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Earthquake Detection Using Submarine Cables

Pierre Mertz
Fellow
Infinera Corporation

1/16/2023

PTC 23

Motivation

Earthquake Early Warning (EEW) system -> Tsunami

NATURAL HAZARDS

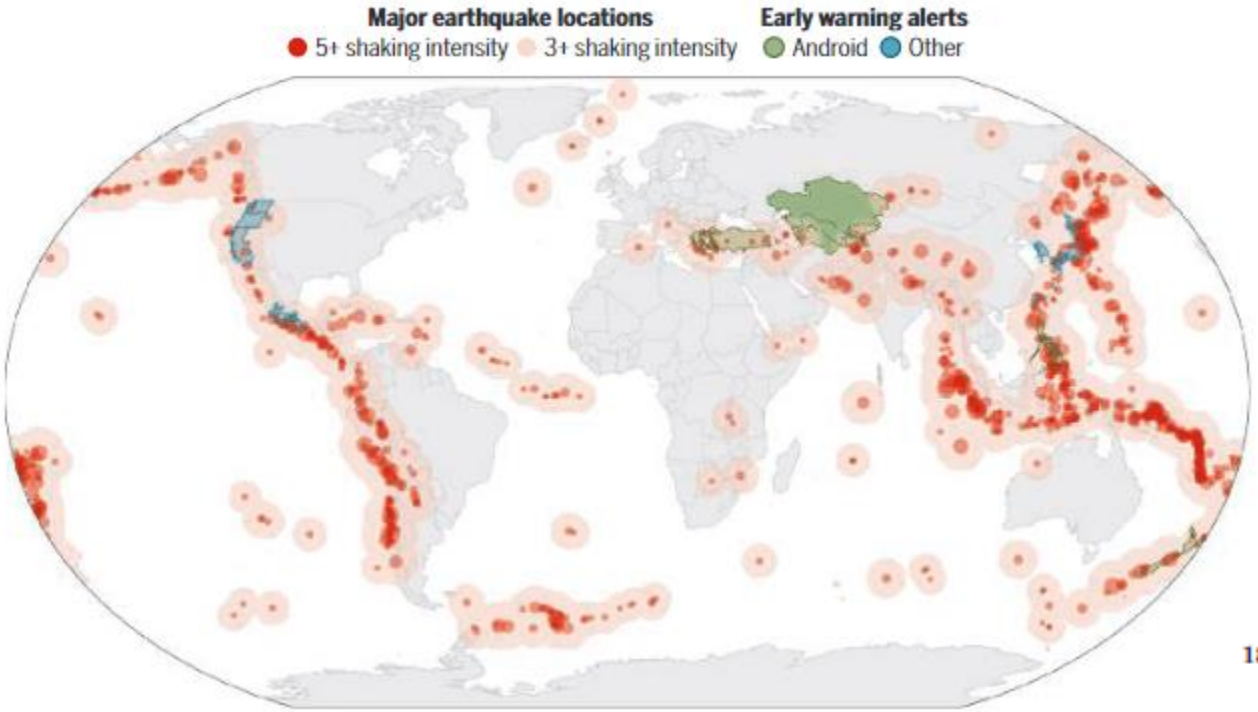
Global growth of earthquake early warning

Public-private partnerships provide a method for vastly expanding sensor networks

By **Richard M. Allen**[1,2] *and* **Marc Stogaitis**[2]

figure) is one example of such a public-private partnership and how a massive observ-

Algorithms to characterize the earthquake source must process large volumes of data



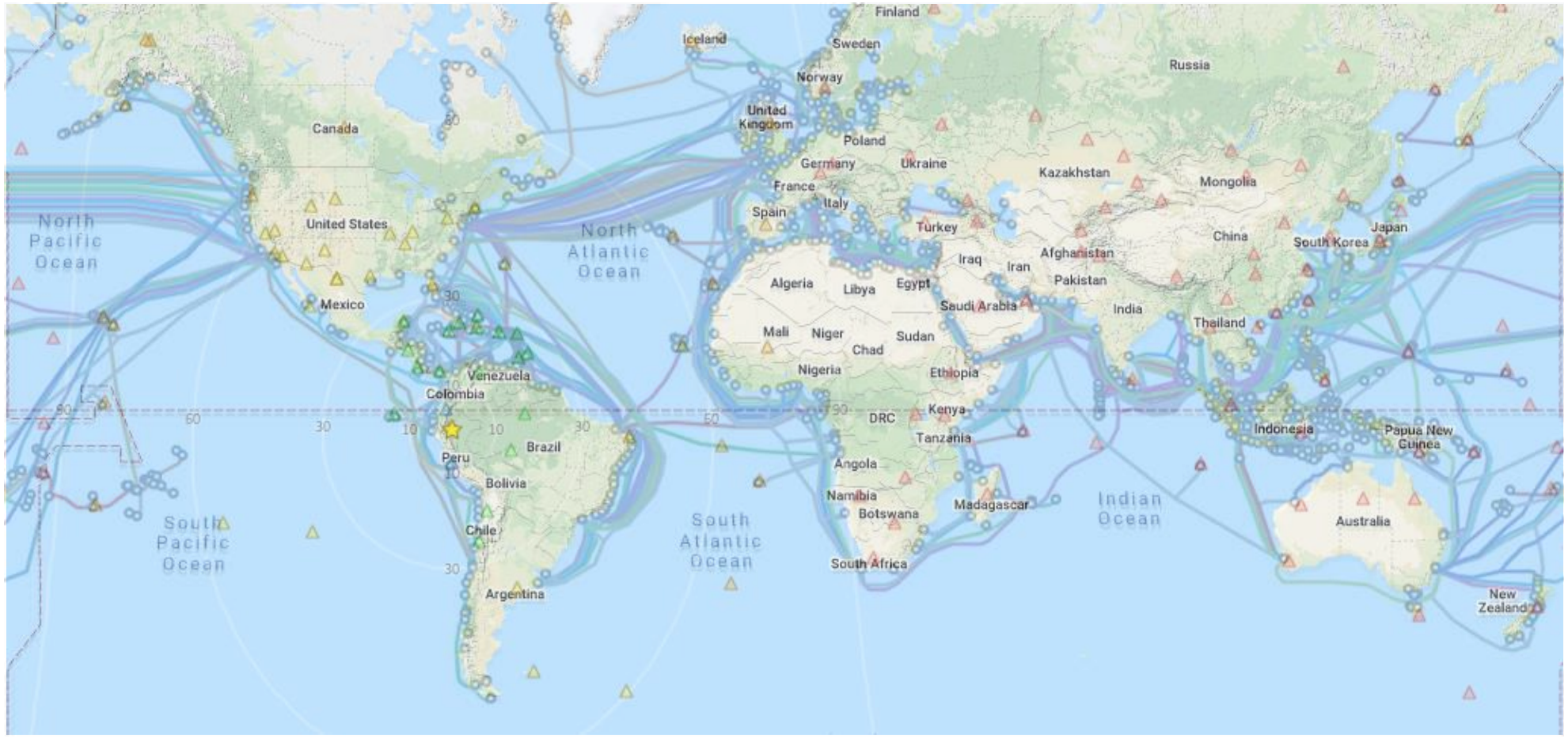
Seismometers are land based

- Seismometers that appear in the ocean are actually on islands
- Earthquakes in ocean:
  - Every 200km between the earthquake and a sensor results in a one minute delay in the warning

From https://ds.iris.edu/wilber3

Seismometers are land based

- Overlay of submarine cable map on seismometer map
- Desirable to use existing communication infrastructure to detect seismic events
  - Subsea cables have repeaters every 50-100km. Using a subsea repeater as a sensor can reduce the distance from the Earthquake to the nearest sensor.

