

SUNET

Sensing on the Sunet Line System

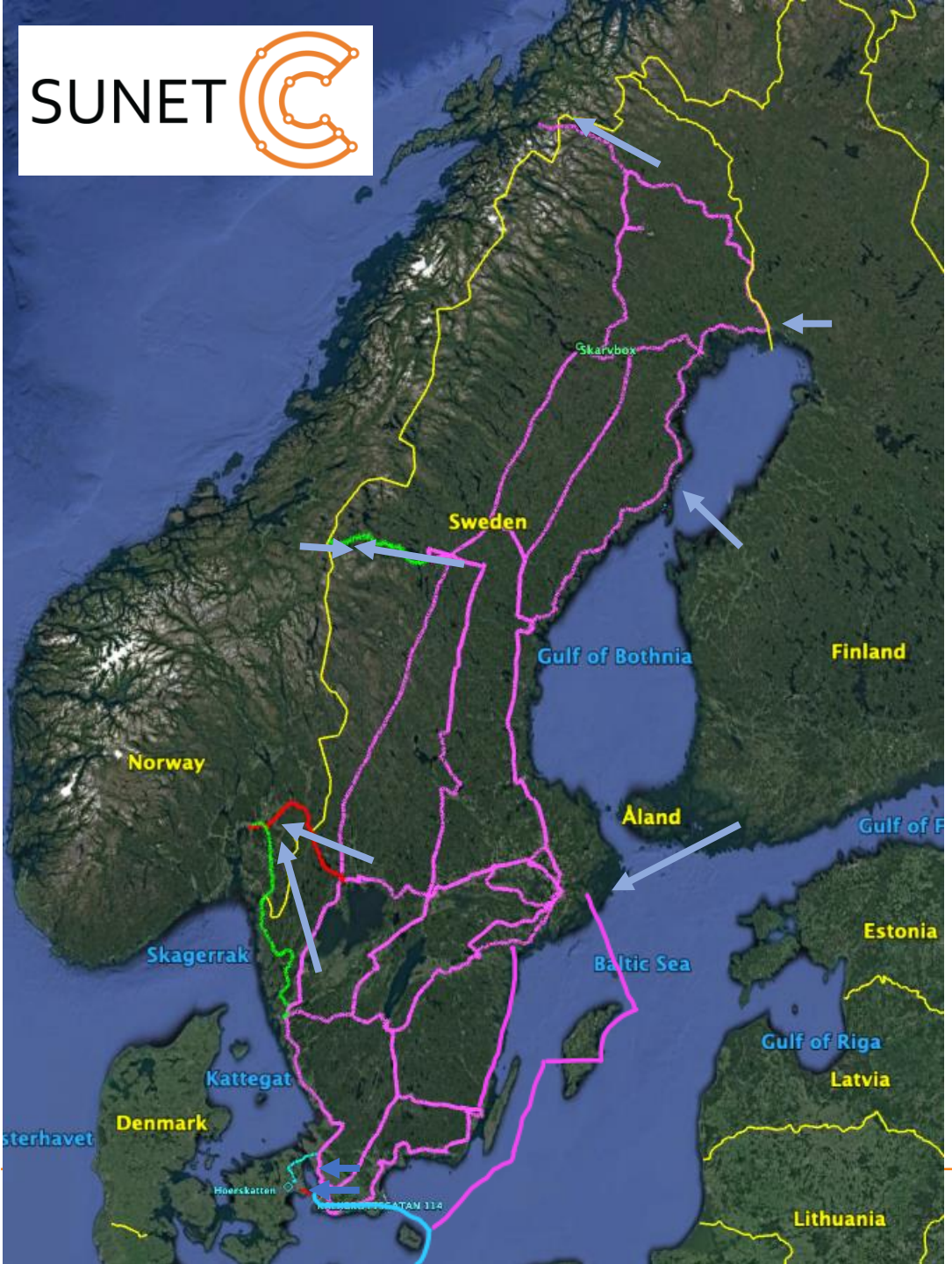
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Network Architect

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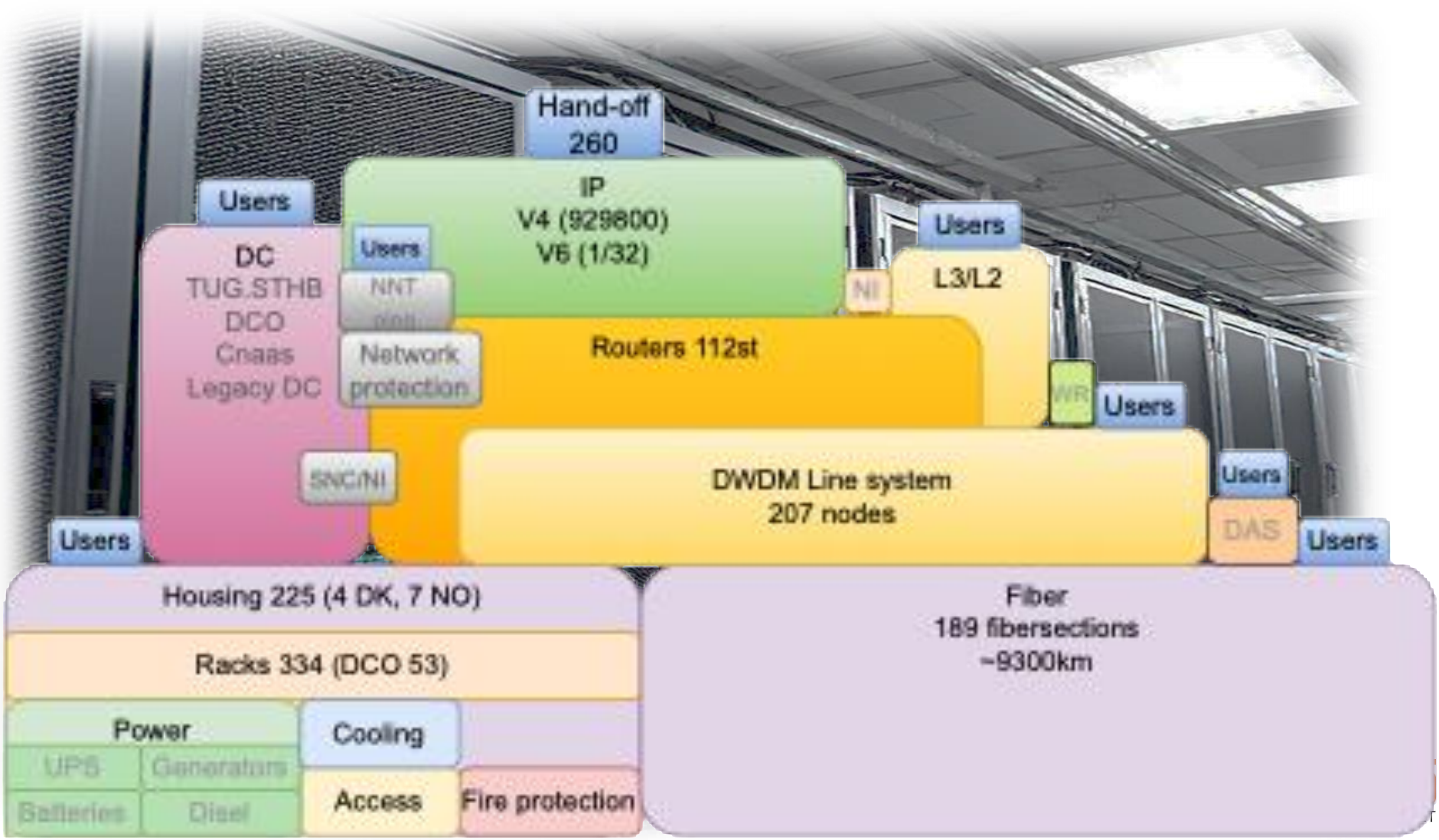
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Nationwide network: 9,300 km

- Three fiber routes to every region,
  - providing good redundancy and availability.
- Customers can connect to our equipment in ~25 cities,
  - either “in town” or at the university.
  - Customers outside these cities can connect via other regional networks.
- Current cross-border connections:
  - Kiruna – Narvik
  - Kalix – Kemi
  - Karlstad – Oslo – Gothenburg
  - Malmö – Copenhagen – Mörarp
  - Östersund – Trondheim
  - Vaasa – Umeå
  - Åbo (Turku) – Stockholm
  - Lund – Bornholm – Germany

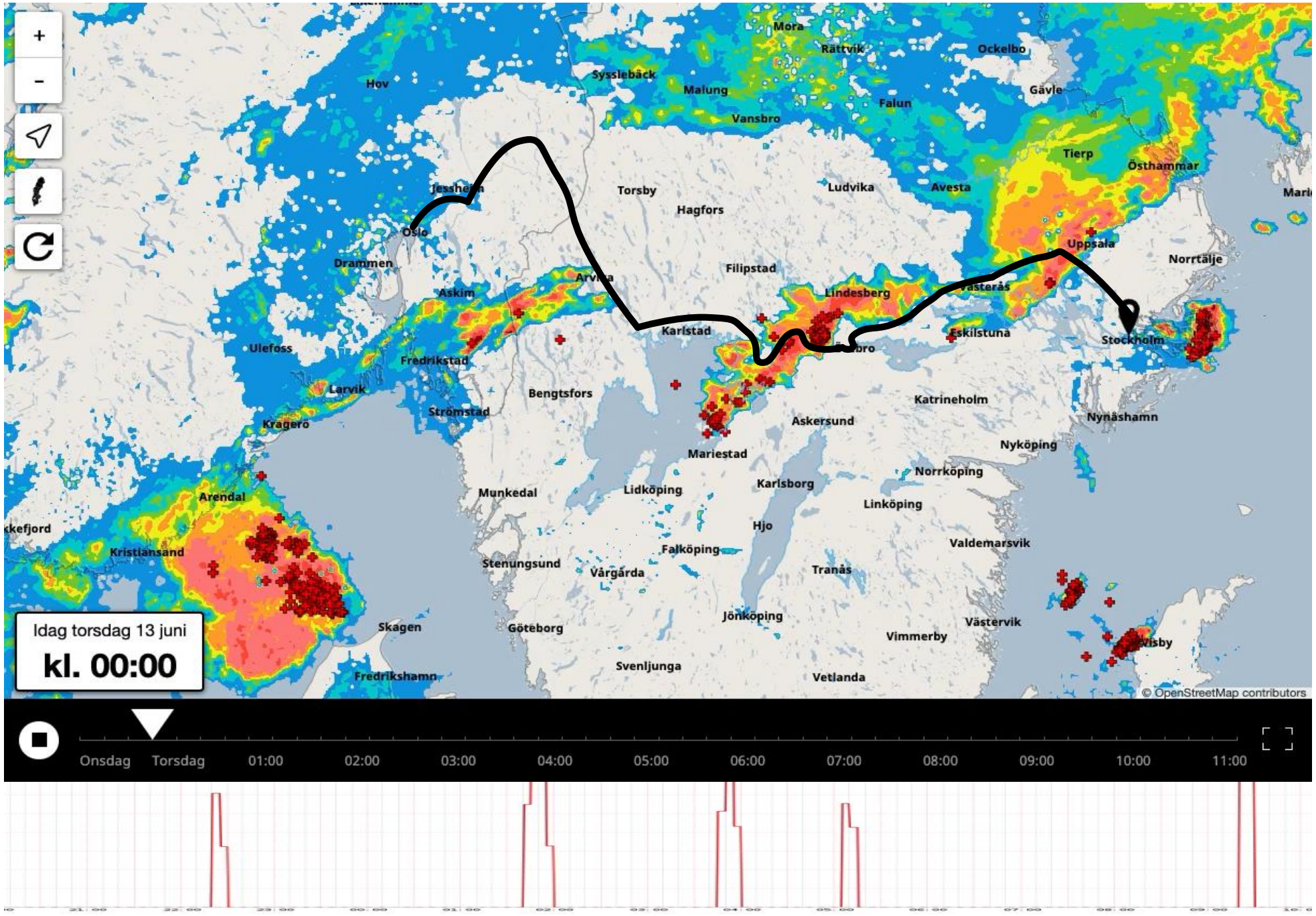
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Hand-off
260
Users
IP
V4 (929800)
V6 (1/32)
Users
Users
DC
TUG.STHB
DCO
Cnaas
Legacy DC
NNT
Network protection
NI
L3/L2
Routers 112st
WR
Users
SNC/NI
DWDM Line system
207 nodes
Users
DAS
Users
Users
Housing 225 (4 DK, 7 NO)
Racks 334 (DCO 53)
Power
UPS
Generators
Batteries
Diesel
Cooling
Access
Fire protection
Fiber
189 fibersections
~9300km

First contact with SOP State of Polarization

- In 2015, we deployed Sunet's first 100G IP-over-DWDM network.
- More than half of the fibers run along power lines.
- We had heard that lightning could affect transmission.
- DWDM optics have a limit on how fast the polarization on the fiber can change.
- But we did not know whether they were fast enough to track the changes caused by lightning.

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HCCS

- High Corrected Count Seconds
- Lightning strikes
- Ciena Transponder

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Lightning impact

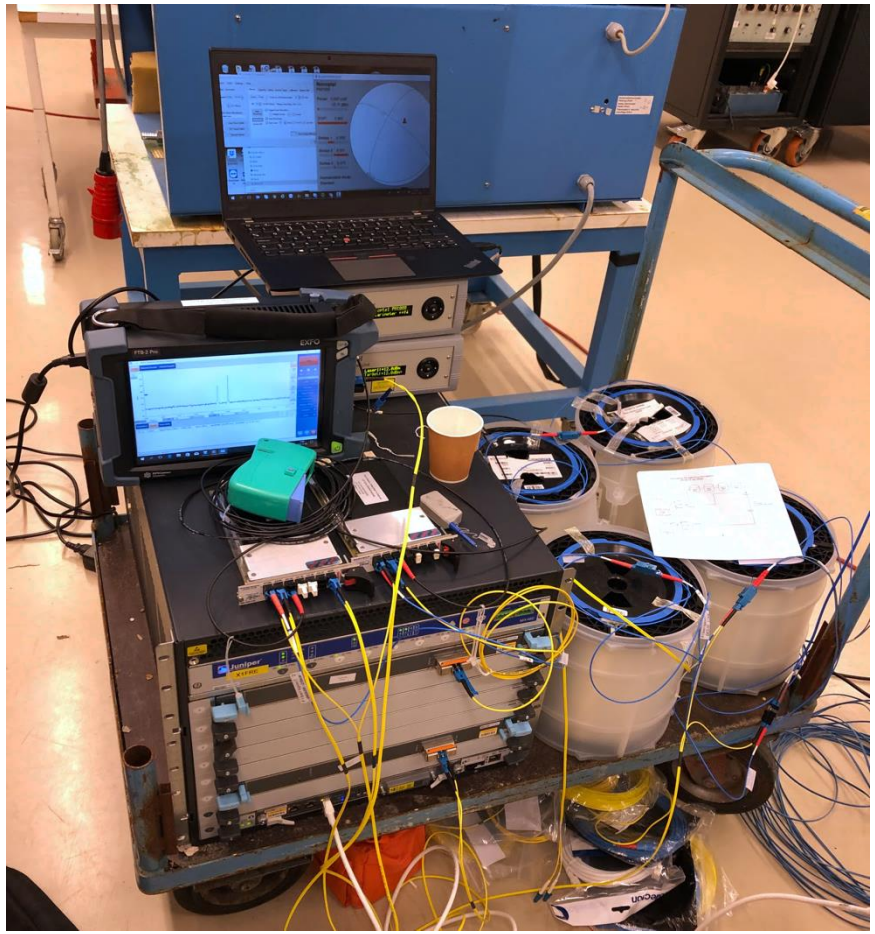
- Worst
  - Receiver loses track and must start over
  - Downtime up to 10 s

