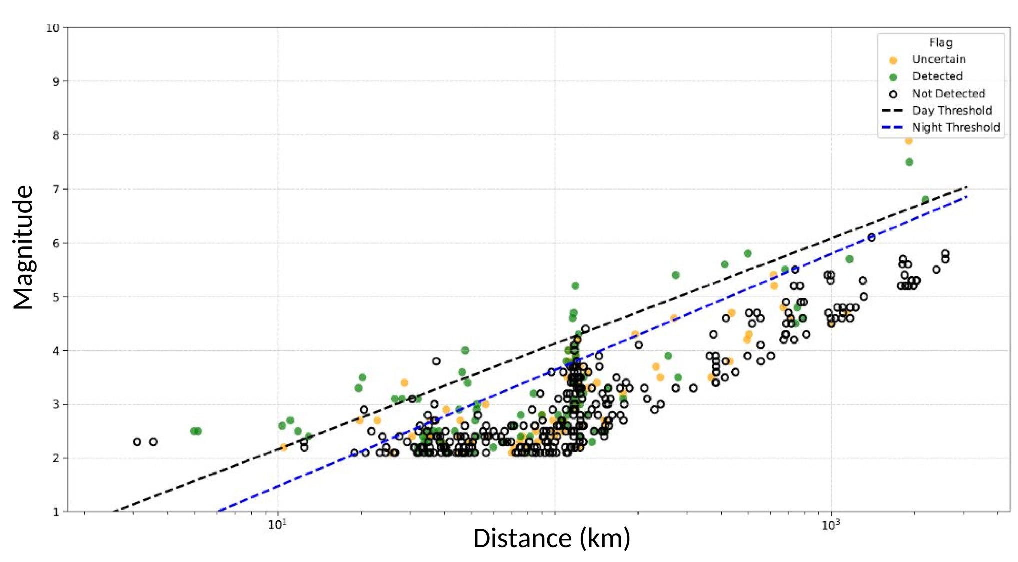


Fig. 5 — Magnitude-distance distribution of detected (A-B), uncertain (C), and not detected (D) events, happening during the day/night.

06 Noise budget sets the floor

Background noise is dominated by the secondary microseism at 0.1–0.4 Hz. At higher frequencies, weather-correlated signals and a diurnal modulation from human activity produce a higher noise floor during typical working hours (Fig. 6).

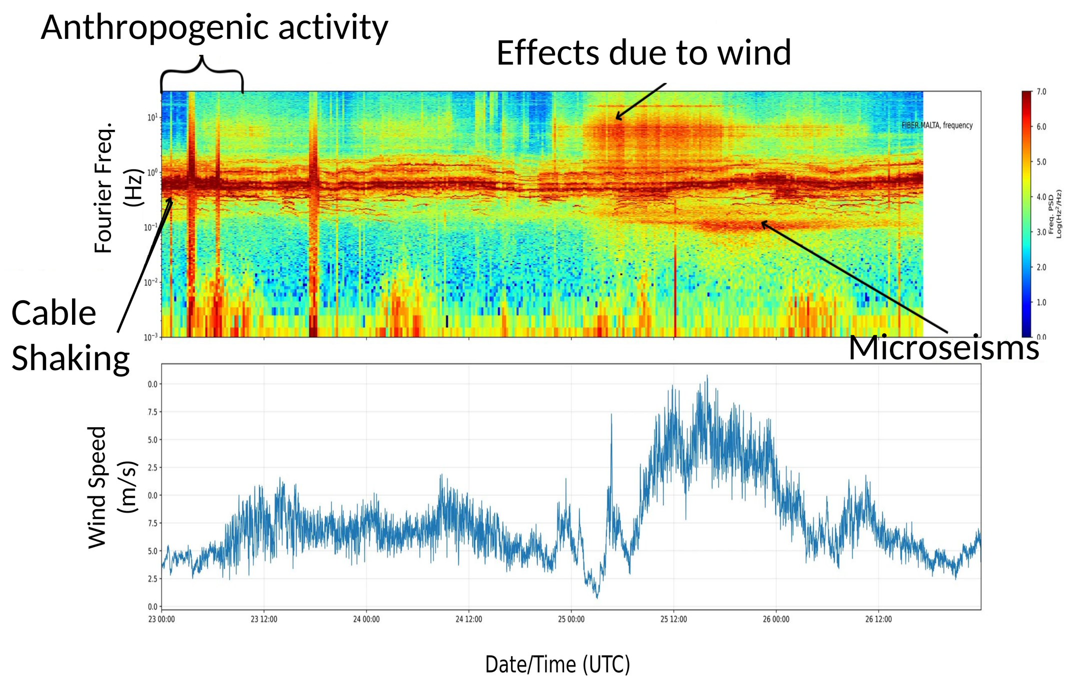


Fig. 6 — Four-day fiber frequency-deviation spectrogram with corresponding wind speed below. Discrepancies reflect spatial separation from the weather station. Distinct spectral bands include anthropogenic activity, wind-related signals, microseisms, and submarine-cable motion.

07 Conclusions

- A live 260 km submarine telecom fiber records arrival phases for magnitudes between 2.3 and 8.8, at distances of up to 9000 km.
- Body-wave phase detection is currently significantly limited by operational noise, but at least 35% of analysed events are identifiable, spanning approximately M 2.3 at 130 km to 7.9 at 1800 km.
- The fiber complements existing land-based seismic networks and extends monitoring into submarine regions.

THE OPEN PROBLEM

Can an integrated, spatially unresolved measurement reveal where and what is happening along the fiber? The response contains contributions from multiple sources. A key challenge is to separate these contributions and determine whether spatial information can be inferred indirectly, enabling weak signals to be recovered from the environmental noise.

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References: [1] G. Marra et al., “Optical interferometry-based array of seafloor environmental sensors using a transoceanic submarine cable,” Science, vol. 376

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[3] C. Fan et al., “300 km ultralong fiber optic das system based on optimally designed bidirectional EDFA Relays,” Photonics Research, vol. 11, no. 6, May 2023.

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