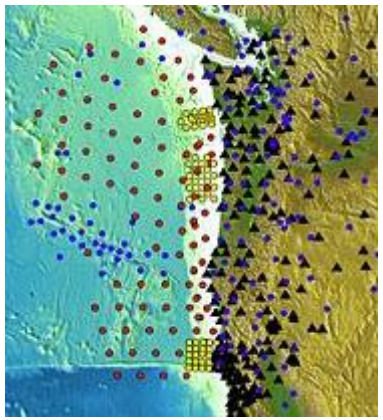


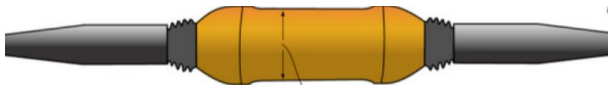
From https://www.submarinecablemap.com/

Ocean-Bottom Seismometer -> Repeater

From Wikipedia

OBS	Repeater
Rests on sea floor	Rests on sea floor
Stores data for period of time	SOP data created in SLTE equipment
Bring to surface to retrieve data	Stream data in real time
Battery powered	Shore powered
2D Array	1D Array





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Fiber Sensing Techniques

Fiber Sensing Techniques

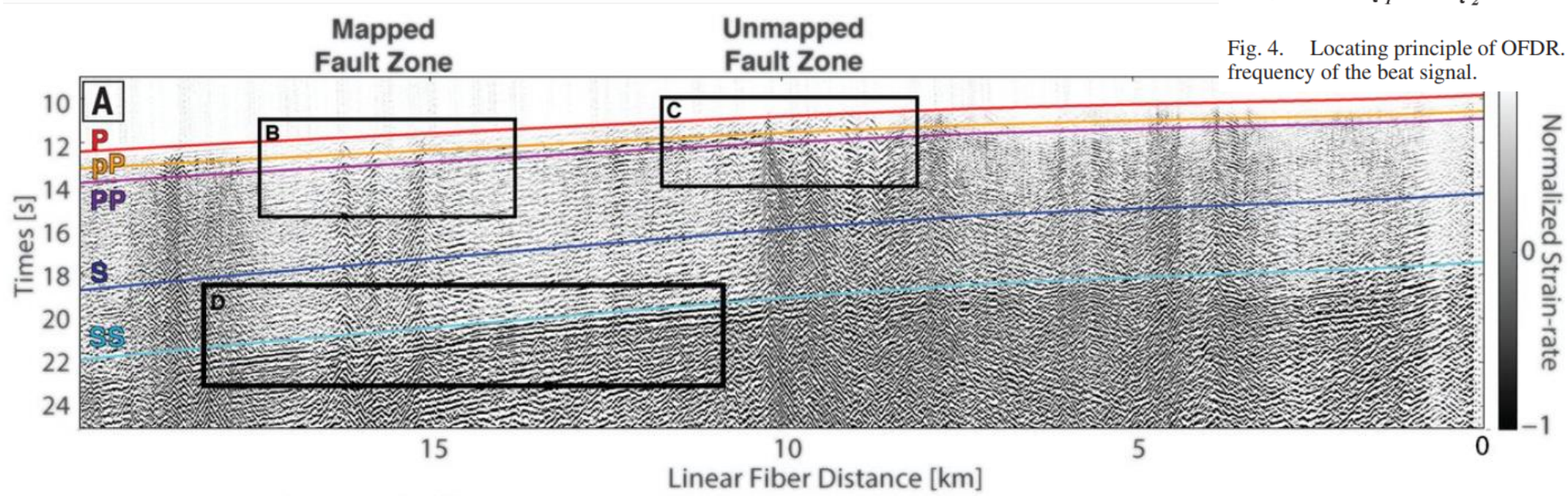
Technique	Frequency	Resolution/ Max Distance	Sensitivity	Telecom compatibility
Distributed Acoustic Sensing (DAS)	kHz	1 m / 50 km	★★★★	Limited to 1st span. Requires high power (no traffic)
State of Polarization (SOP)		10,000 km / 10,000 km	★★	Transponder compatible (today)
Phase	5 Hz	50 km / 10,000 km	★★★	Ultra stable laser
Michelson Interferometer	100 Hz	10 m / 20 km	★★	Use 2 fiber pairs.
SOP-OTDR	5 Hz	50 km / 10,000 km	★★	Transponder compatible SOP detection circuit needed

Distributed Acoustic Sensing (DAS)

Illuminating seafloor faults and ocean dynamics with dark fiber distributed acoustic sensing

NATHANIEL J. LINDSEY, T. CRAIG DAWE, AND JONATHAN B. AJO-FRANKLIN Authors Info & Affiliations

SCIENCE • 29 Nov 2019 • Vol 366, Issue 6469 • pp. 1103-1107 • DOI: 10.1126/science.aay5881



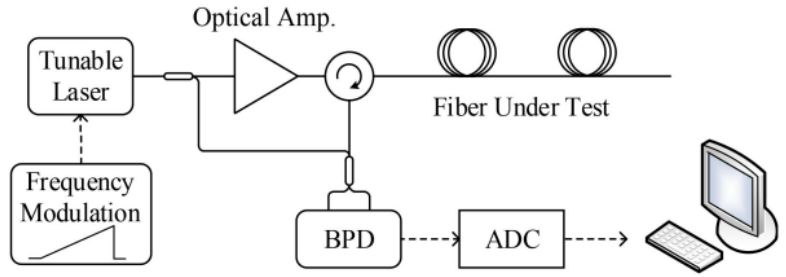


Fig. 3. OFDR configuration.

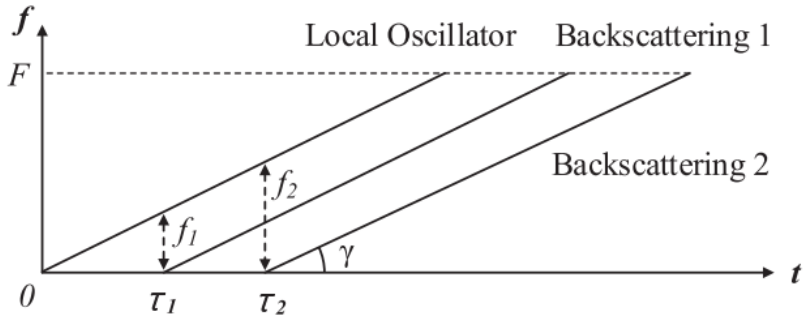


Fig. 4. Locating principle of OFDR. The time delay of RBS is mapped to the frequency of the beat signal.