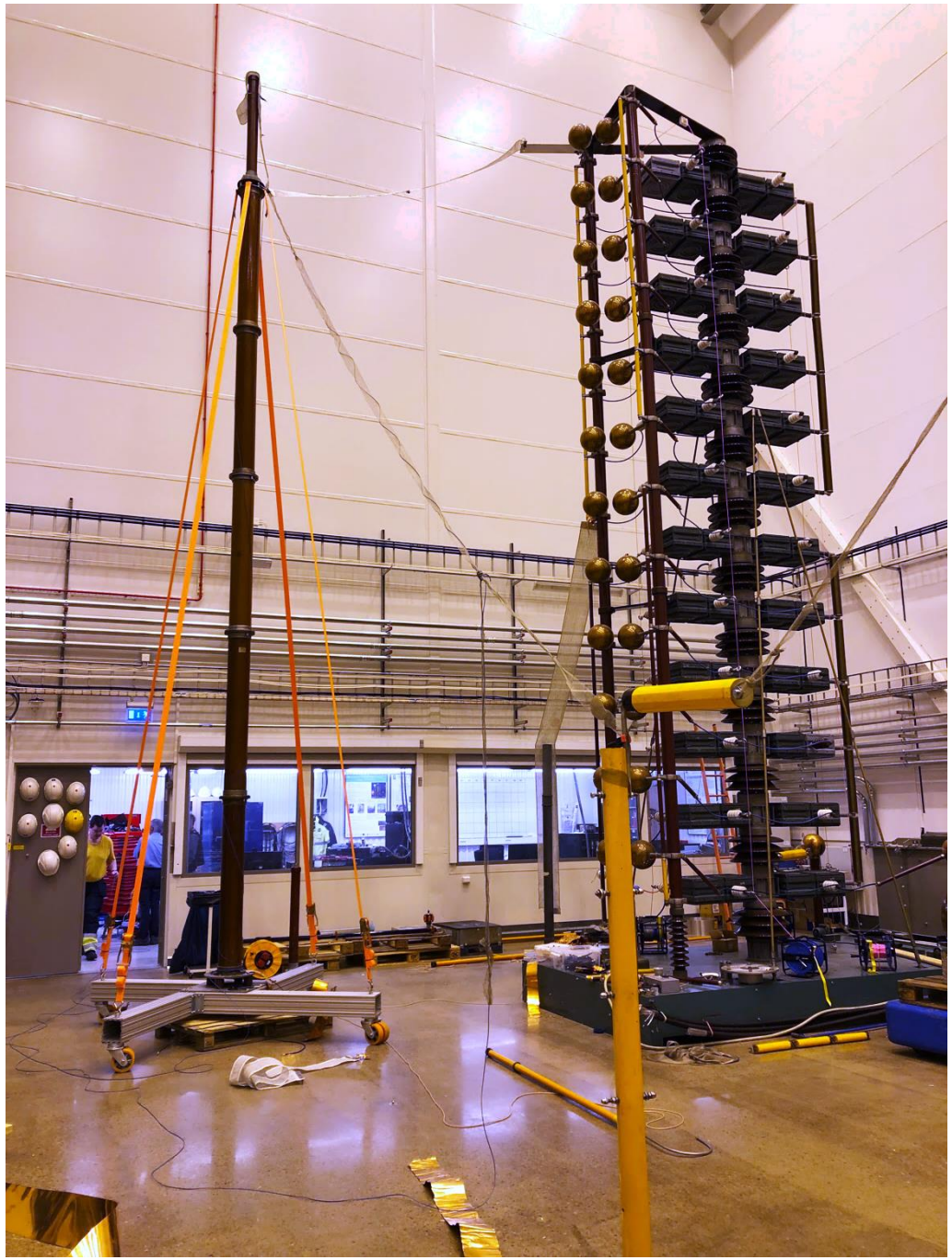


- Bad
  - Bit errors on the PCS layer; receiver sees the link as down
  - Down for less than 500 ms

- Minor
  - Bit errors
  - TCP retransmissions

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RISE/SP Borås

Tested up to 800 kV

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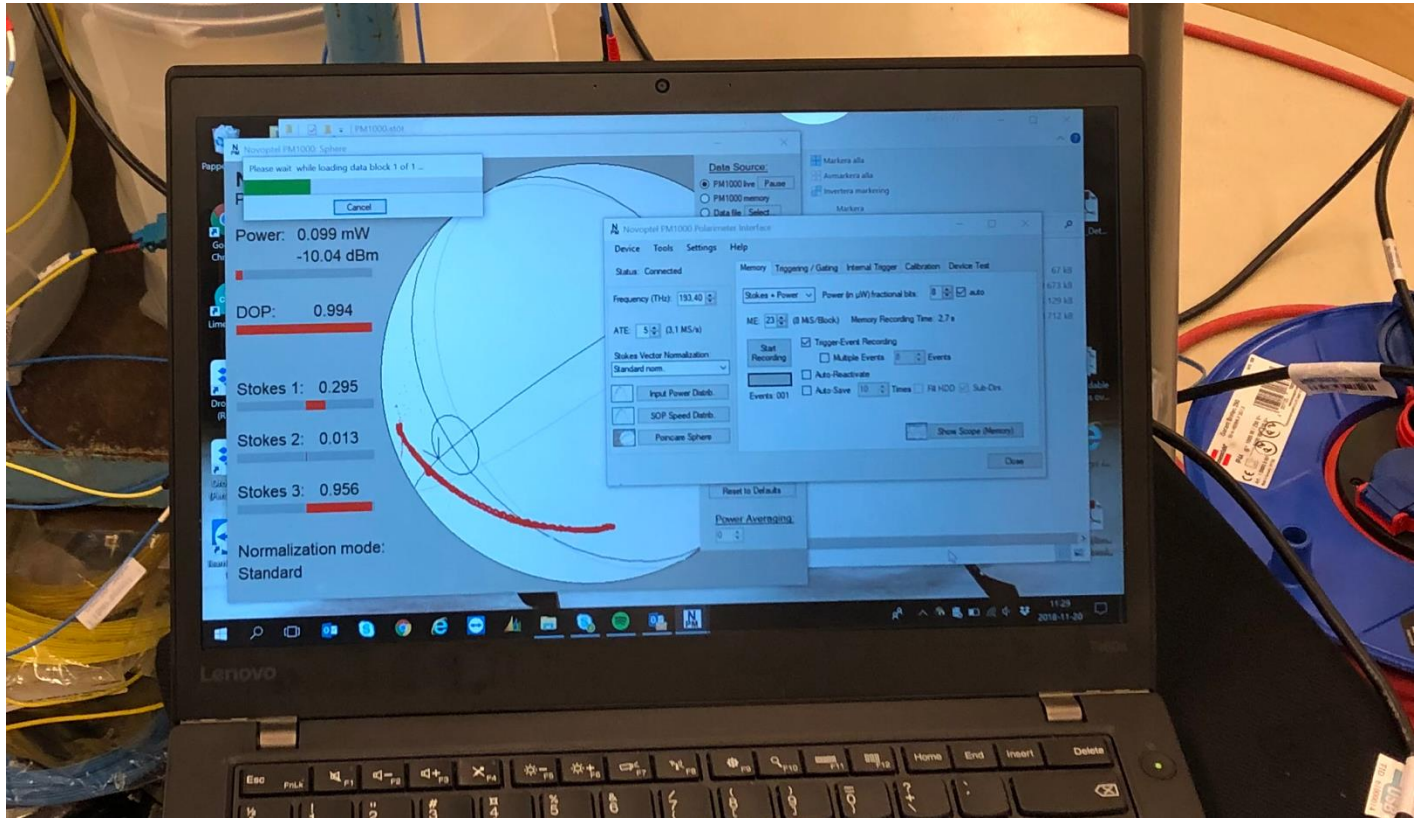
State on the sphere

We built a lightning detector.

It turned out that the 100G coherent DWDM cards in the Juniper routers were fast enough that lightning only caused bit errors,

which we could live with.

Even the 400G IP-over-DWDM we run today shows no problems with lightning.

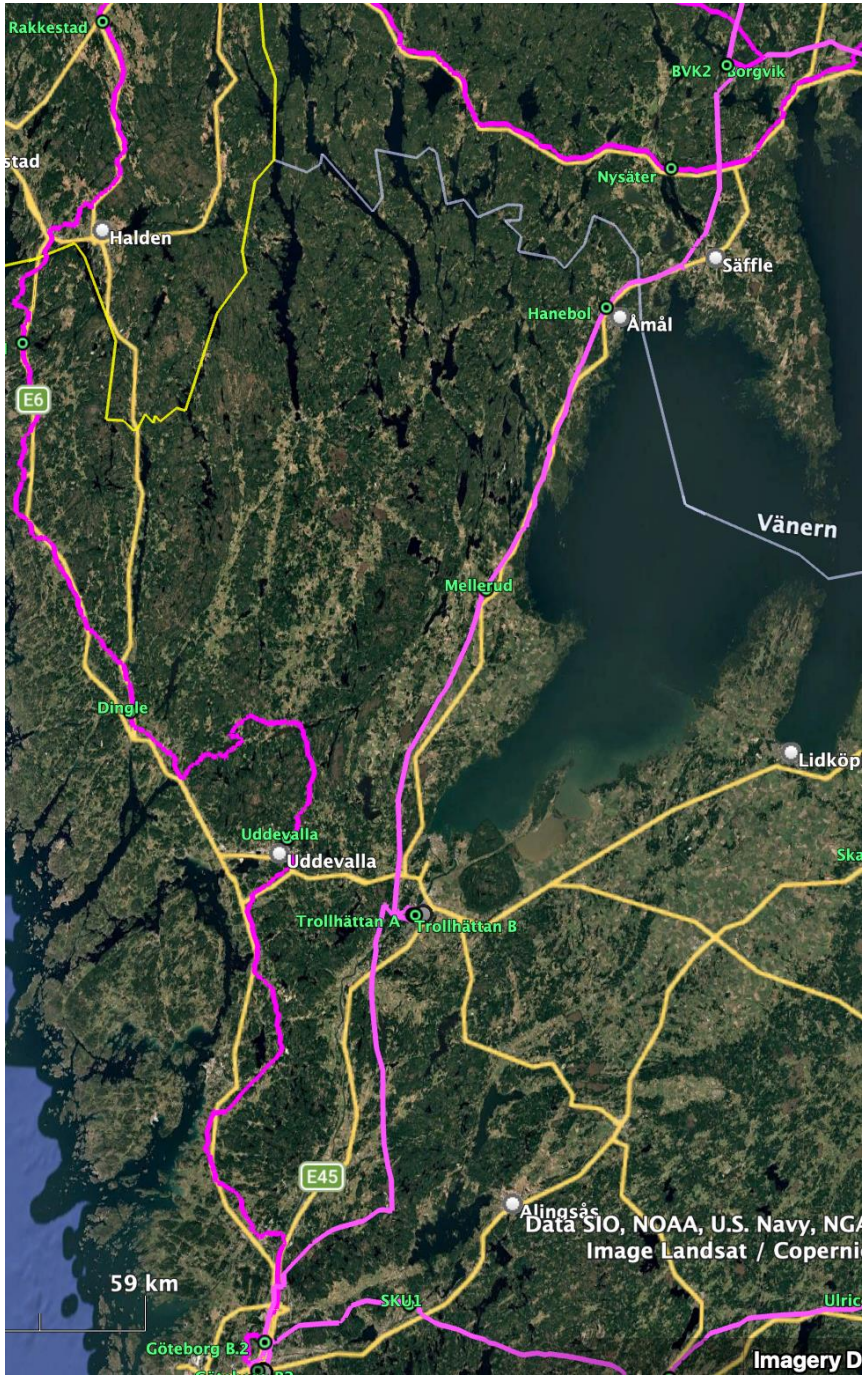


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SOP on Powerlines

Togher with Chalmers and Bell Labs

- Count the turns around the phase wire and you can measure the current.
- One fibercut and you could clearly show in advance that the cut was going to happen. But not where
- As the signal was looped on the end site the event was measured twice.



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Distributed Acoustic Sensing

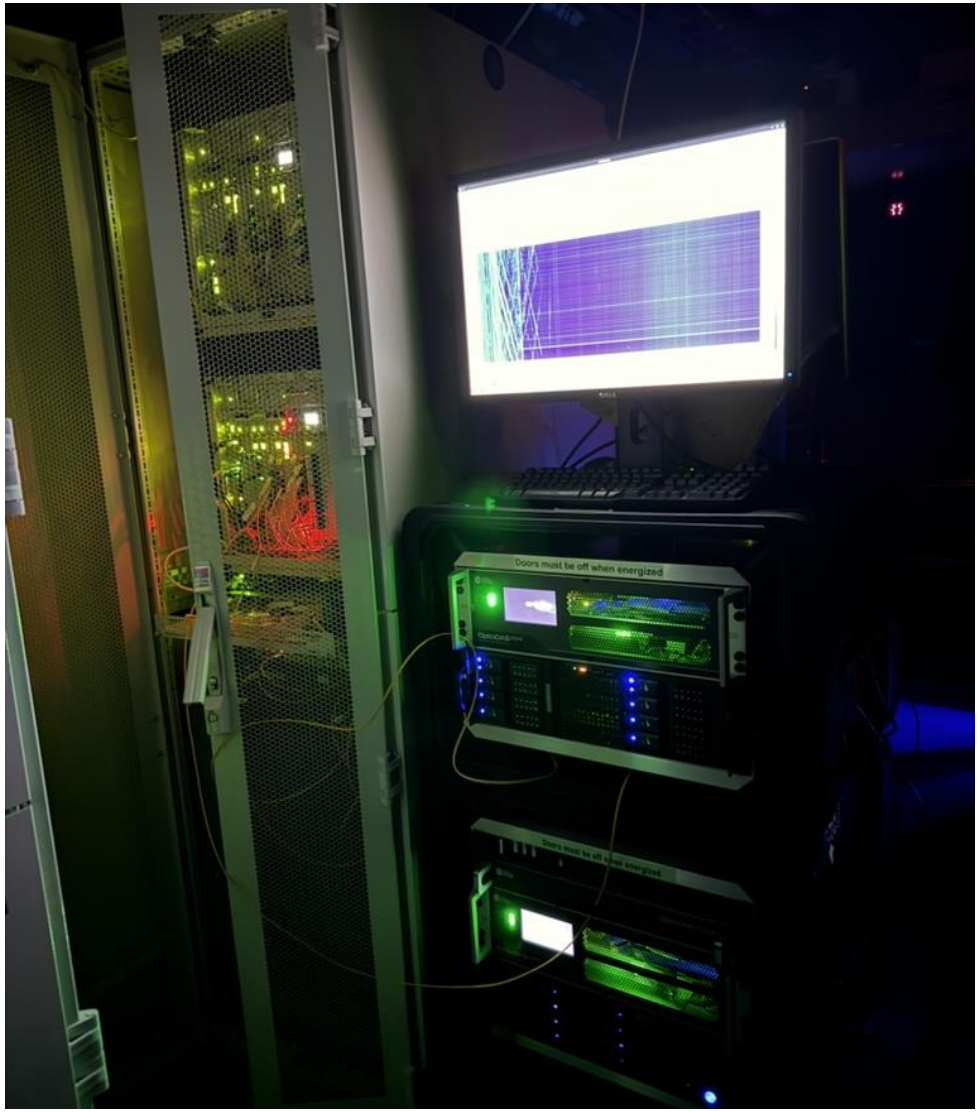
We first came into contact with DAS in early 2023.

It turned out that a researcher at LTU (Luleå University of Technology) was already ahead of us.

LTU used DAS to track problems on the railway.

Sunet received its own DAS units in early 2024.

But first, we ran tests together with Matti Rantatalo at LTU.

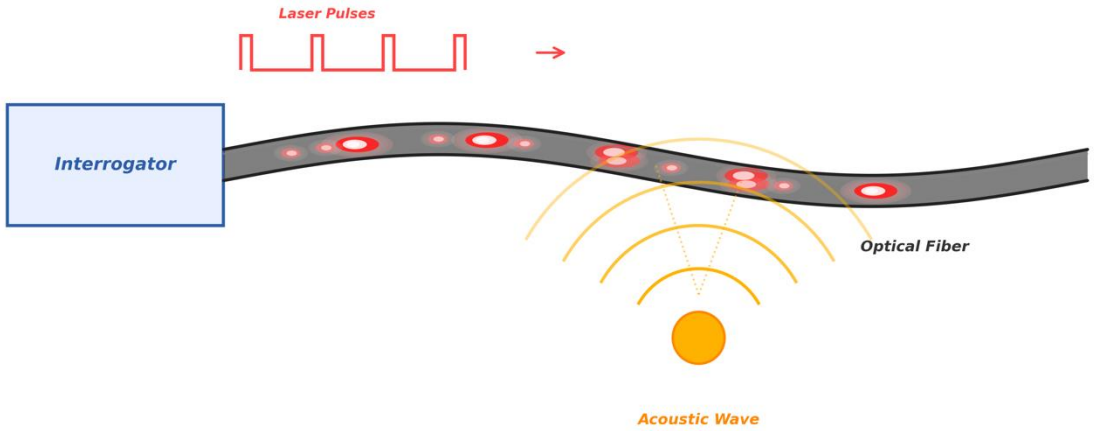


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DAS – Distributed Acoustic Sensing

- A very short introduction to how DAS works with fiber.
  - It works by sending out pulses of light at a specific wavelength and measuring the reflections from impurities in the fiber.
  - The reflections are very small, so the energy pulses going into the fiber need to be relatively high.
  - You measure the phase difference between each section of the fiber.