State of Polarization (SOP) of data channel

Polarization sensing using submarine optical cables

ANTONIO MECOZZI[1,*], MATTIA CANTONO[2], JORGE C. CASTELLANOS[3], VALEY KAMALOV[2], RAFAEL MULLER[2], AND ZHONGWEN ZHAN[3]

[1] Department of Physical and Chemical Sciences, University of L'Aquila, L'Aquila 67100, Italy
[2] Google Inc., USA
[3] Seismological Laboratory, California Institute of Technology, Pasadena, USA
[*] Corresponding author: antonio.mecozzi@univaq.it

Compiled March 4, 2021

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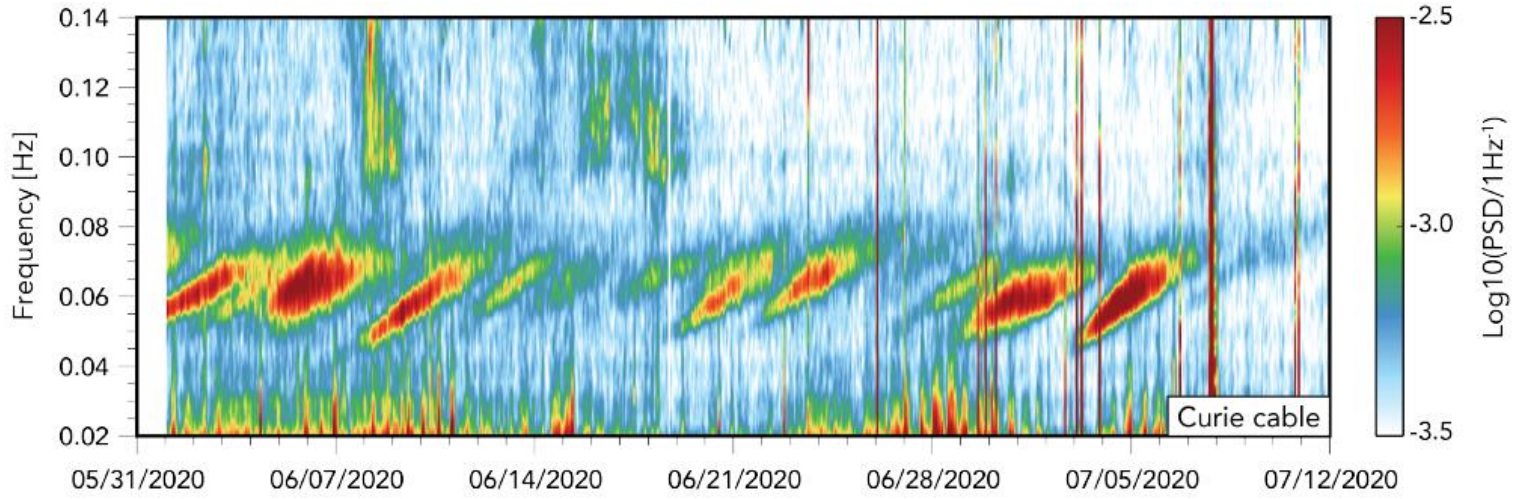
12 days, ocean swells from storms



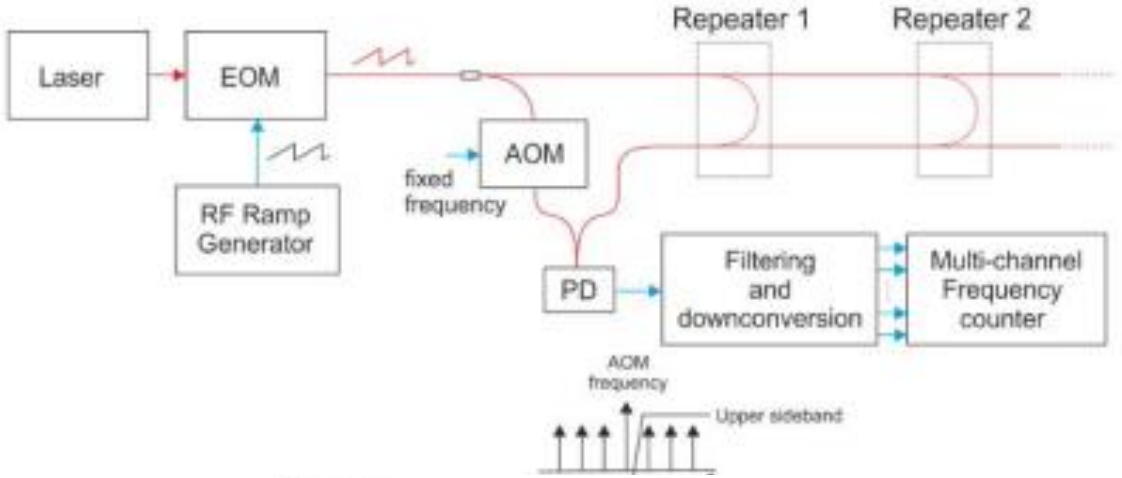
- SOP streamed from Coherent transponders on both sides
  - Integrated SOP variation across cable
  - Difficult to Localize

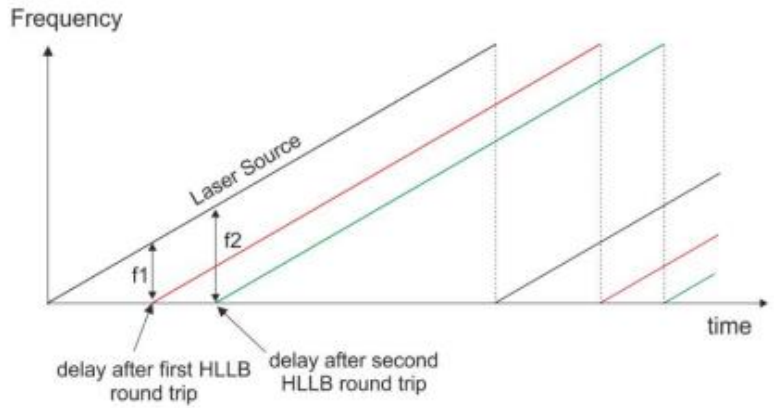
Phase Sensing

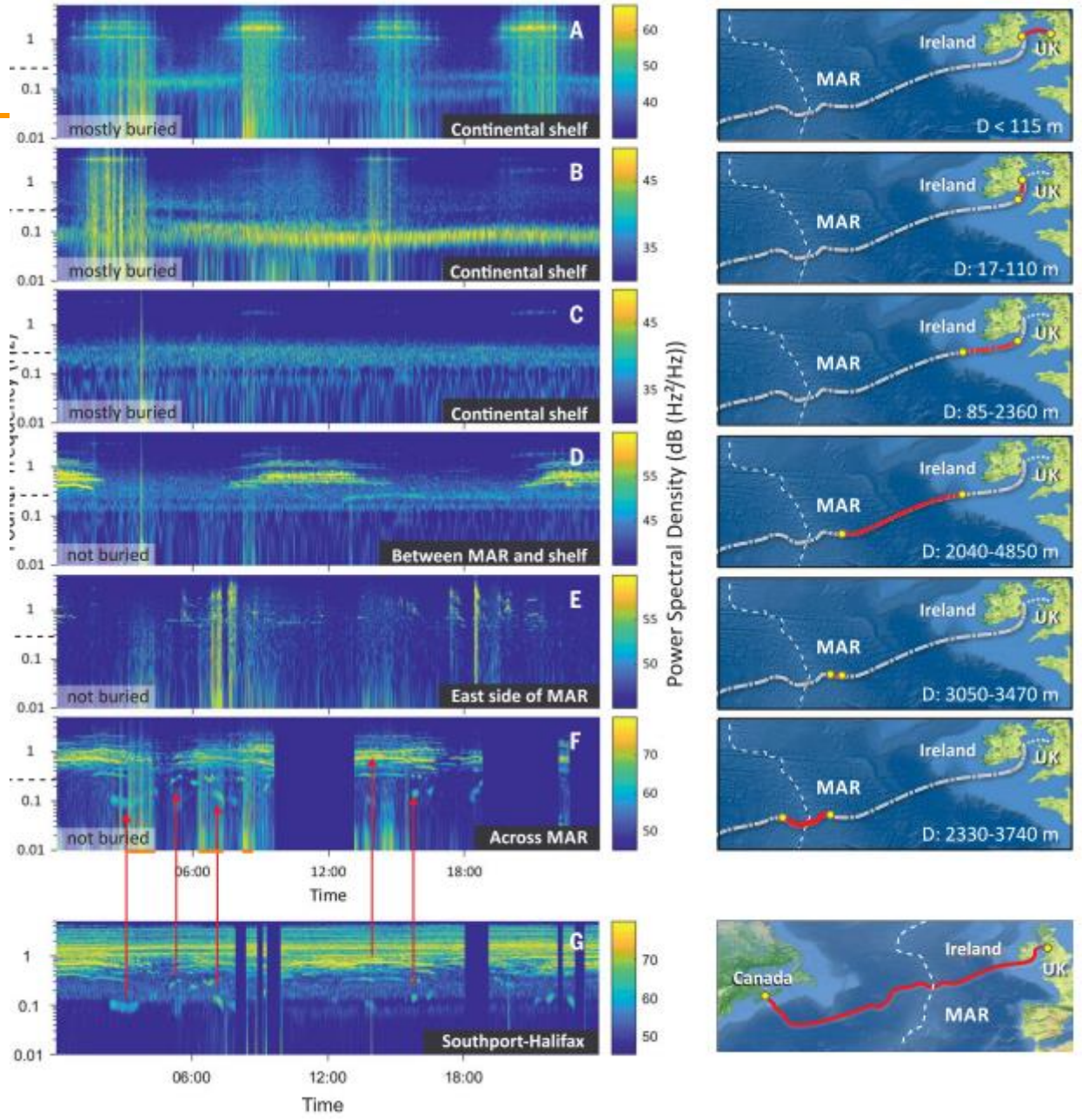
GEOPHYSICS

Optical interferometry–based array of seafloor environmental sensors using a transoceanic submarine cable

G. Marra[1*], D. M. Fairweather[2], V. Kamalov[3], P. Gaynor[1], M. Cantono[3], S. Mulholland[1], B. Baptie[4], J. C. Castellanos[3], G. Vagenas[1], J.-O. Gaudron[1], J. Kronjäger[1], I. R. Hill[1], M. Schioppo[1], I. Barbeito Edreira[1], K. A. Burrows[1], C. Clivati[5], D. Calonico[5], A. Curtis[2]







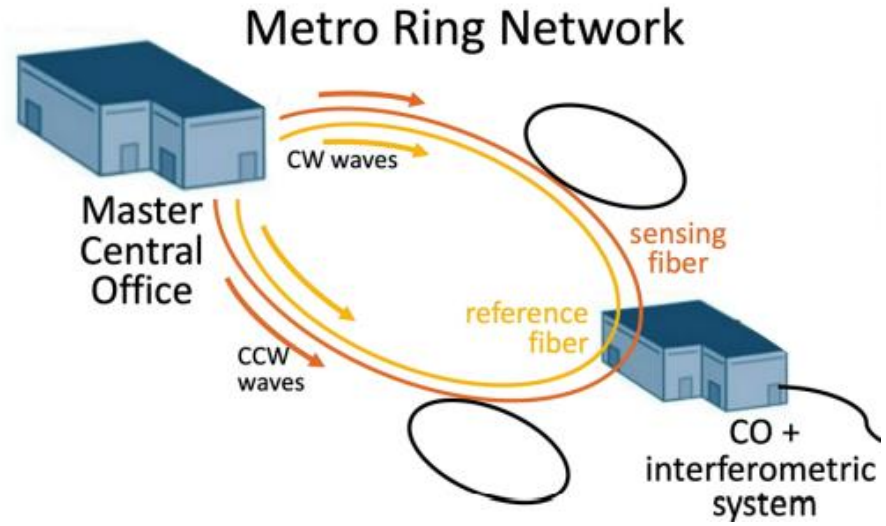
Michelson Interferometer

Mo4A.4 European Conference on Optical Communication (ECOC) 2022 © Optica Publishing Group 2022

Sensing Applications in Deployed Telecommunication Fiber Infrastructures

Pierpaolo Boffi

- Use 2 fibers, one as reference arm in Michelson Interferometer
- Phase sensitivity without ultra-stable lasers



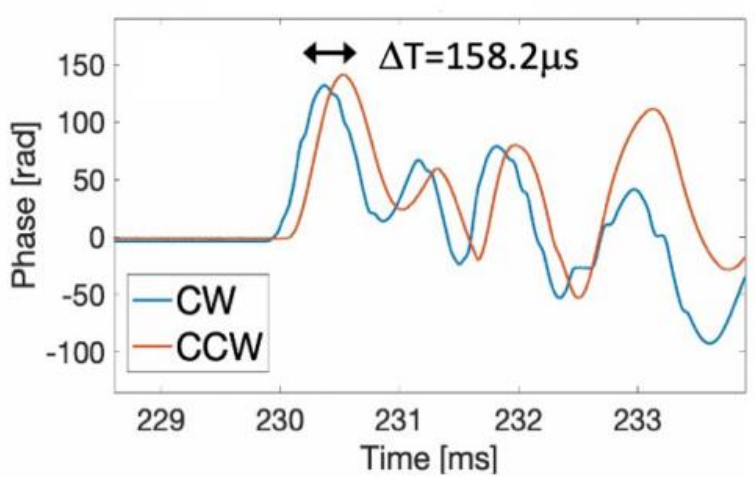


Fig. 5: Localization after 1 km of the onset of a dynamic event through the measure of the time delay in the 32-km long deployed ring.

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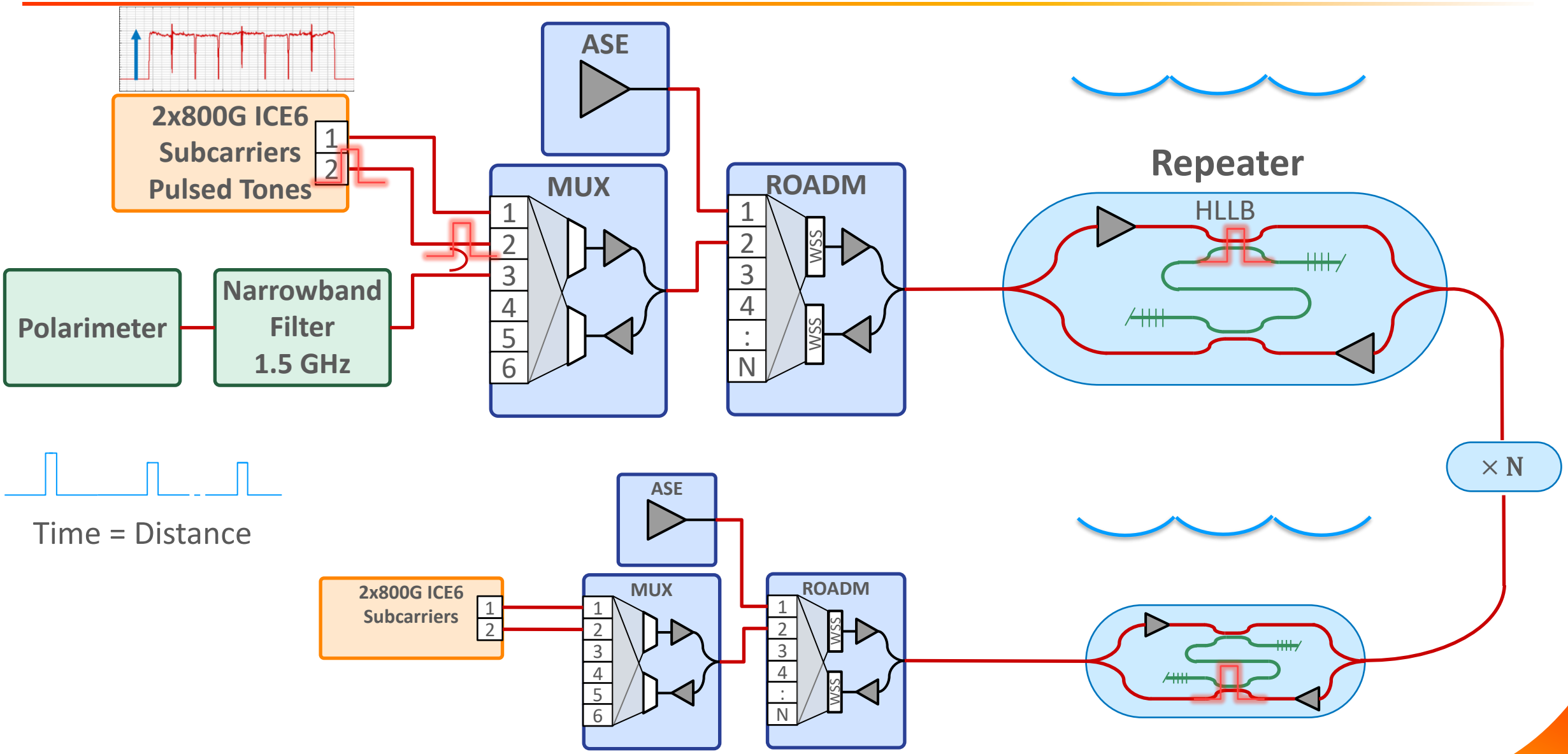
SOP-OTDR