- So how can you combine pulsed light with an always-on coherent DWDM system? The short answer: **with caution.**



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Train and DAS

- Use existing fibers along the tracks
- Measure train and car axles to prevent derailments and rail damage
- People on the tracks
- Reindeer on the tracks



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First test location

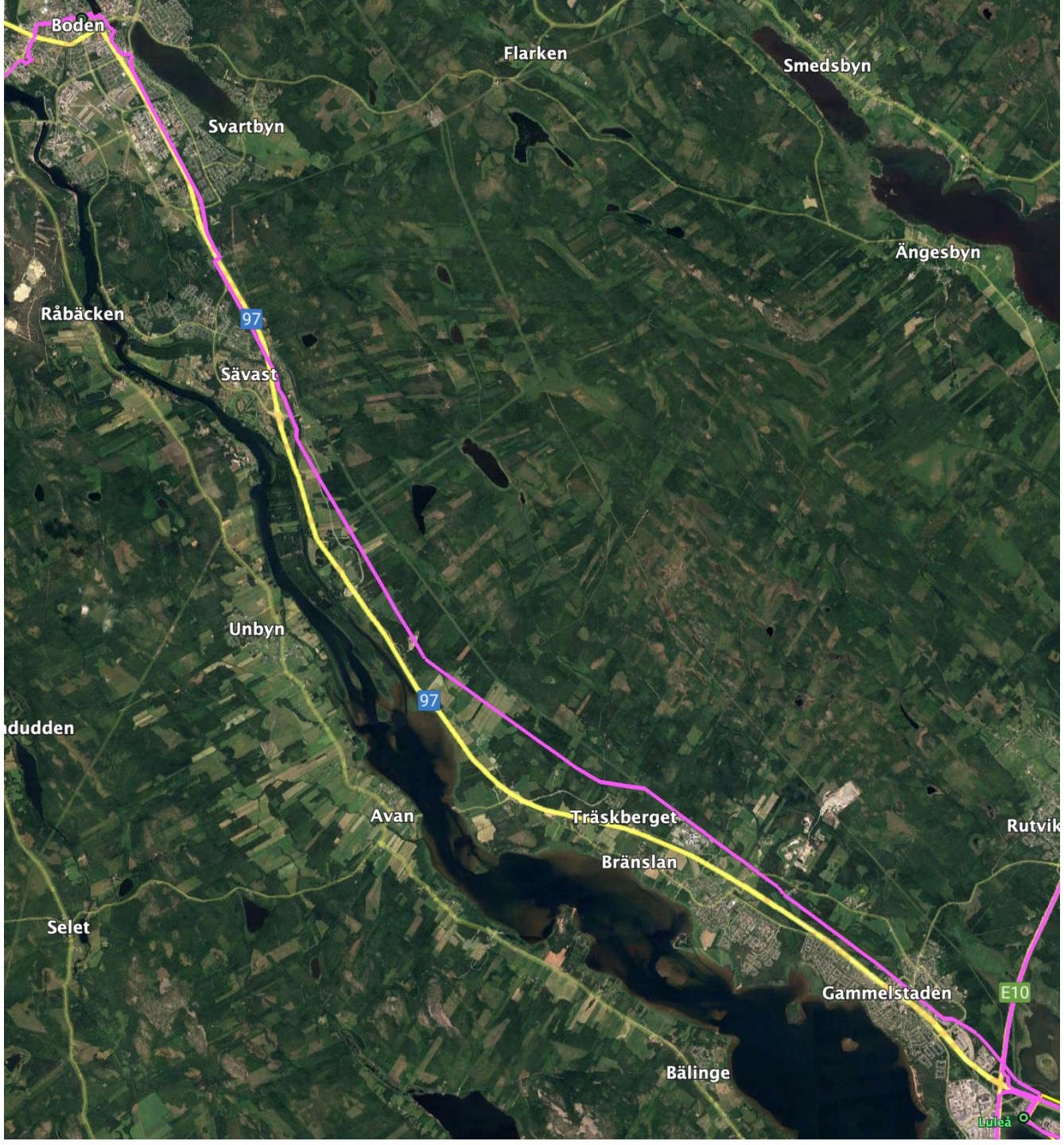
- Tests at the Sunet network PoP in Luleå
- Two fibers: towards Boden and Kalix
- Boden: aerial fiber on a power line
- Kalix: buried fiber along the E4 highway



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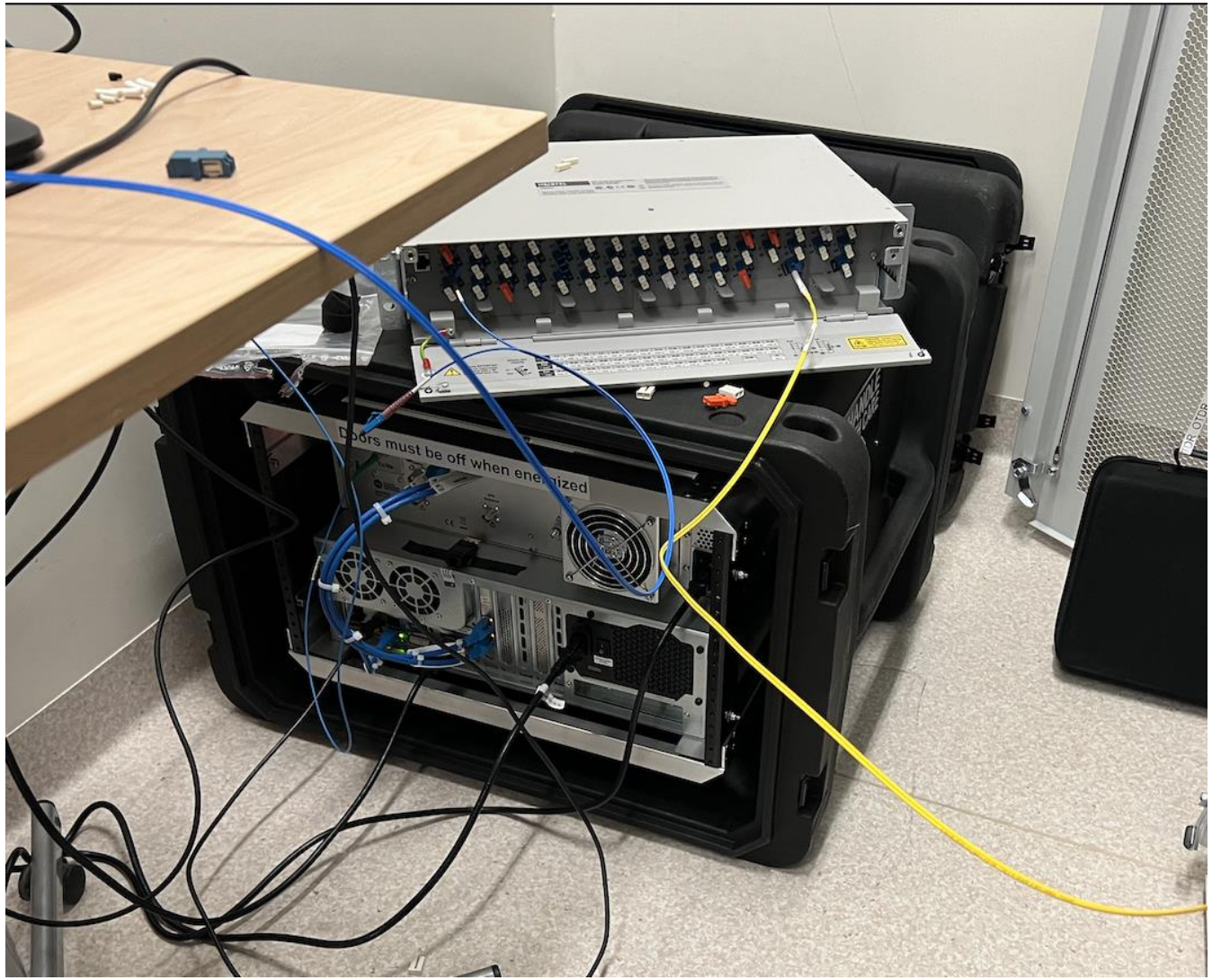
Luleå – Boden

- ~35 km long
- The power line follows the railway.



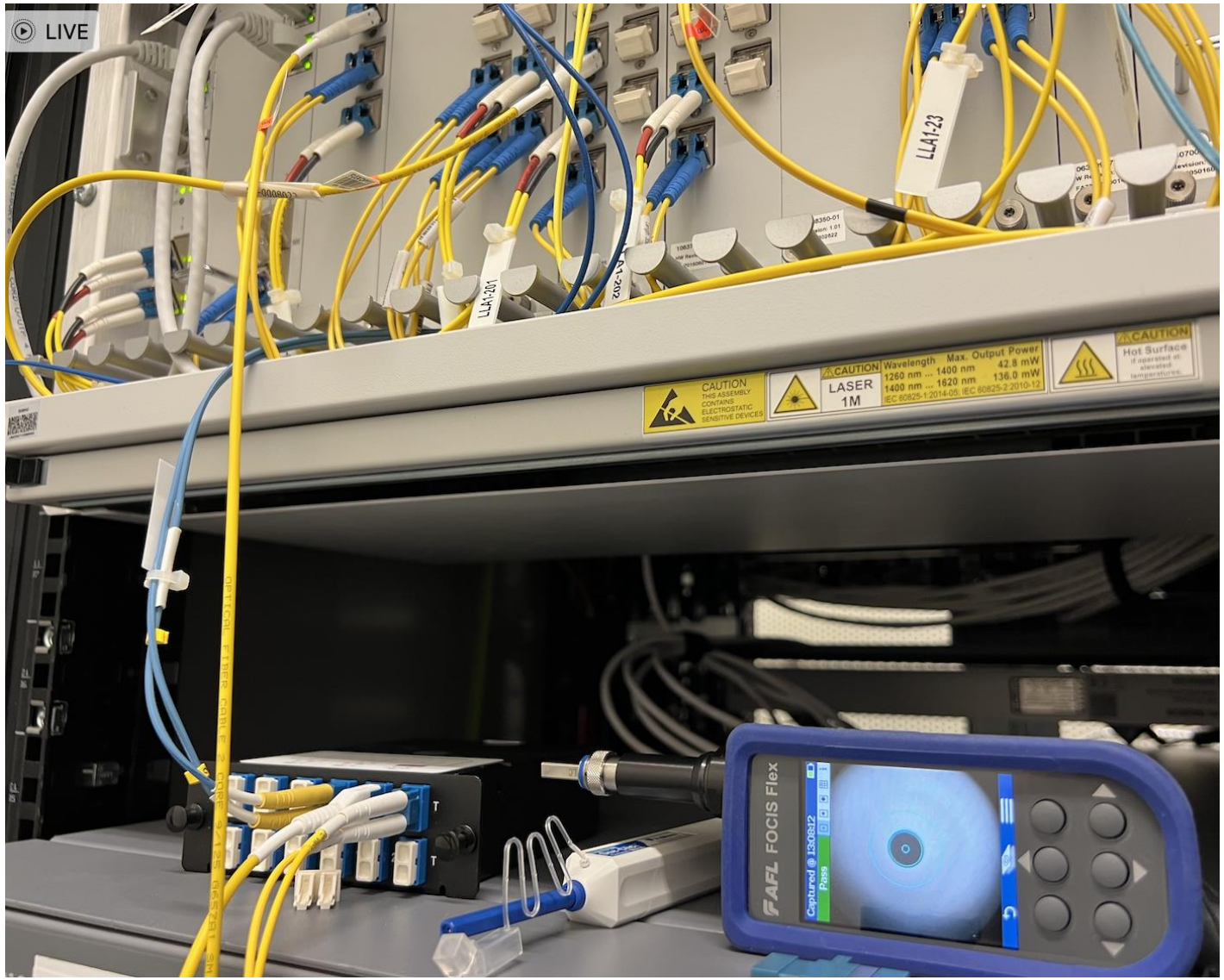
Test setup

- DAS: LTU
- Fiber equipment we could find:
  - DWDM filter: from NORDUnet
    - Rasmus Lund
  - TAP: Sunet Monitoring Project



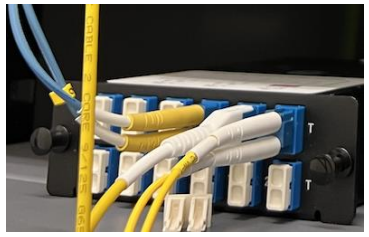
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Cleaning connectors (as always)

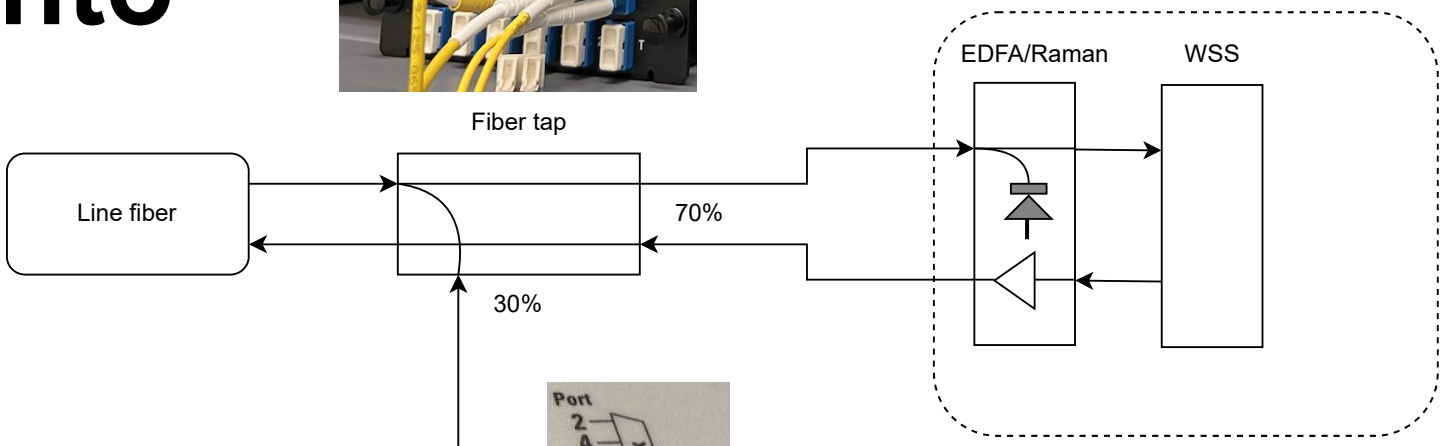


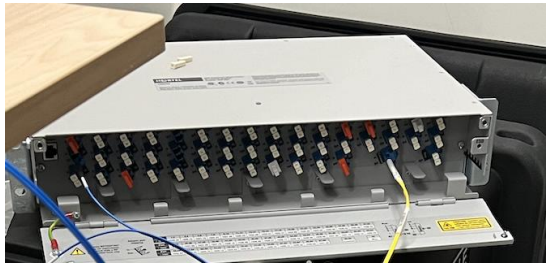
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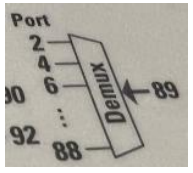
Injecting DAS into the line



Fiber tap



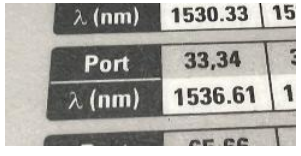




Demux

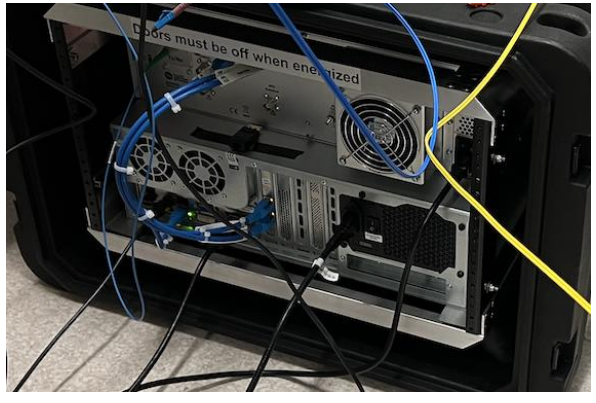
Ciena CMD44 Blue

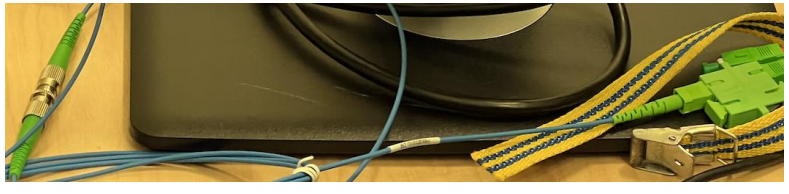
50GHz
1536,61nm





LC/UPC
->
SC/APC
->
FC/APC
->
FC/APC





DAS

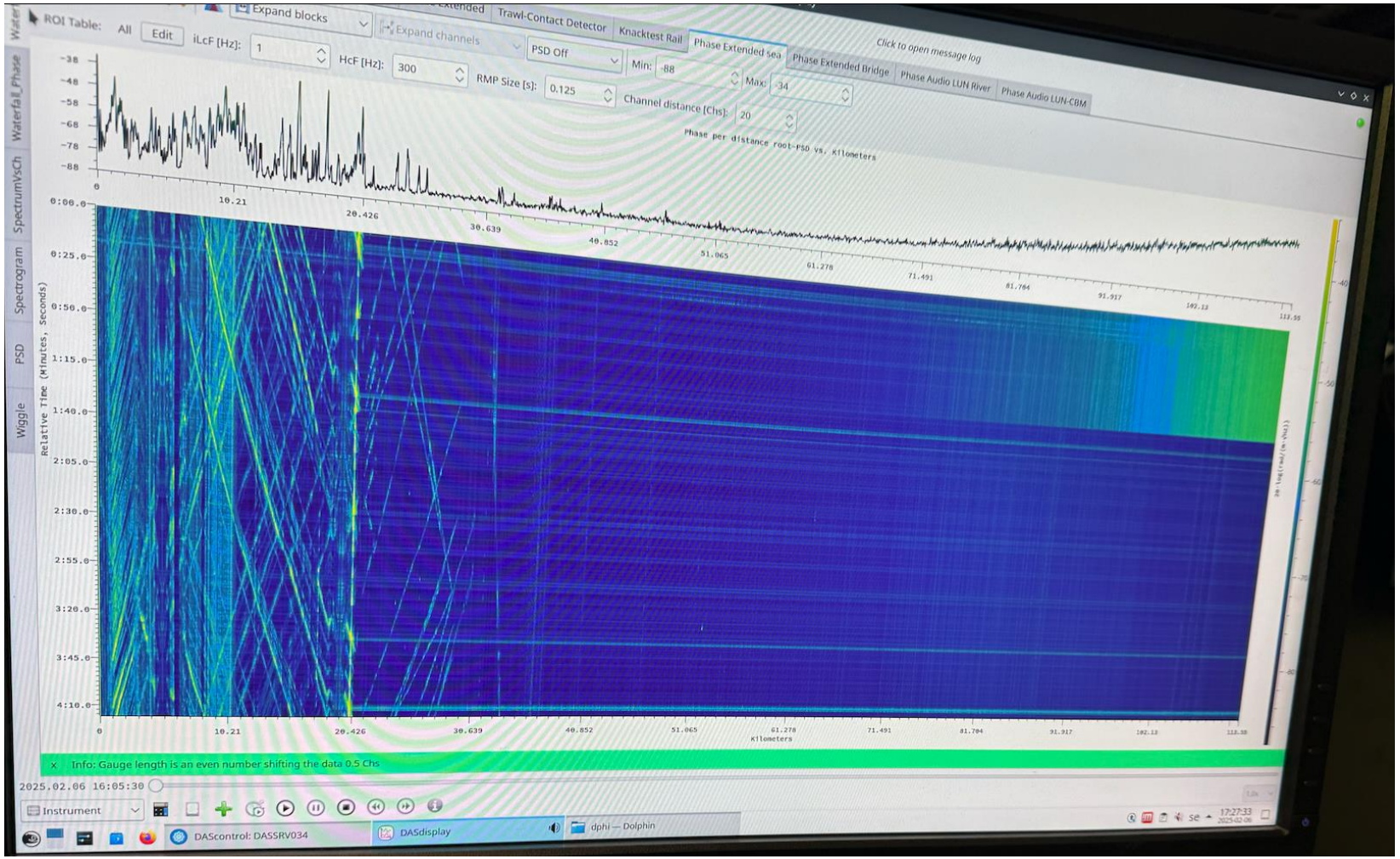
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Matti collecting data



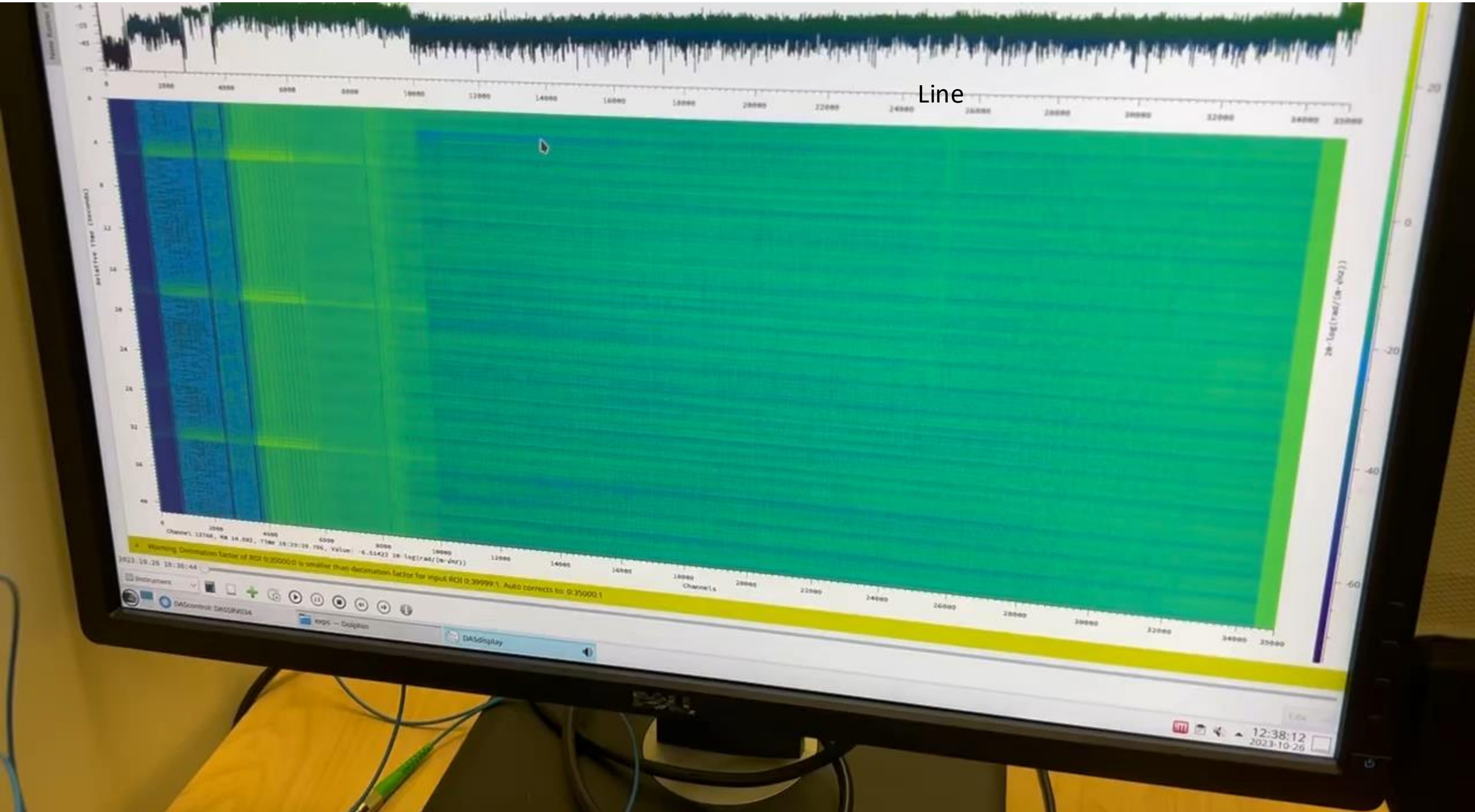
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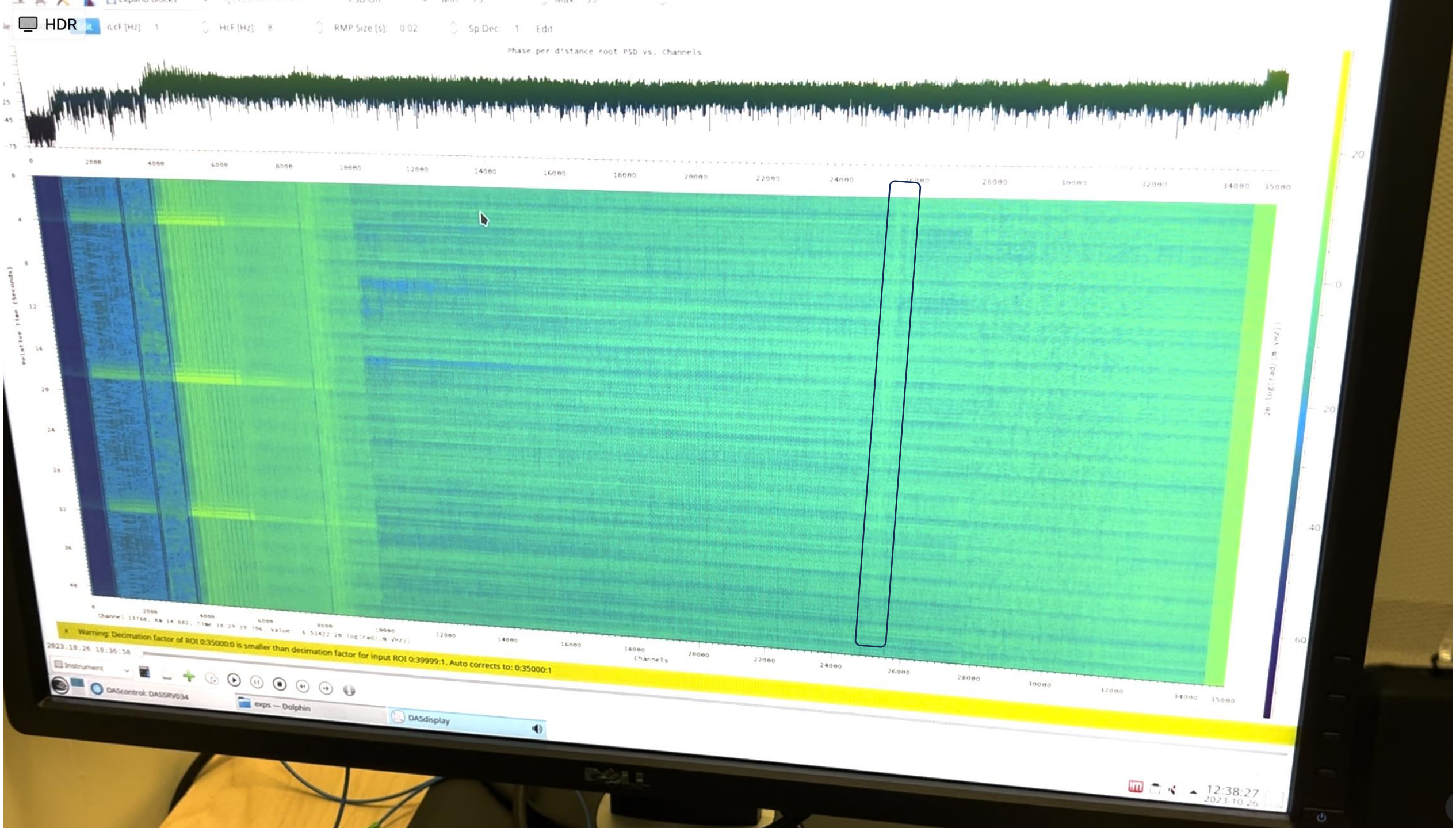
Waterfall diagram, 113 km



- Raman gives a better signal beyond 71 km

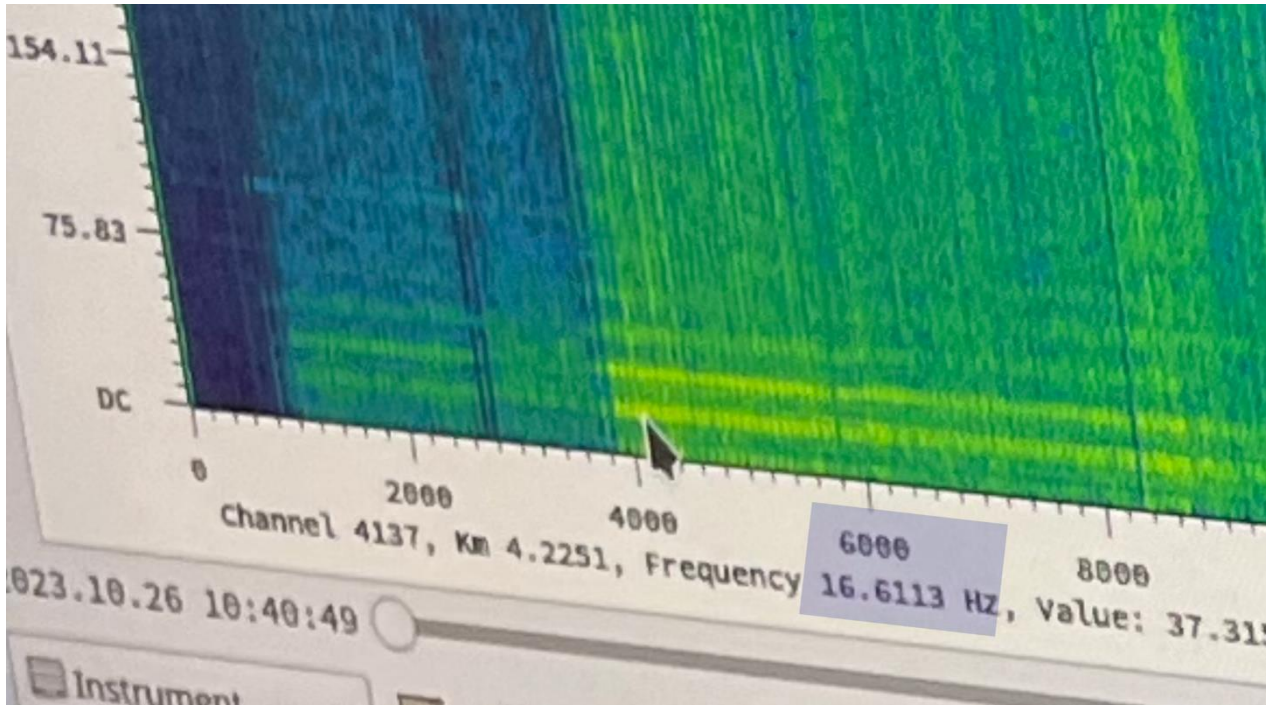
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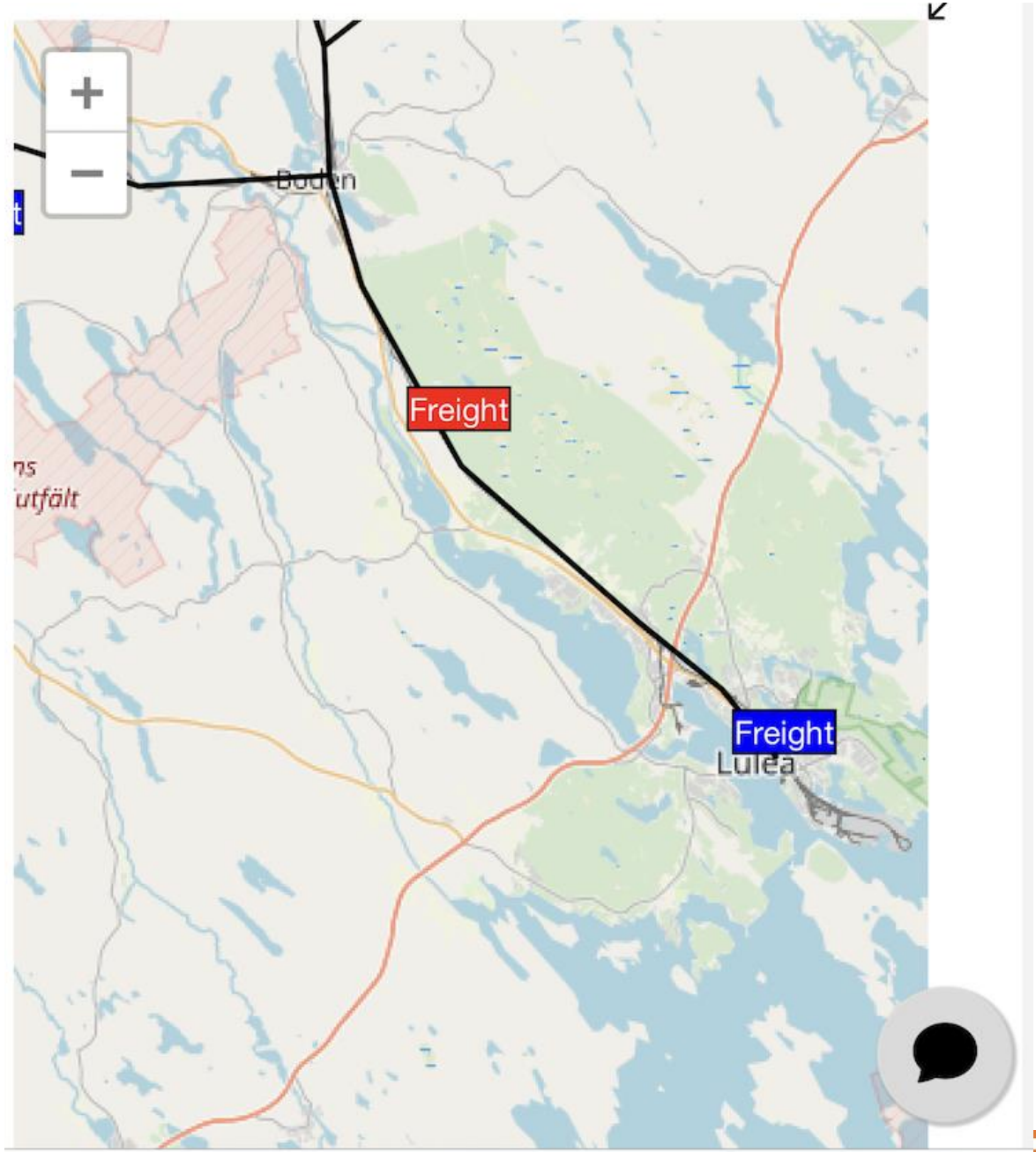