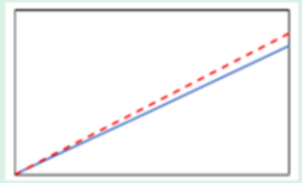
Experimental Setup



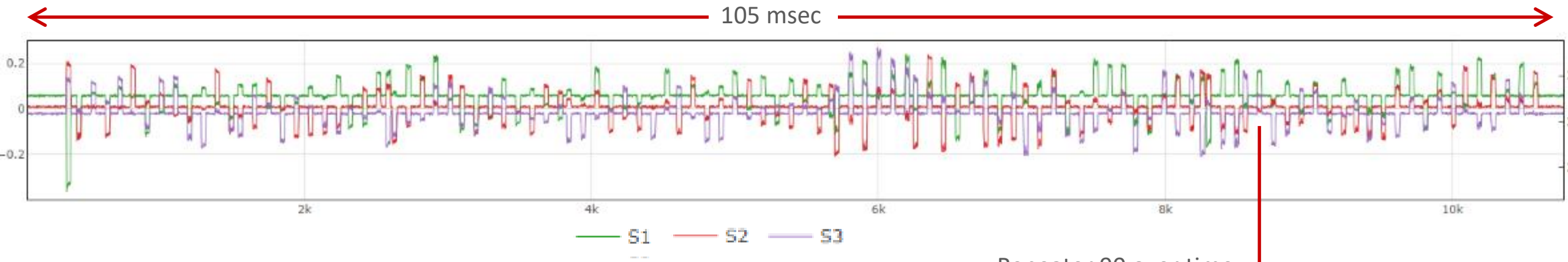
Reflected Pulses. SOP per repeater

Cable Spec.

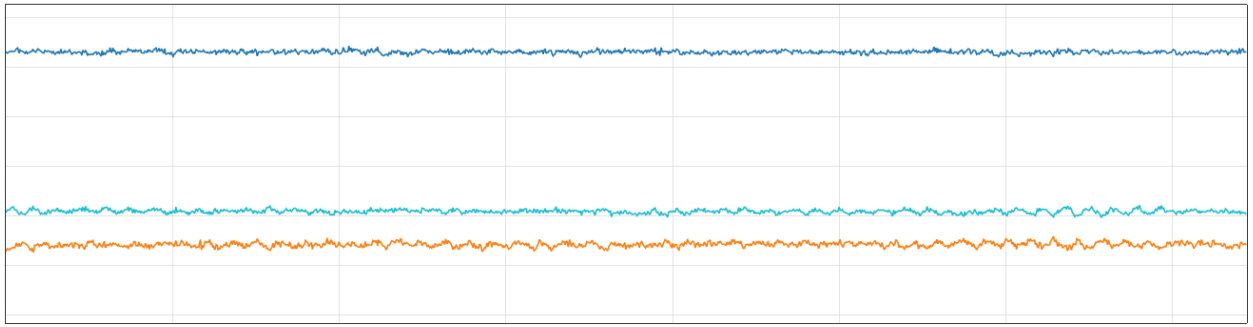
- 10,200 km
- LA, D+ fiber
- RFS August 2018
- 8 fiber pairs
- Design capacity **13.5 Tb/s** per fiber pair



- 300 μsec pulses @ 105 msec intervals
- Each SOP is from aggregated round trip to repeater
- 110 reflections per pulse from repeaters