Line


HDR
Phase per distance root PSD vs. channels
Channels
Warning: Decimation factor of ROI 0:35000:0 is smaller than decimation factor for input ROI 0:39999:1. Auto corrects to: 0:35000:1
DASdisplay
12:38:27
2023.10.26

Correlates with trains

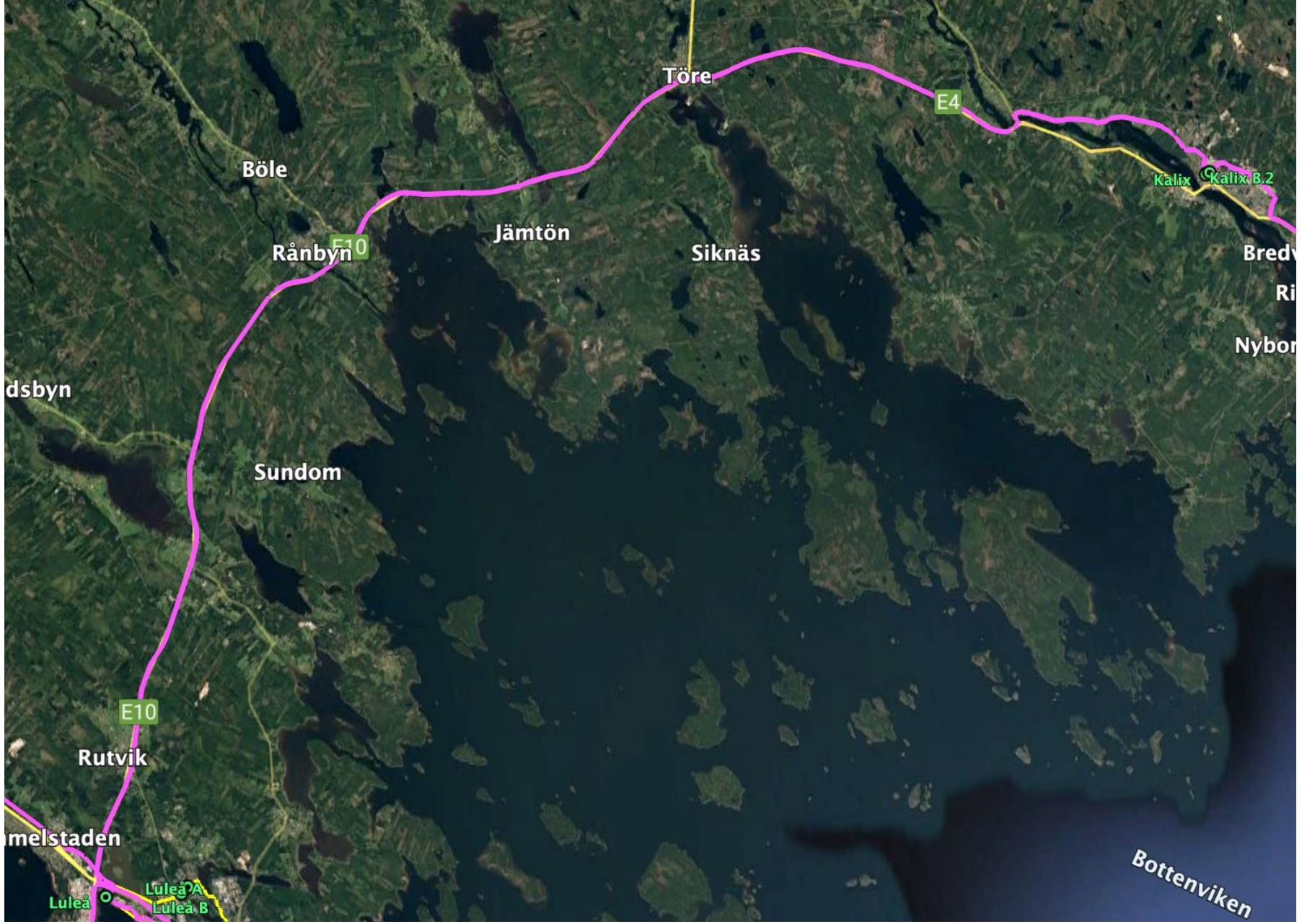
- 1409.se



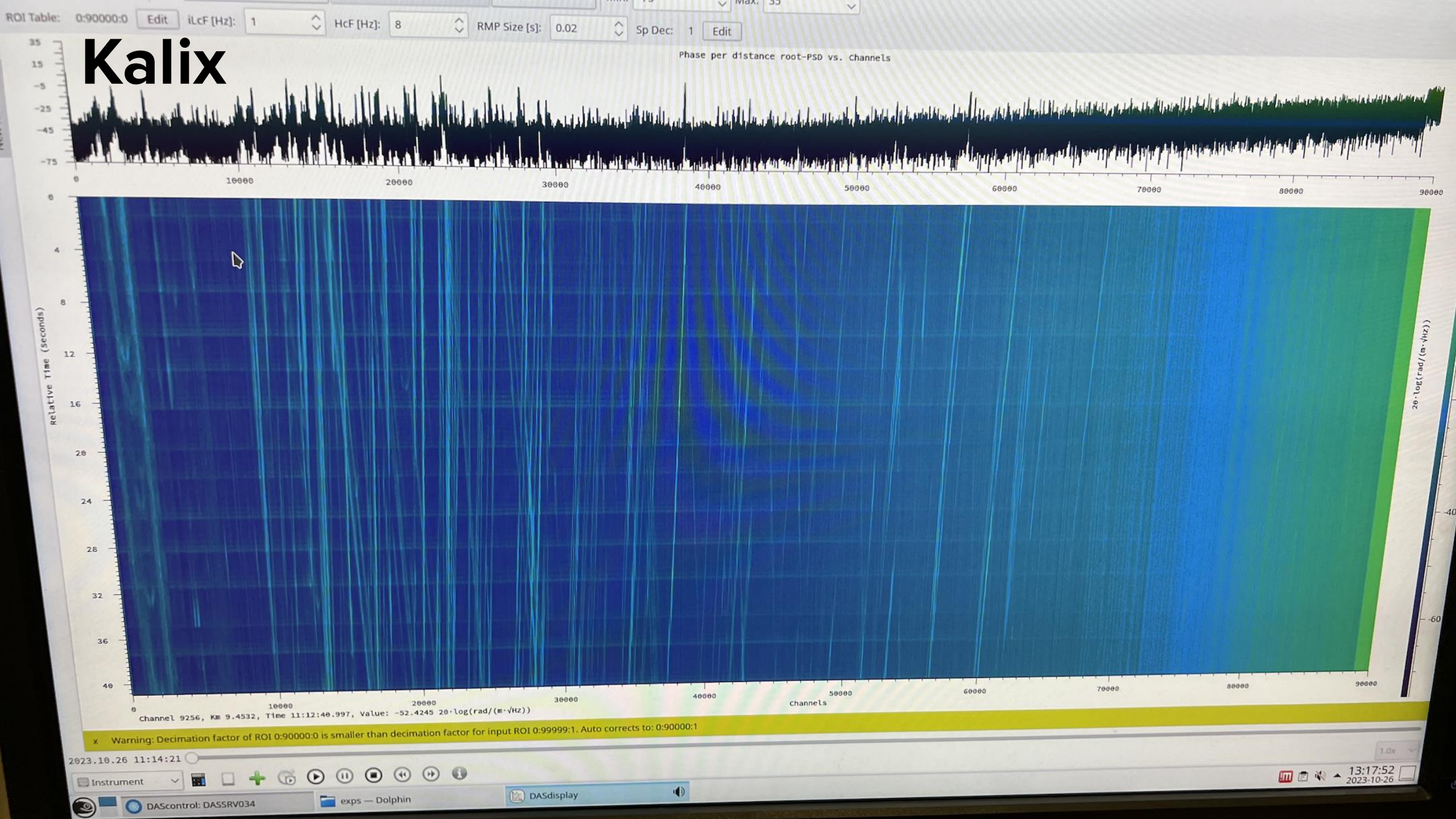


Luleå – Kalix

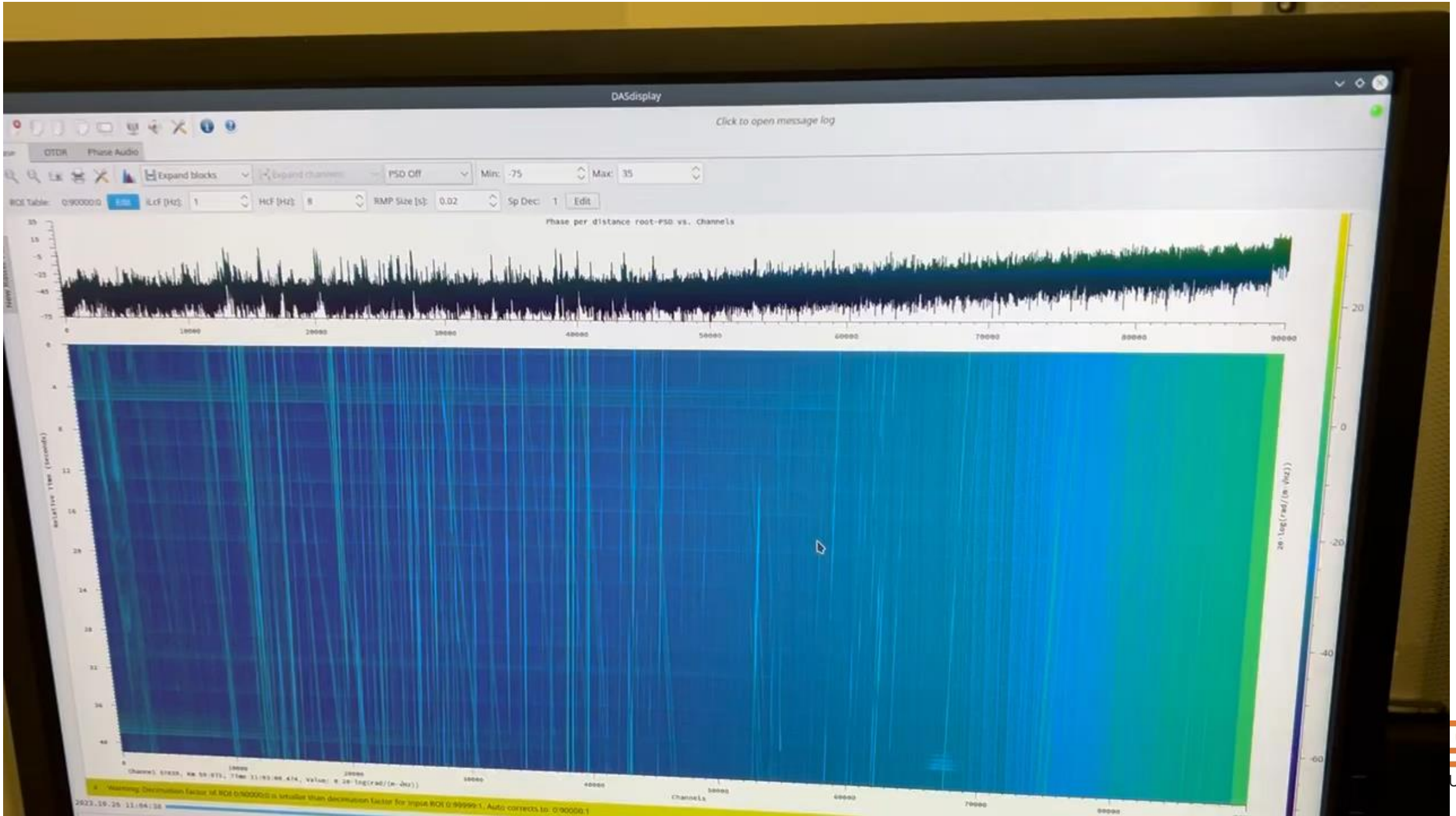
- ~89 km long
- Buried next to the E4 highway



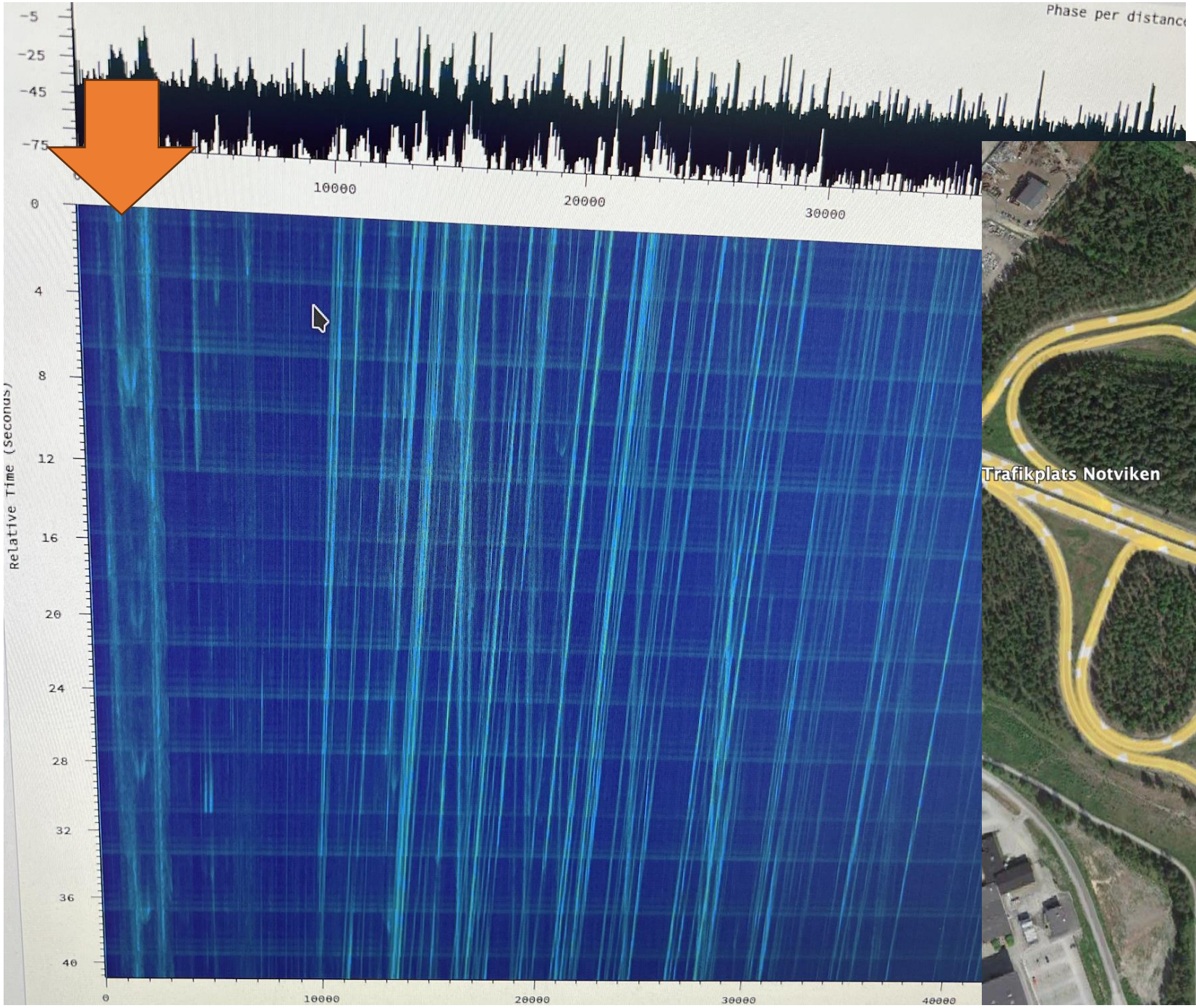
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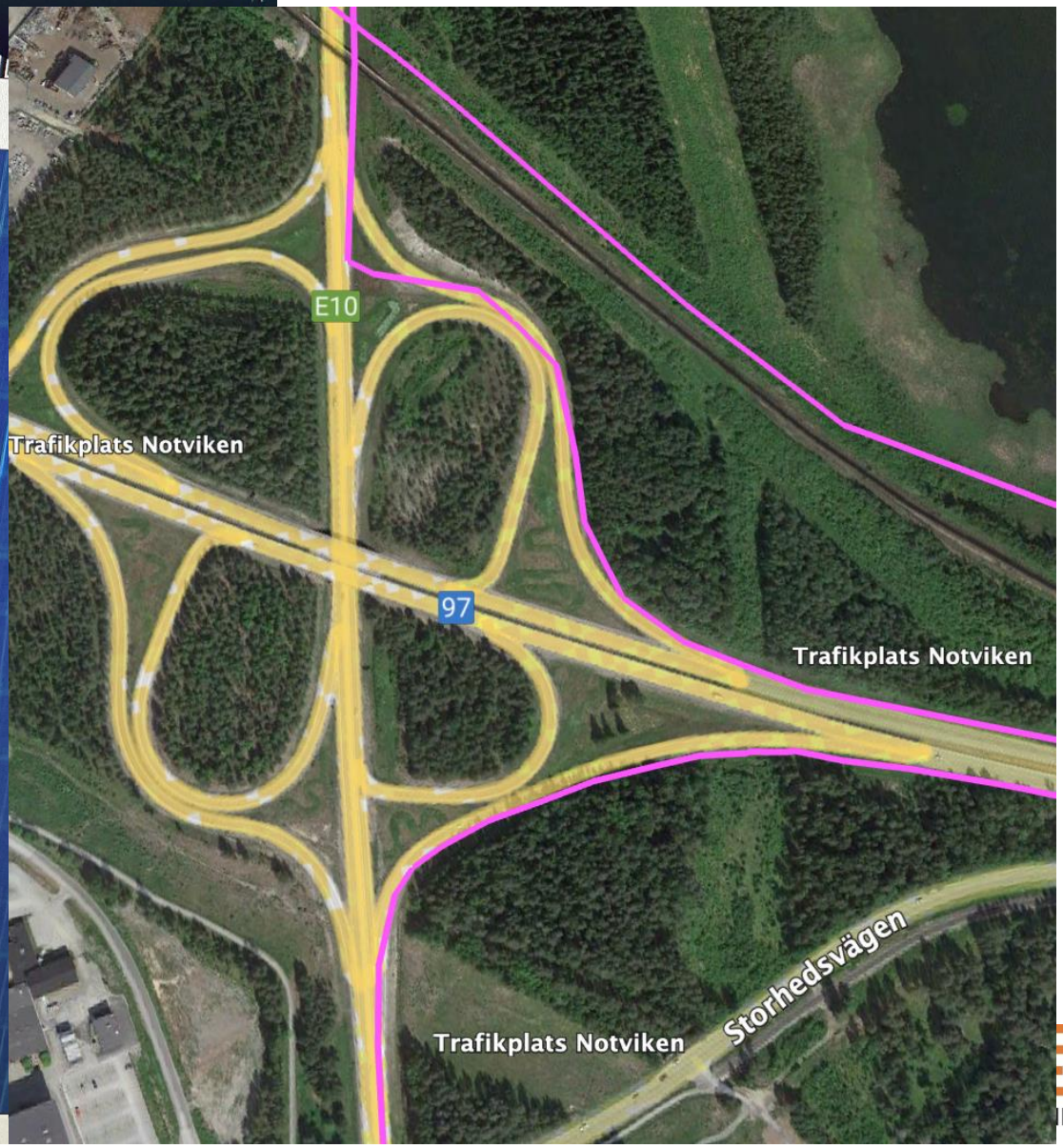