Repeater 90 over time



- Proof of Concept trial
  - Data stored in database
  - Post processed

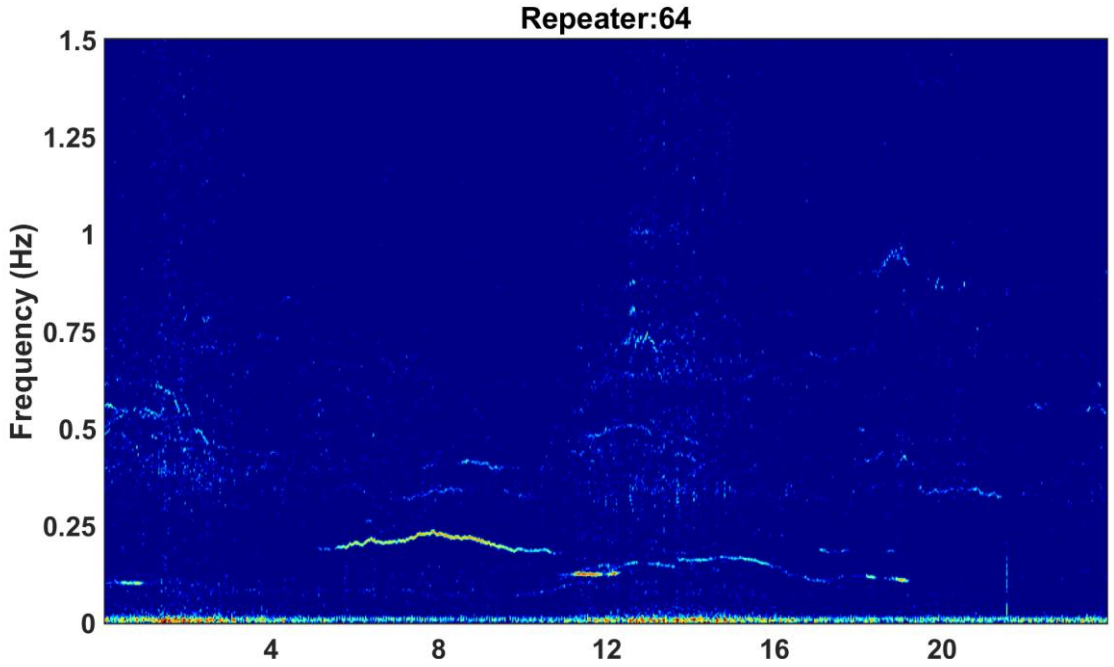
Polarization subtraction

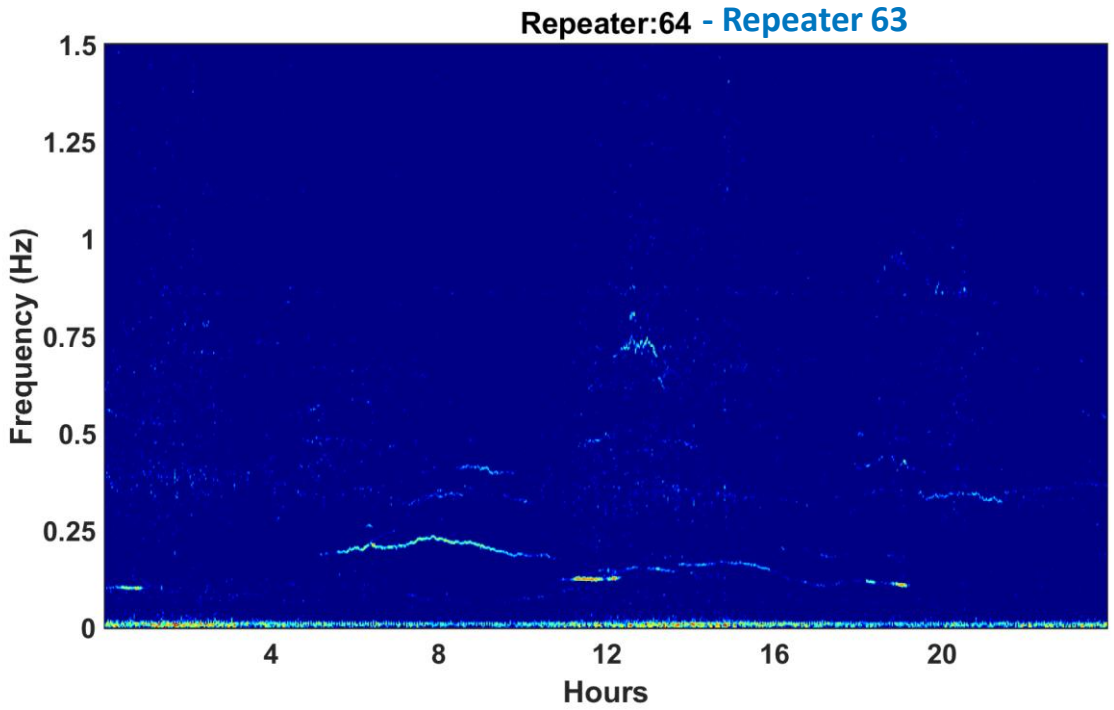
- Desired to measure SOP variation in single span between repeaters
  - Subtract prior repeater's SOP
  - Scaling and subtraction

$$S^{n'} = \left(\frac{S_1^n}{S_0^n} \quad \frac{S_2^n}{S_0^n} \quad \frac{S_3^n}{S_0^n}\right) - \left(\frac{S_1^{n-1}}{S_0^{n-1}} \quad \frac{S_2^{n-1}}{S_0^{n-1}} \quad \frac{S_3^{n-1}}{S_0^{n-1}}\right)$$

  - Assumes small polarization variations
- Spectrograms Using Polarization Subtraction
  - Some spectral features clean up
  - While some remain

- Adding SOP-OTDR to Santiago will enable cleaner signals



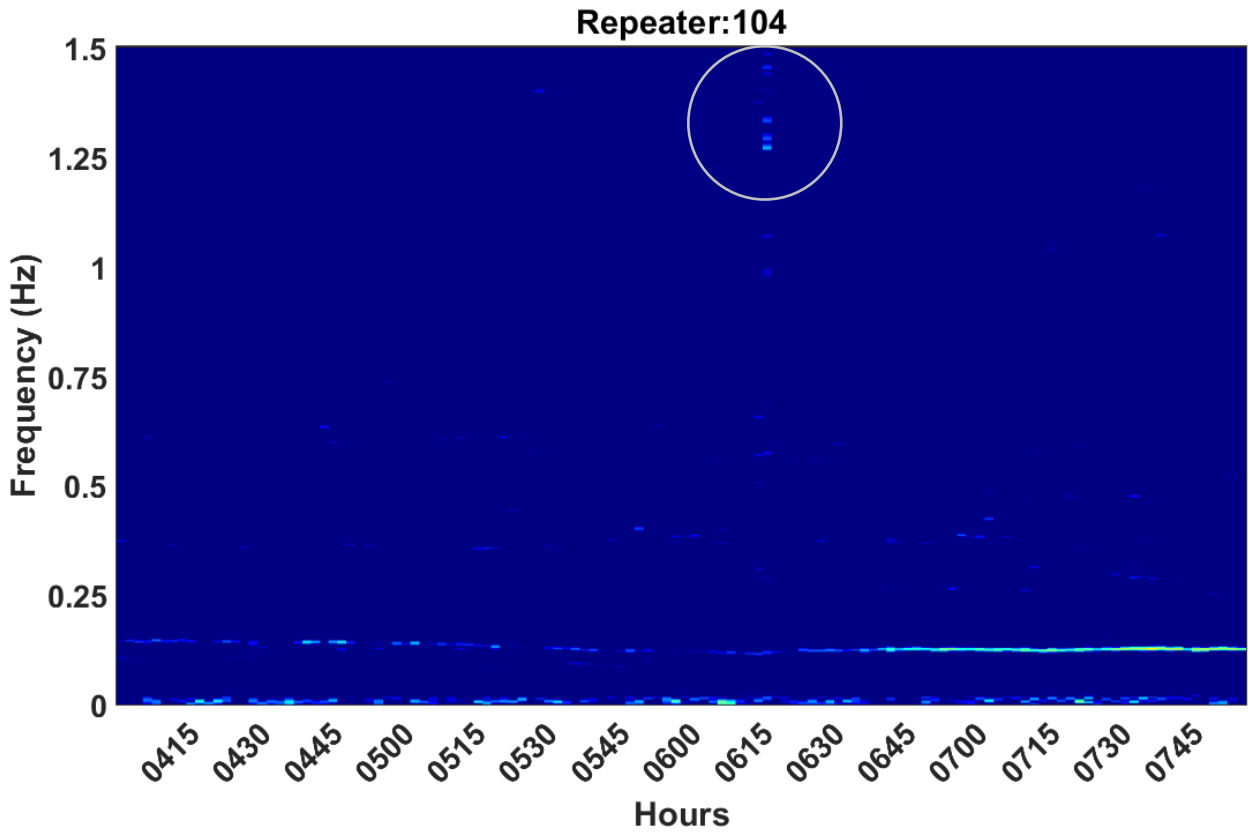


Earthquake on 2/22/2022

Wilber 3: Select Stations

2022-02-22 mww6.0 Jujuy Province, Argentina

Latitude	Longitude	Date	Depth	Magnitude	Description
22.6625° S	66.2673° W	2022-02-22 06:12:49 UTC	242.29 km	mww6.0	Jujuy Province, Argentina