Kalix
ROI Table: 0:90000:0
Edit
iLcF [Hz]: 1
HcF [Hz]: 8
RMP Size [s]: 0.02
Sp Dec: 1
Edit
Phase per distance root-PSD vs. Channels
Relative Time (seconds)
Channels
20·log(rad/(m·√Hz))
Channel 9256, Km 9.4532, Time 11:12:40.997, Value: -52.4245 20·log(rad/(m·√Hz))
Warning: Decimation factor of ROI 0:90000:0 is smaller than decimation factor for input ROI 0:99999:1. Auto corrects to: 0:90000:1
2023.10.26 11:14:21
Instrument
DAScontrol: DASSRV034
exps — Dolphin
DASdisplay
13:17:52
2023-10-26

Bright lines are cars; slope = speed



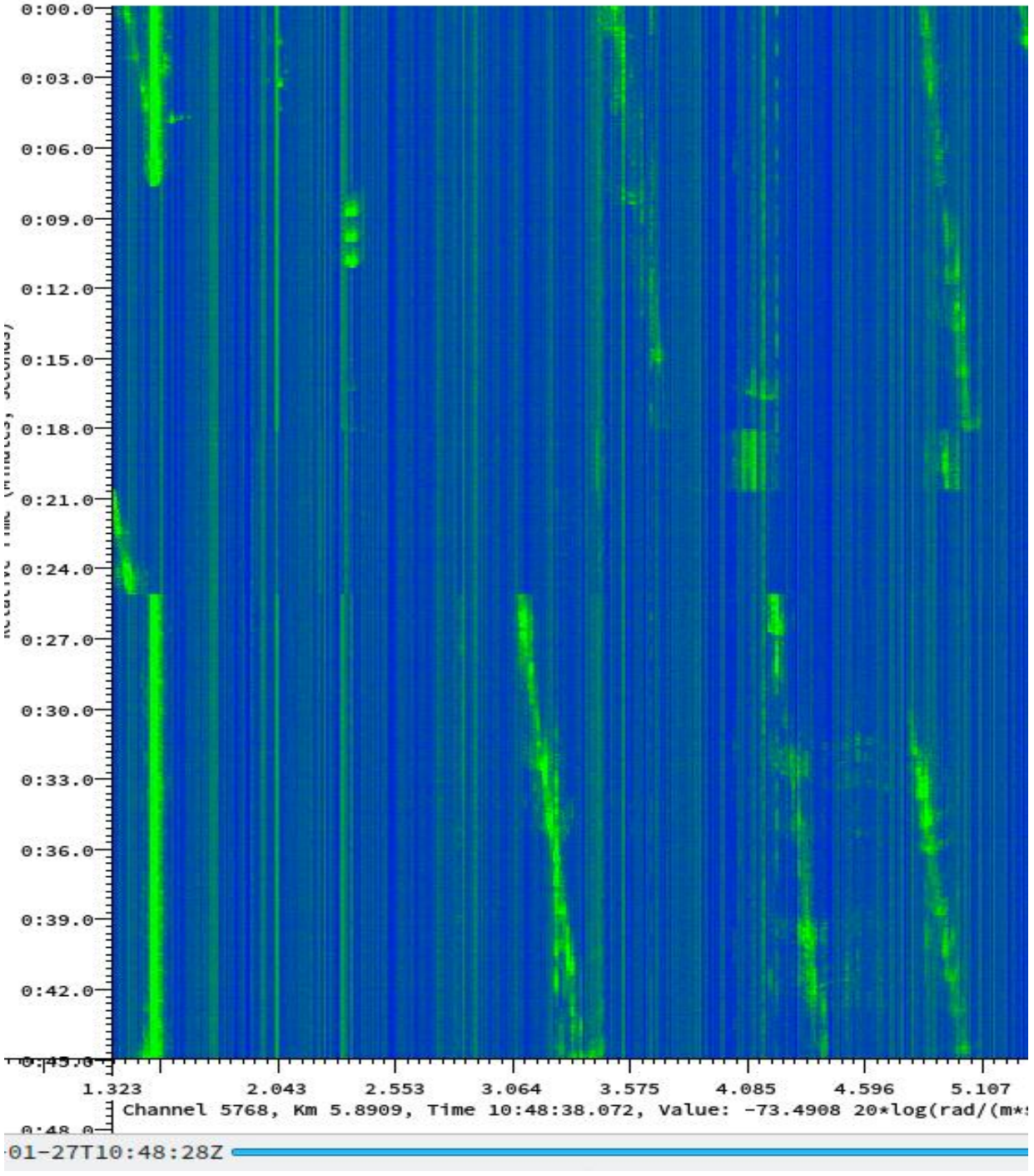
Roundabout


Phase per distanc
-5
-25
-45
-75
10000
20000
30000
Relative Time (seconds)
0
4
8
12
16
20
24
28
32
36
40
0
10000
20000
30000
40000


E10
97
Trafikplats Notviken
Trafikplats Notviken
Trafikplats Notviken
Storhedsvägen

Exercises

- How fast are the cars going?
- 0:25 at 3.064 km
- 0:45 at 3.490 km
- (3490 − 3064) m / 20 s
- = 21.3 m/s ≃ 76.7 km/h



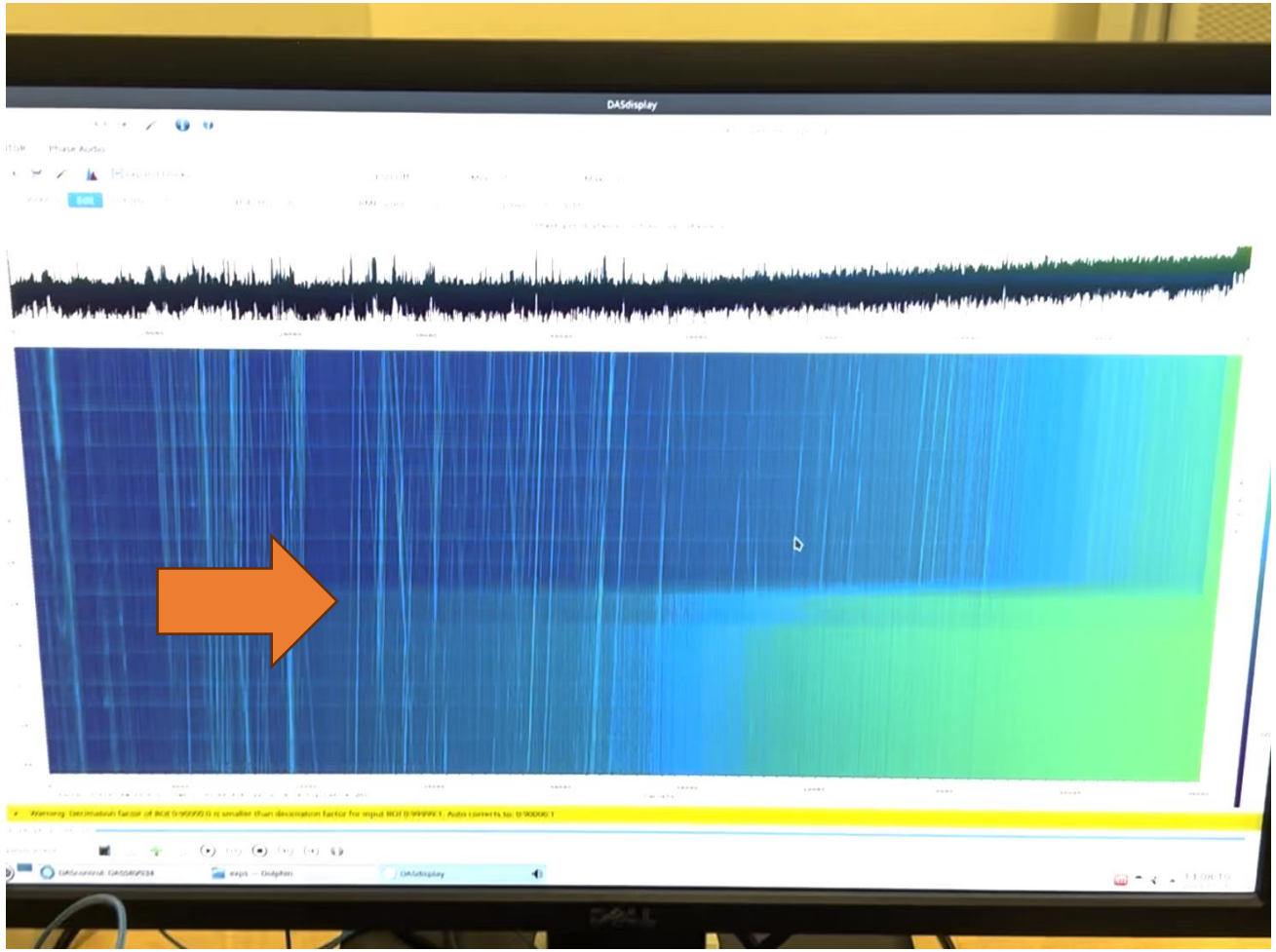
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Optical amplifiers and DAS

The Raman amplifier used for the DWDM data channels also amplifies the DAS signal.

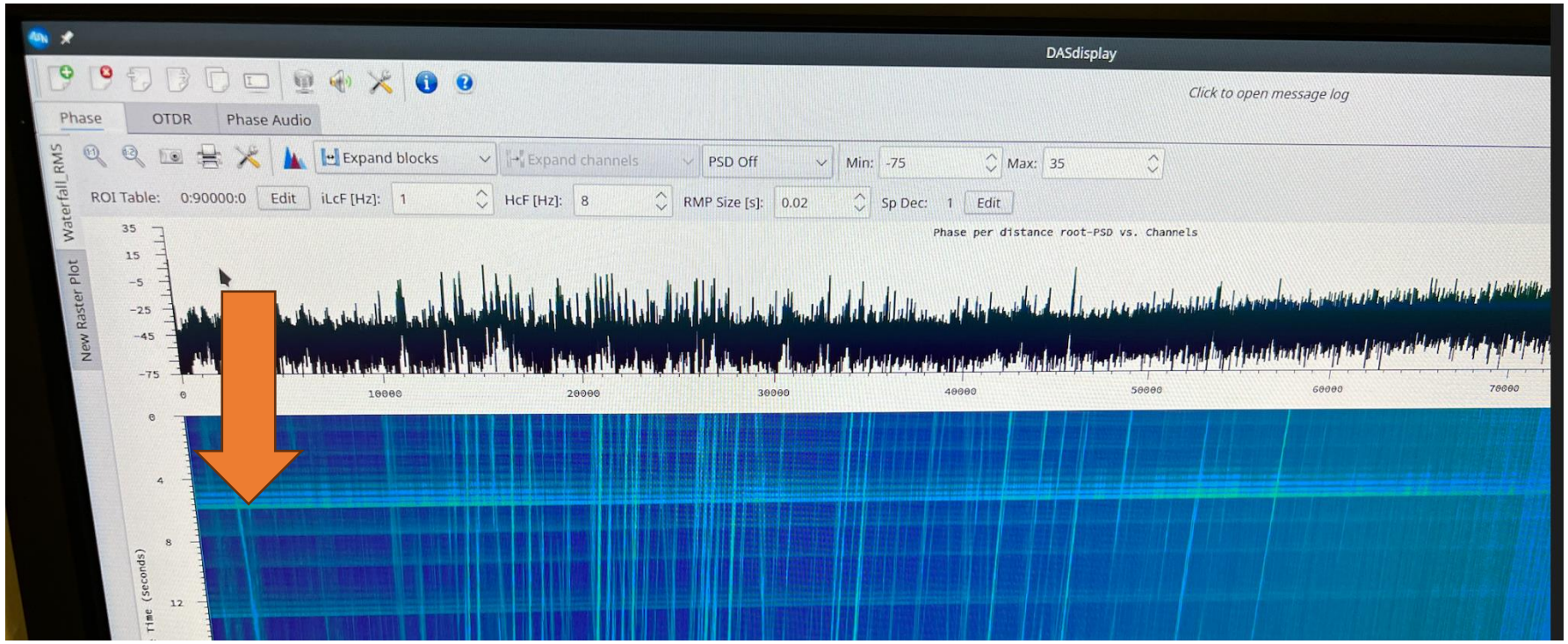
It is not perfect, as it adds some noise, but the reach is much longer.