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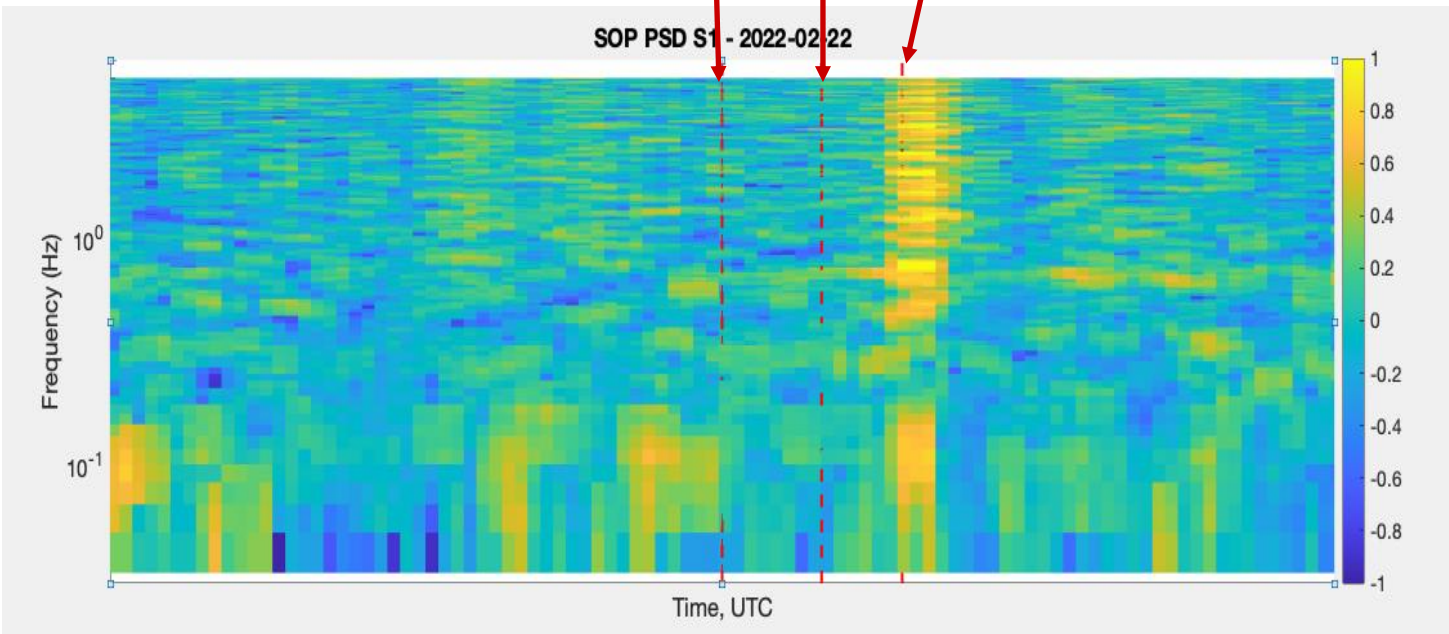
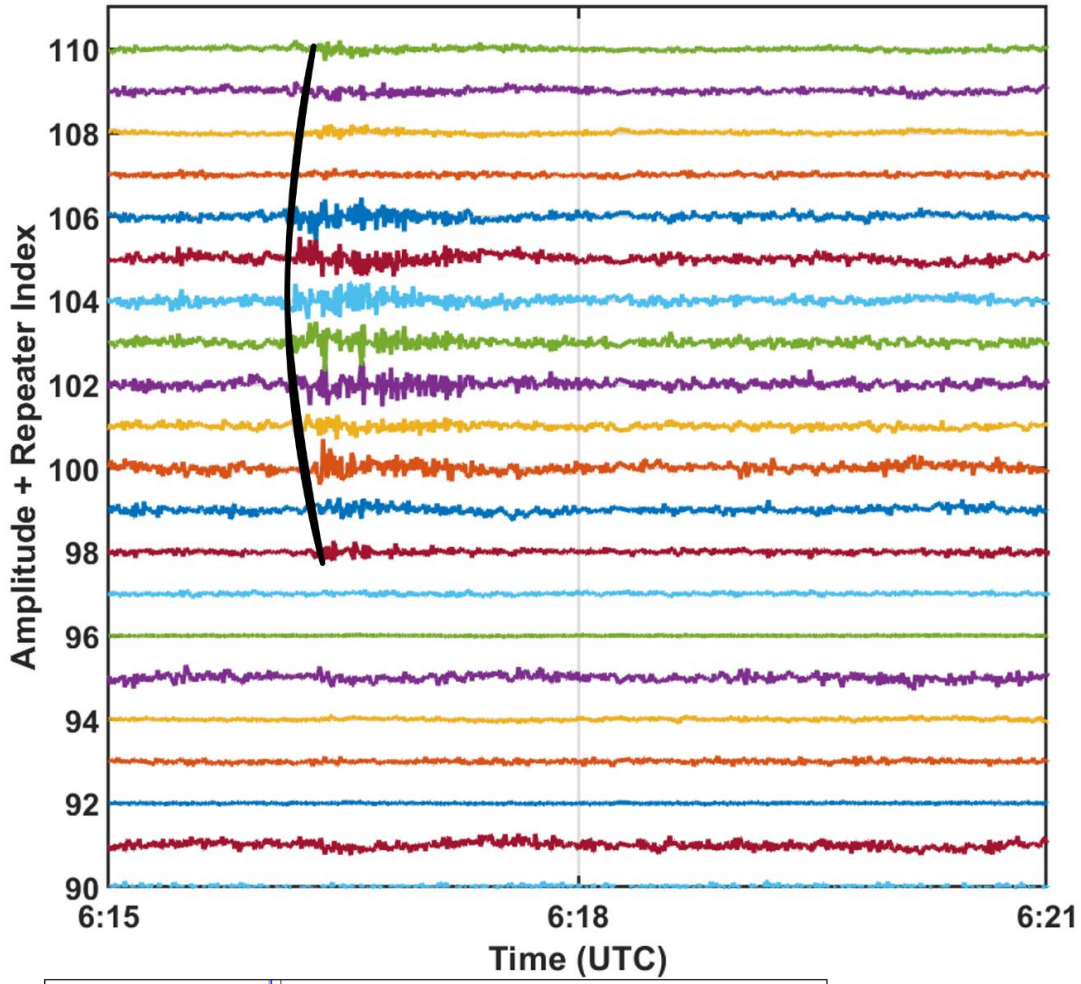
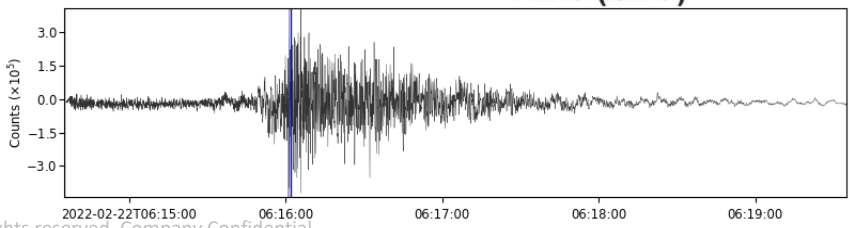