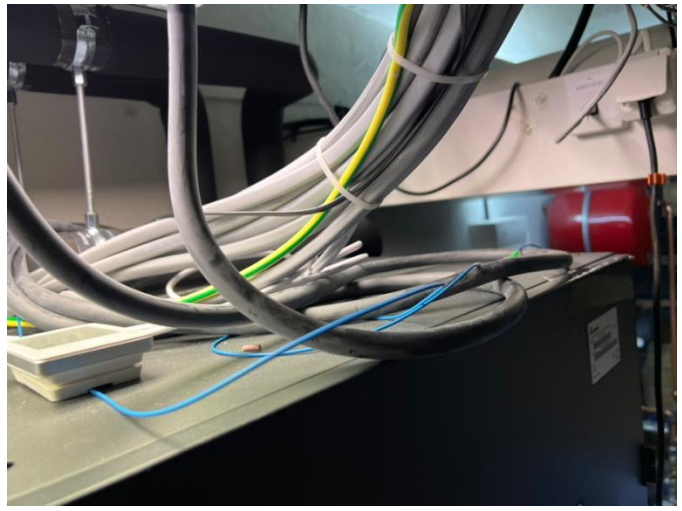
Raman: top = on, bottom = off



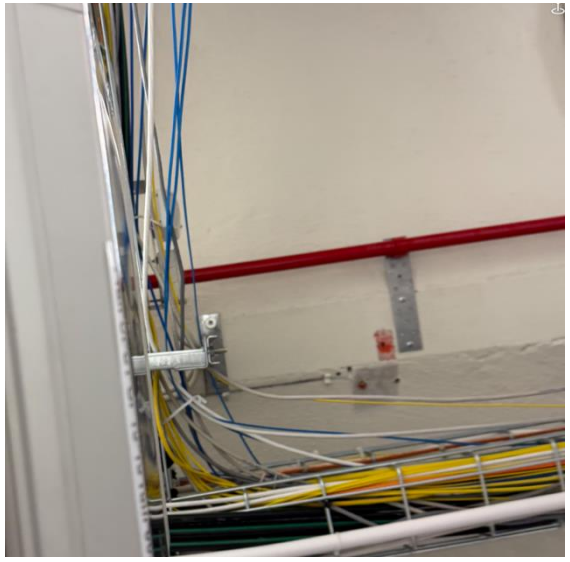
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Tapping on the fiber cable leaving the site



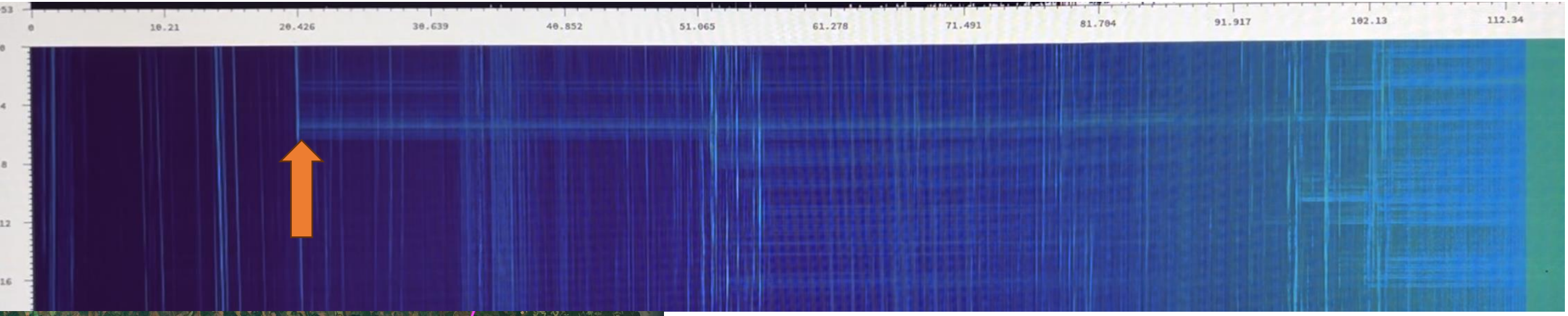






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Disturbing the measurement





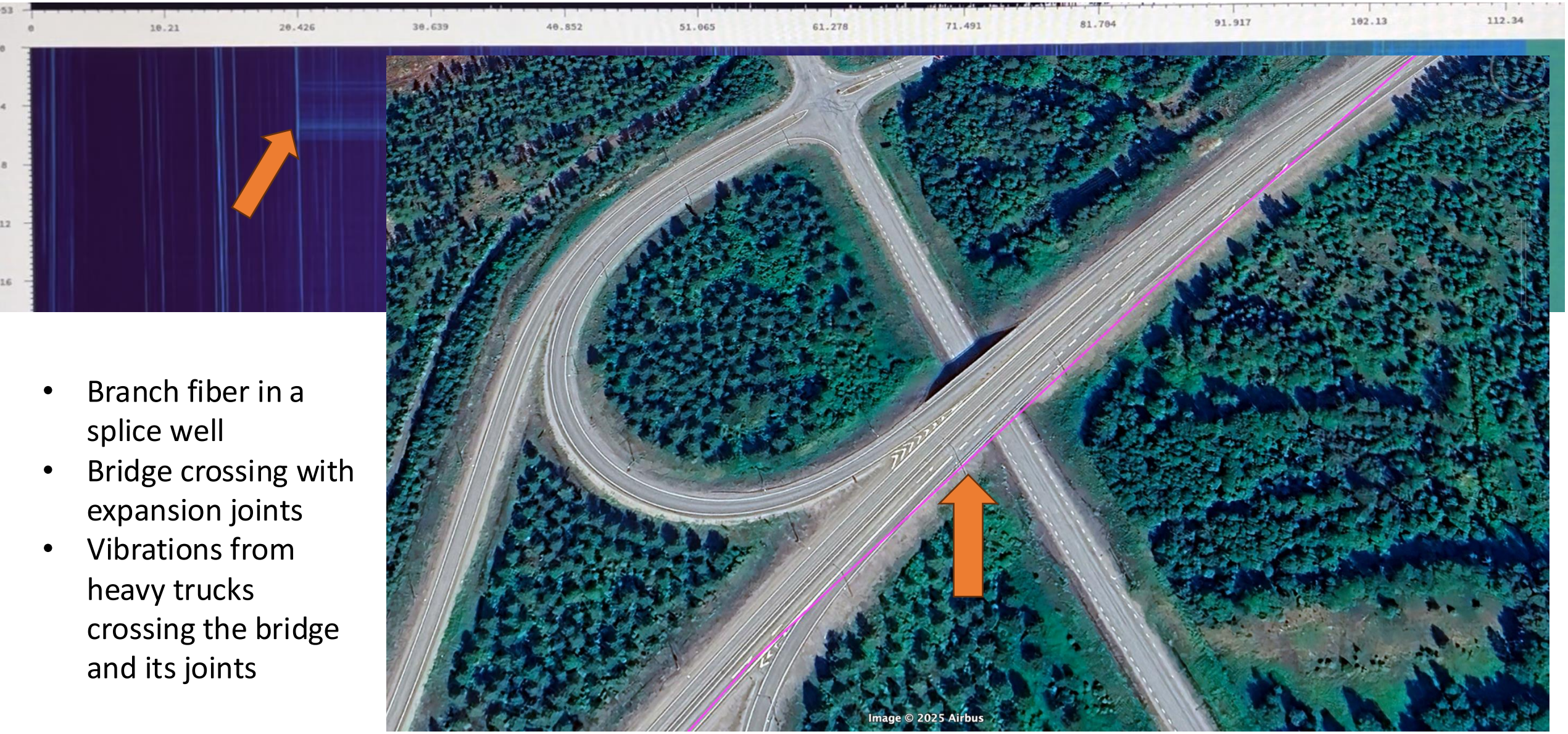
Tapping on the fiber disturbs the outgoing pulse, making all reflections useless.

At our first test location, the cooling fans vibrated the trunk fiber to the next room, with the same result.



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Disturbing the measurement



- Branch fiber in a splice well
- Bridge crossing with expansion joints
- Vibrations from heavy trucks crossing the bridge and its joints

What do snow and a BIG rubber mallet have to do with DAS?





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Sunet has a data center near Haparanda in northern Sweden.

It is connected to the PoP in Kalix.

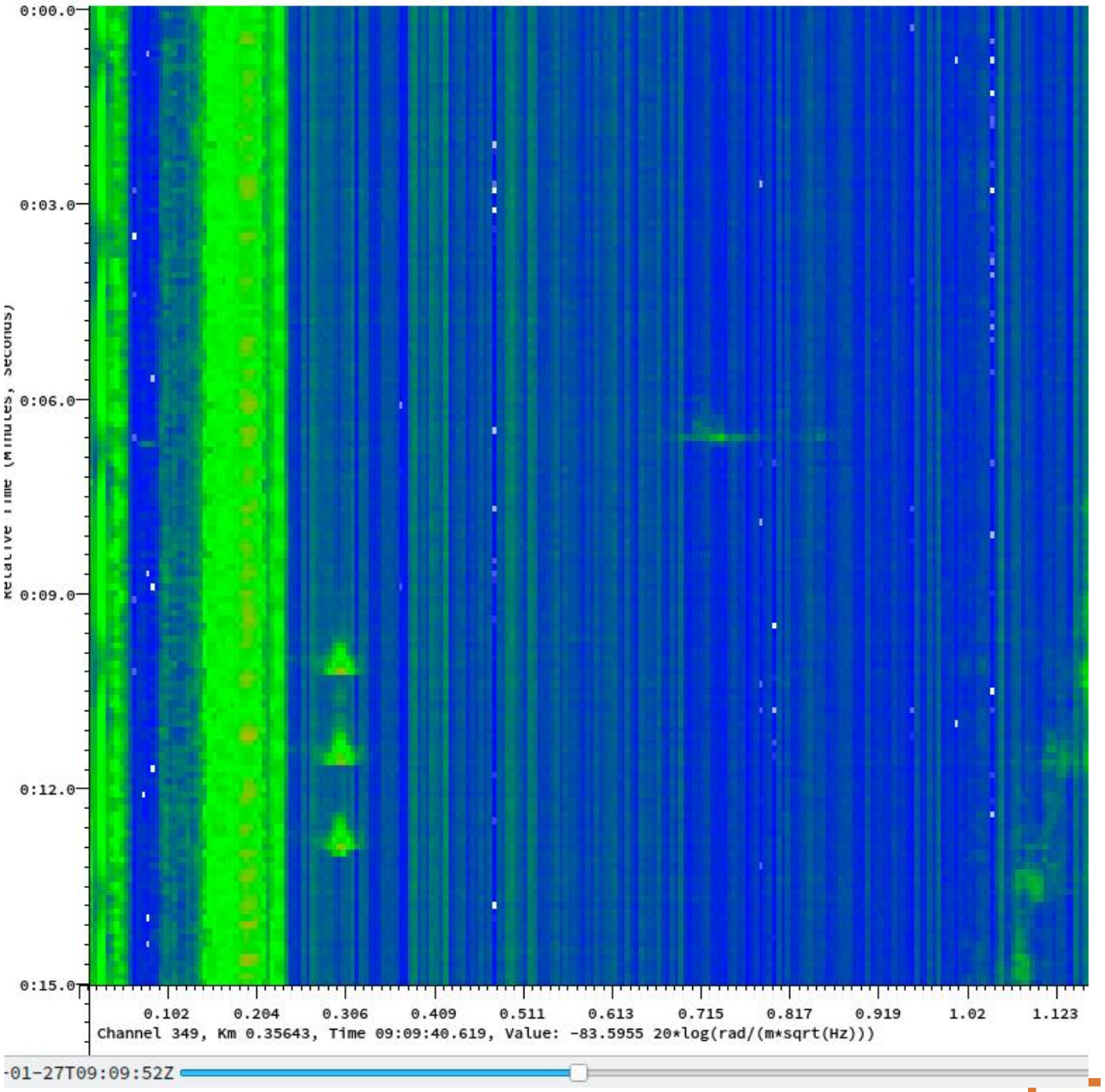
No KMZ map of the fiber route – just a rough overview.



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Knock test

- We connected our DAS system to the fiber.
- Identify position and amplitude



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Knock, knock, knock



GPS

Altitude	12,73 m (41,77 ft)
Altitude Reference	above sea level
Date Stamp	27 Jan 2026
Destination Bearing	320,345
Destination Bearing Reference	True direction
Horizontal Positioning Error	3,374
Image Direction	320,345
Image Direction Reference	True north
Latitude	65° 48′ 53,76″ N
Latitude Reference	N
Longitude	23° 14′ 33,948″ E
Longitude Reference	E
Speed	0,031
Speed Reference	Kilometres per hour
Time Stamp	10:52:16 UTC

iPhone metadata

Latitude

Longitude

Timestamp

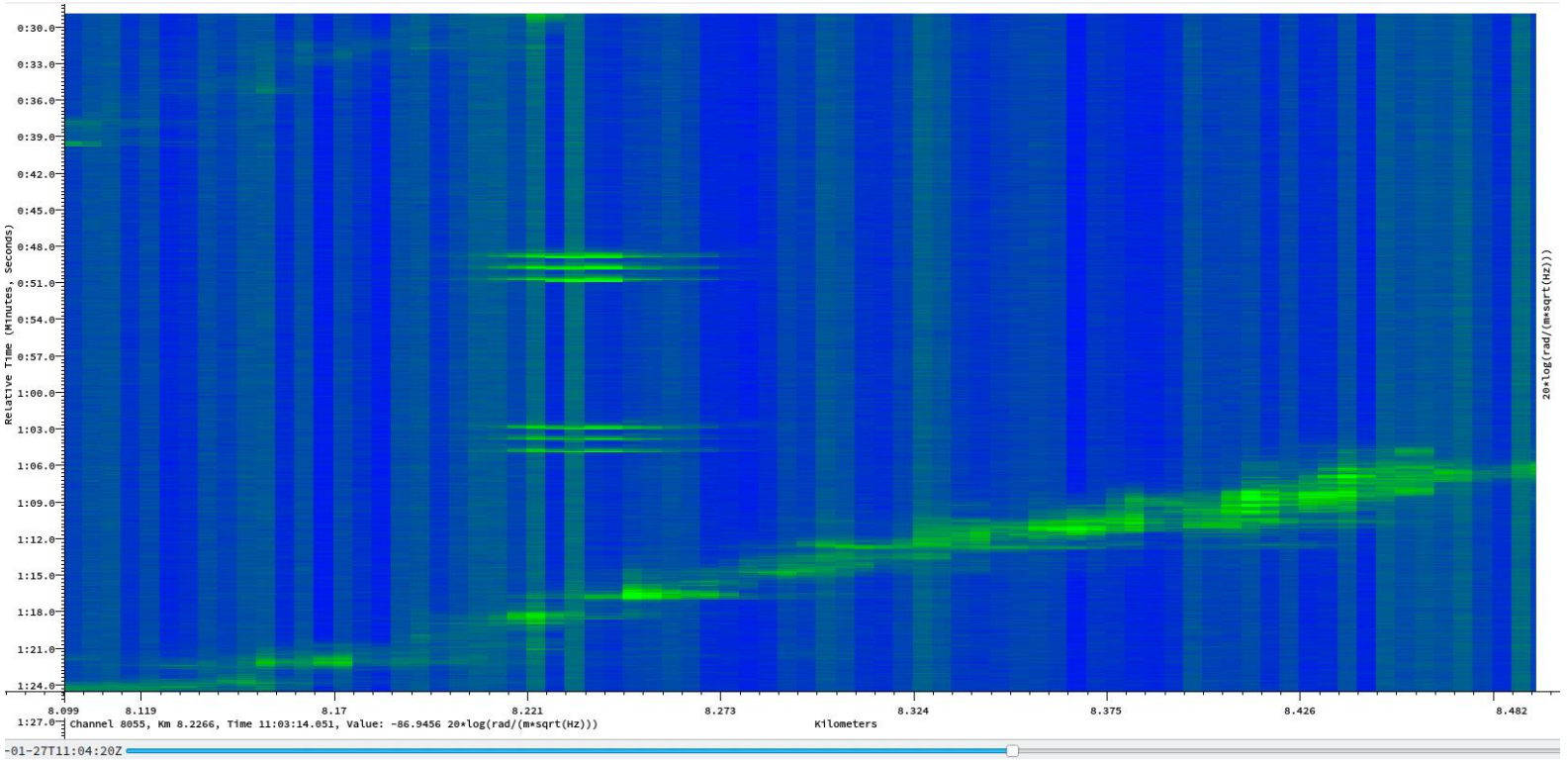
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Amplitude shows which side of the road