Zhongwen Zhan, Caltech

Earthquake on 2/22/2022





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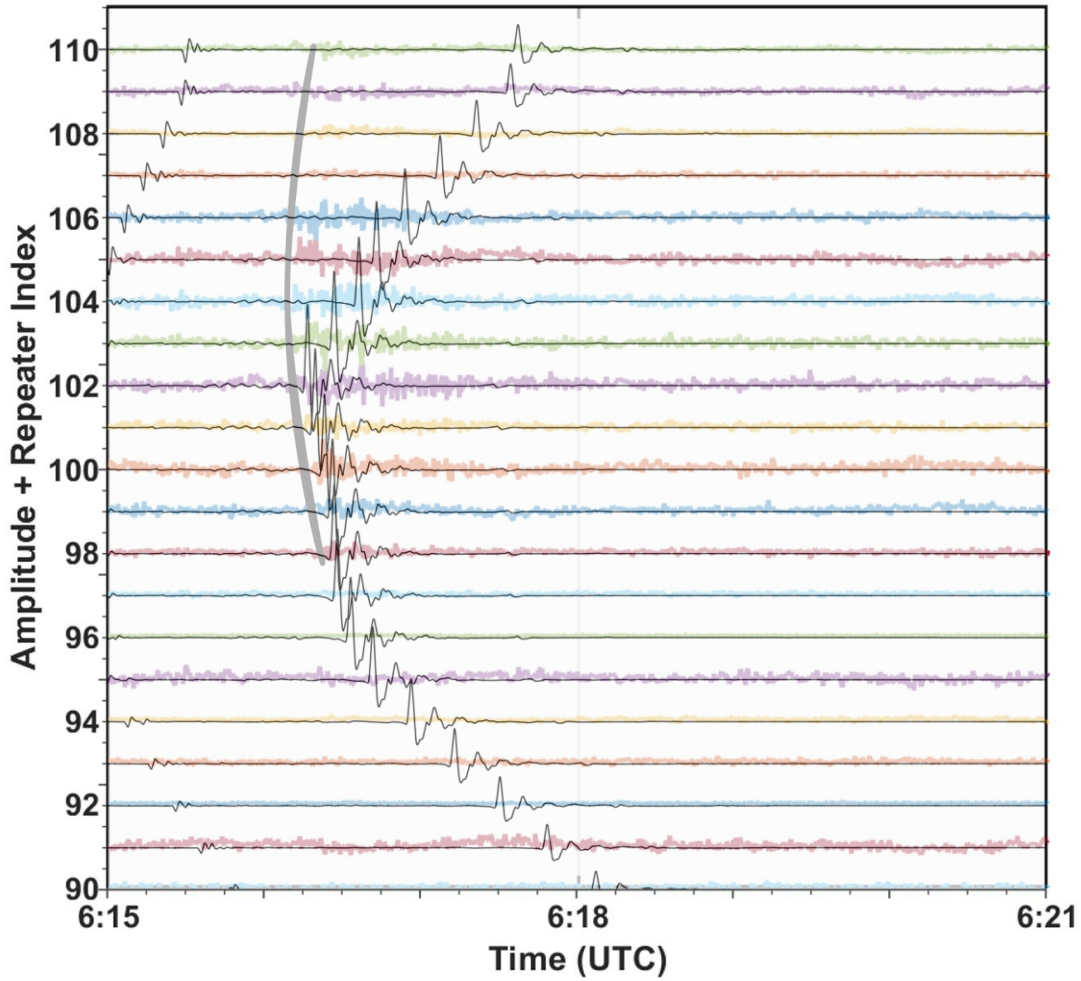
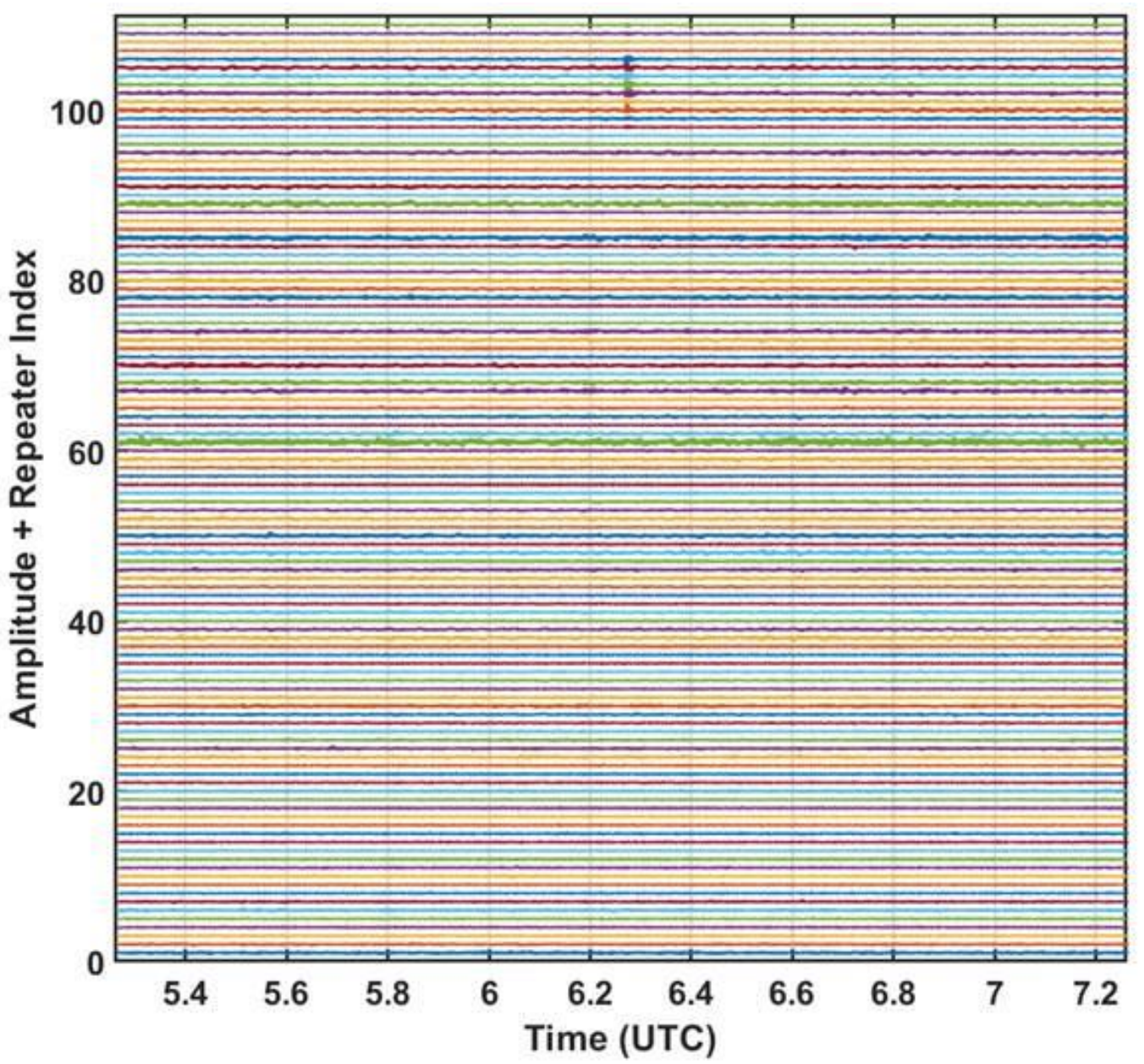


- Simulation assuming a 1-D and laterally homogeneous earth
- More realistic simulations to come

Jorge Castellanos, Google

Earthquake on 2/22/2022



Optical Fiber Networks for Environmental Sensing

September 2022

Valey Kamalov, Google

ECOC 2022, Mo4A.3

What's next? Get the conversation started

Cable Owners

Scientific Community

Regulators

National Security

- Most of subsea wet plants are able to sense environmental effects. It is a cable owner obligation / goodwill to report earthquake?
- Cable safety - improvements through monitoring
- An opportunity to start global warming induced temperature variation monitoring - is it scientific interest or modern world requirement?
- Data Sharing Practices for the creation of a global platform
- Call for Optical Environmental Fiber Networks
- Subsea and Terrestrial
- DAS, SOP, Phase, and Voltage based
- Collaboration between private and public institutions with government regulations and public warning

Thank You