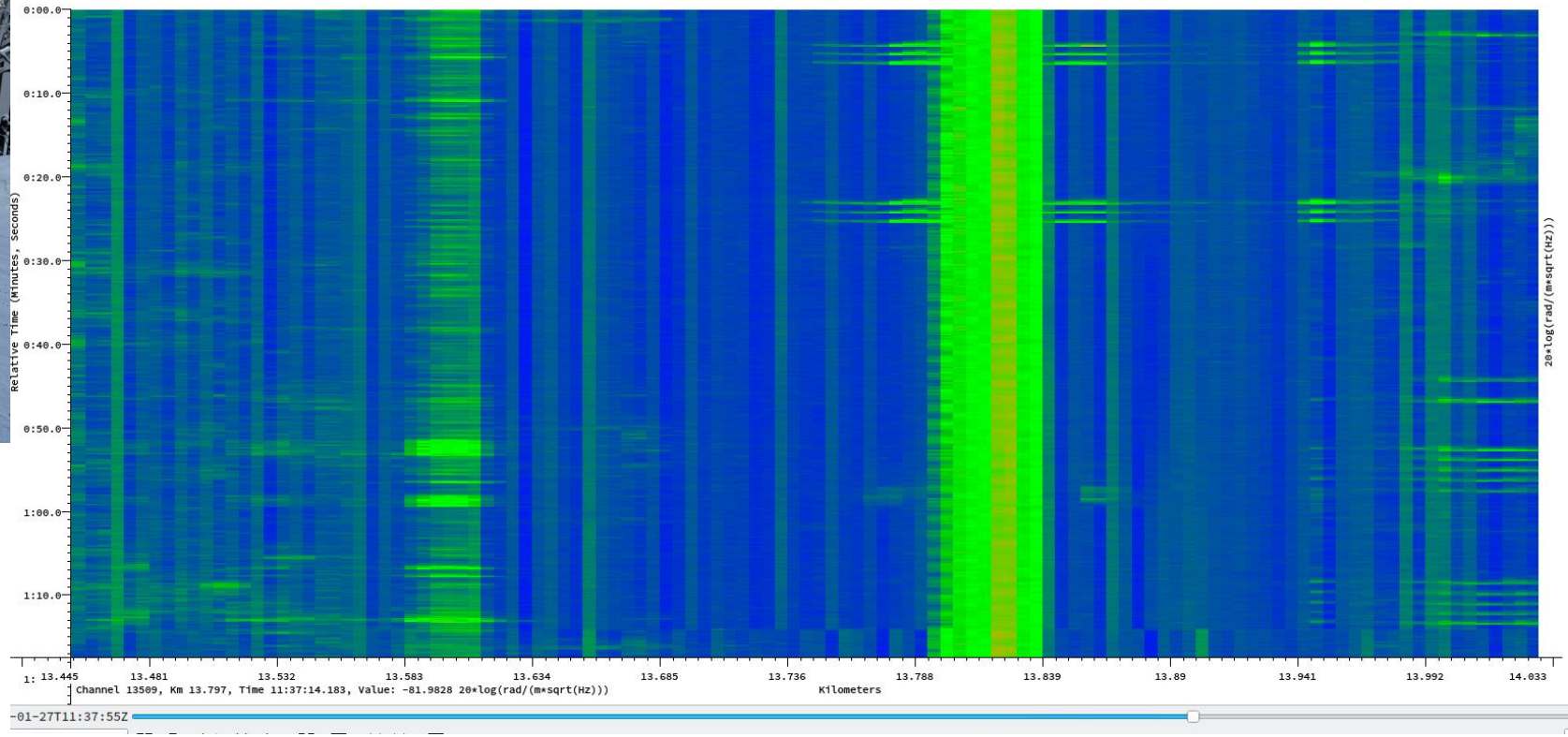




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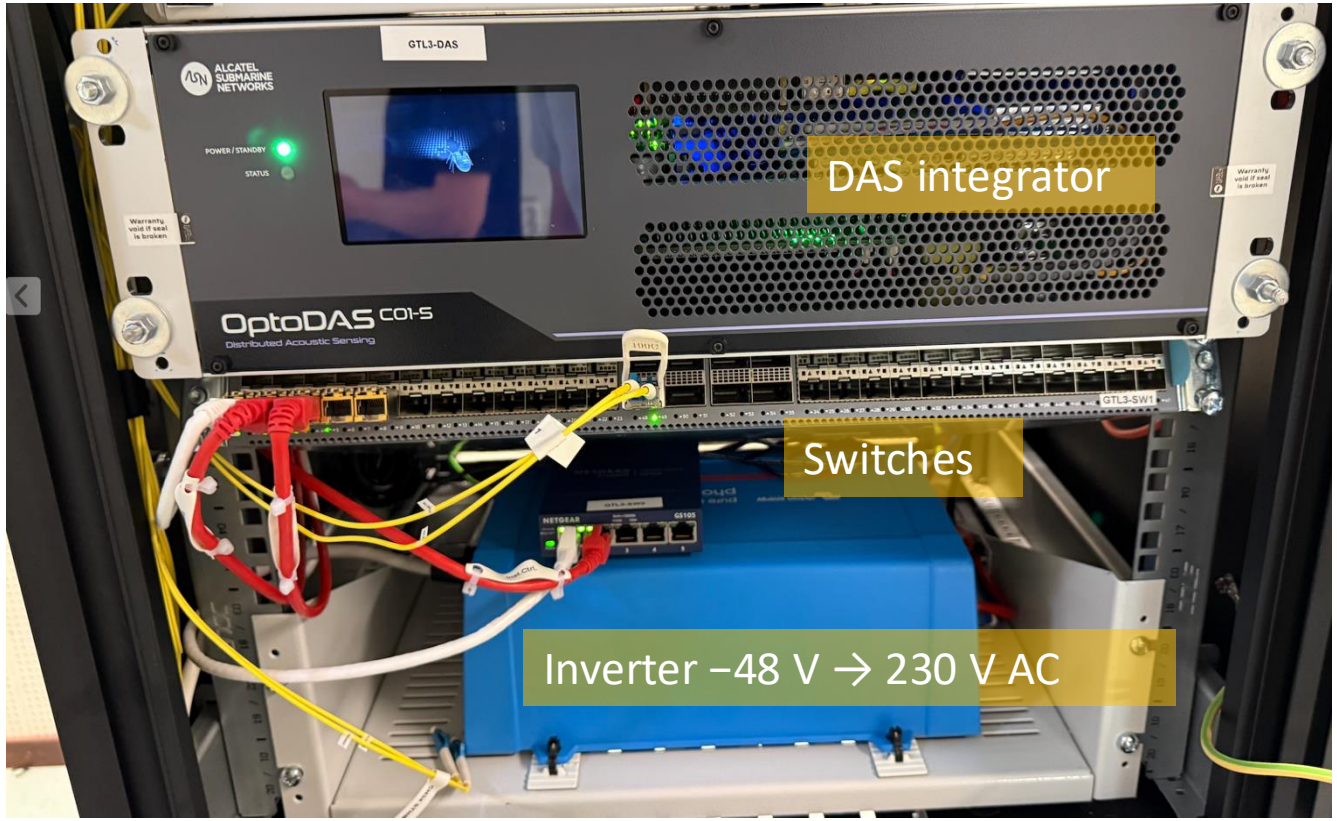
Why multiple signals at the same place?





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Three DAS systems in production



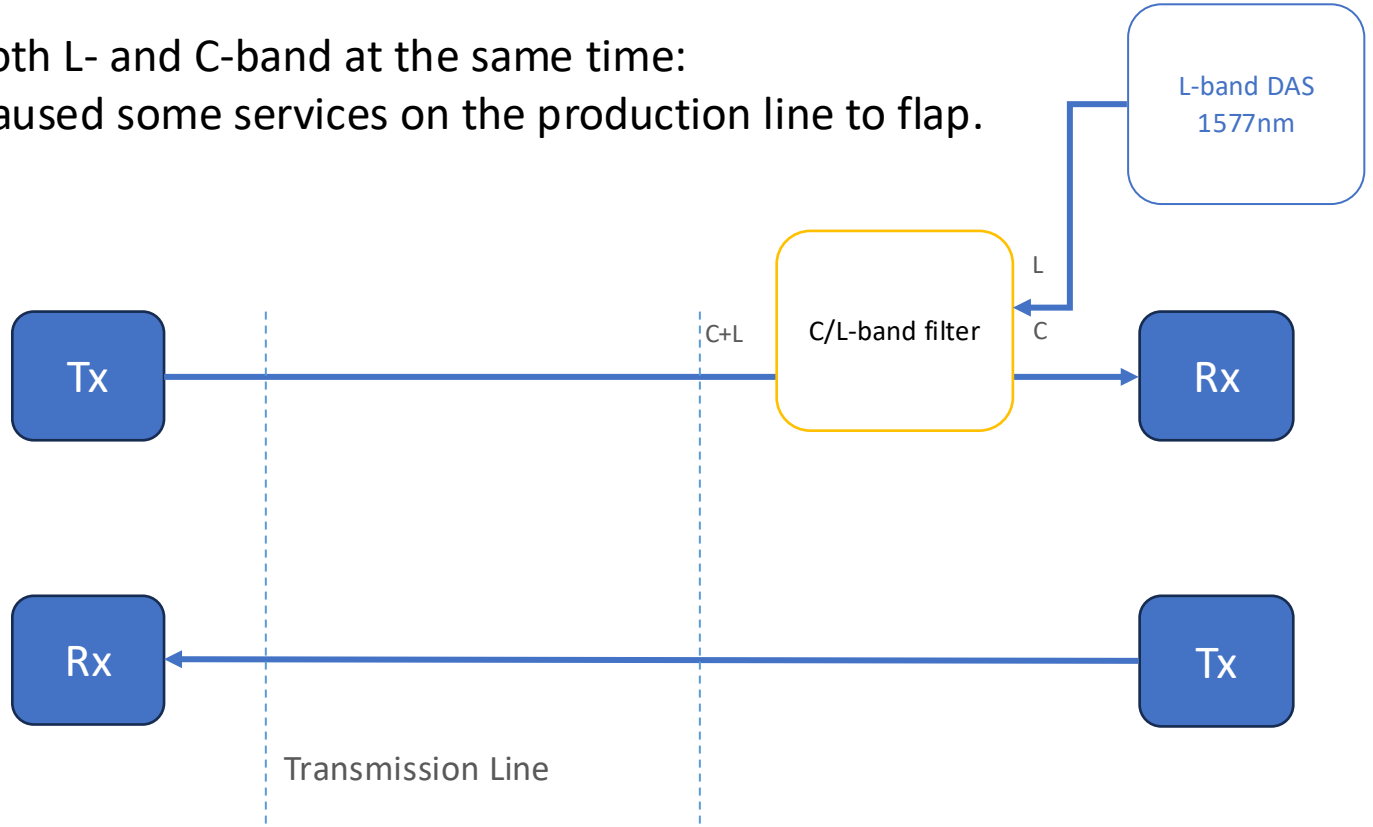


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DAS and DWDM on one fiber

Recommended way to connect DAS

Field trial with both L- and C-band at the same time:
It continuously caused some services on the production line to flap.

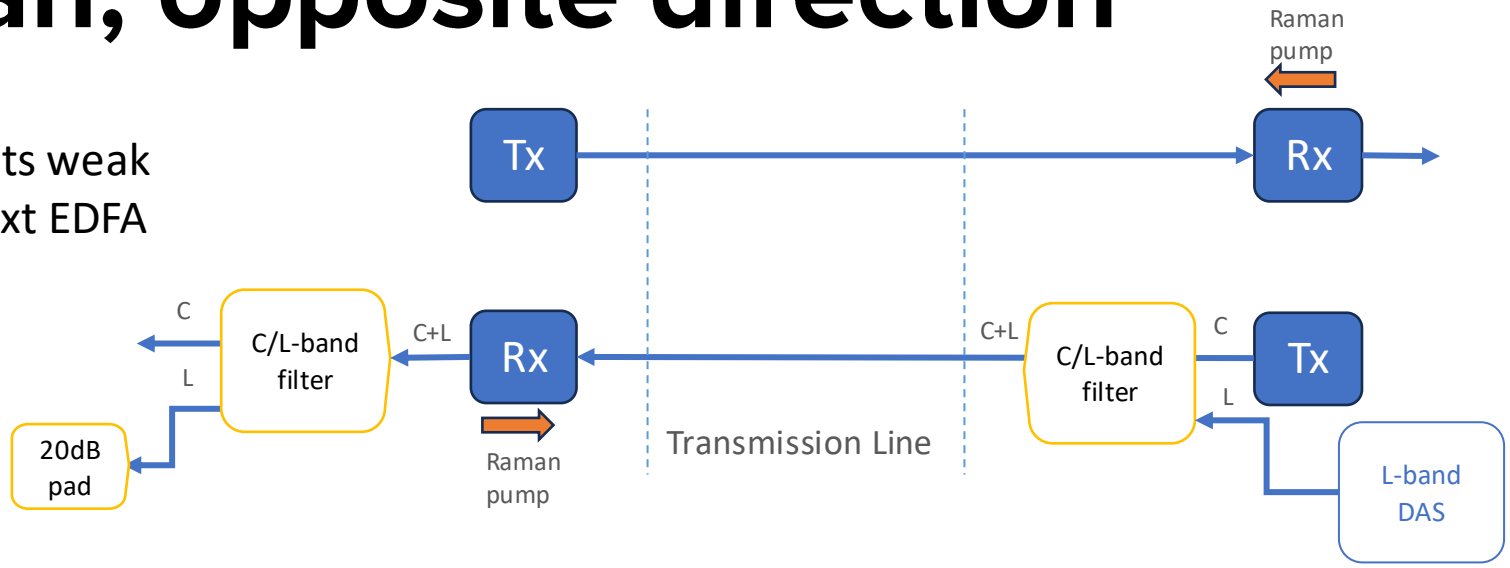




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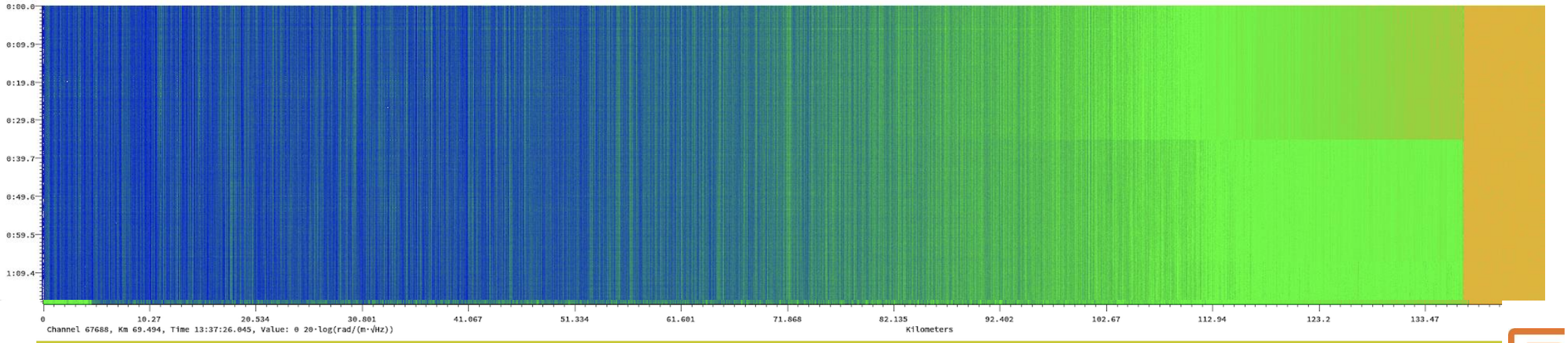
DAS and Raman, opposite direction

Raman gain where the DAS signal gets weak
DAS signal filtered out before the next EDFA



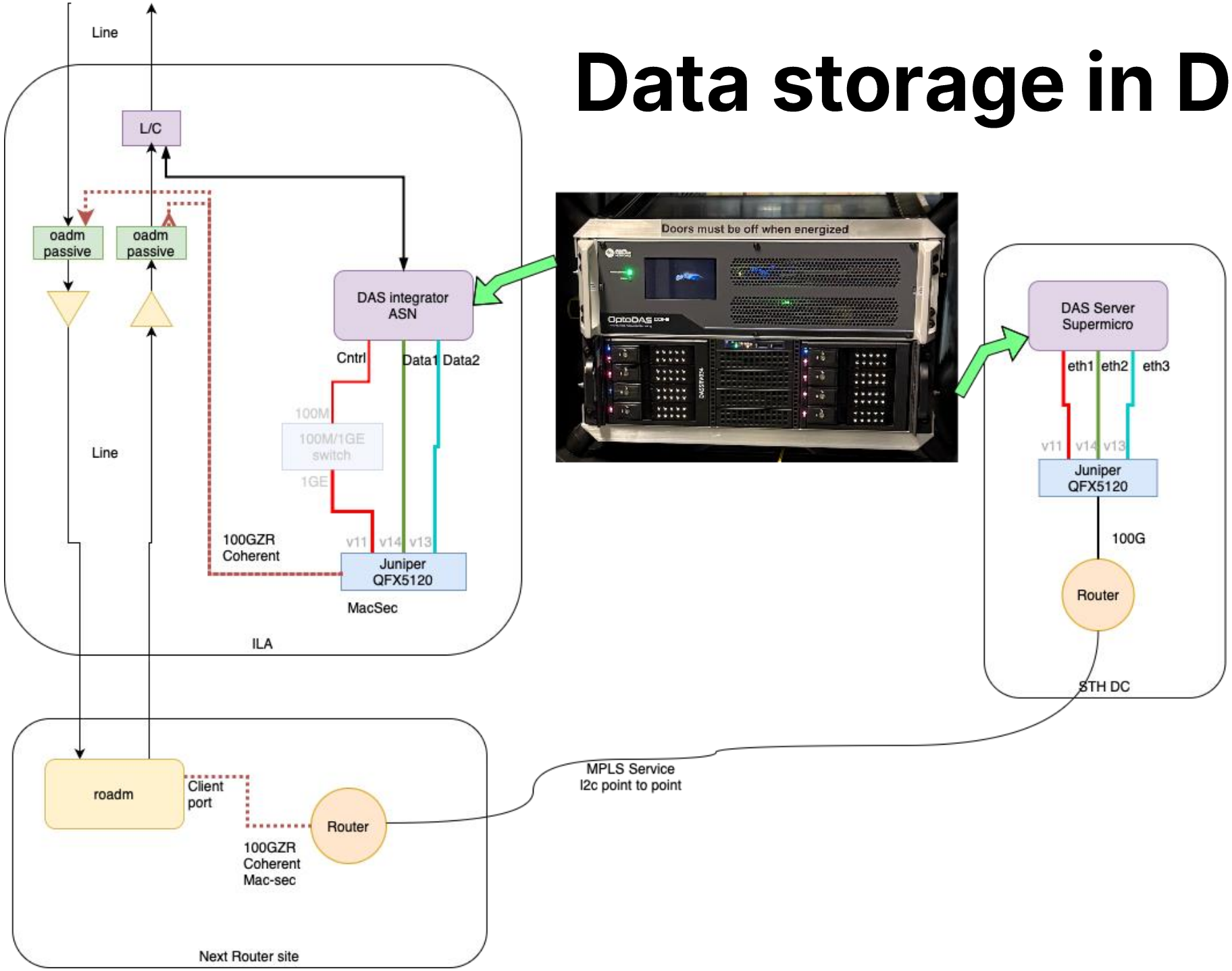
Raman Off

Raman On



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Data storage in DC



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Point event

- P-wave
- S-wave

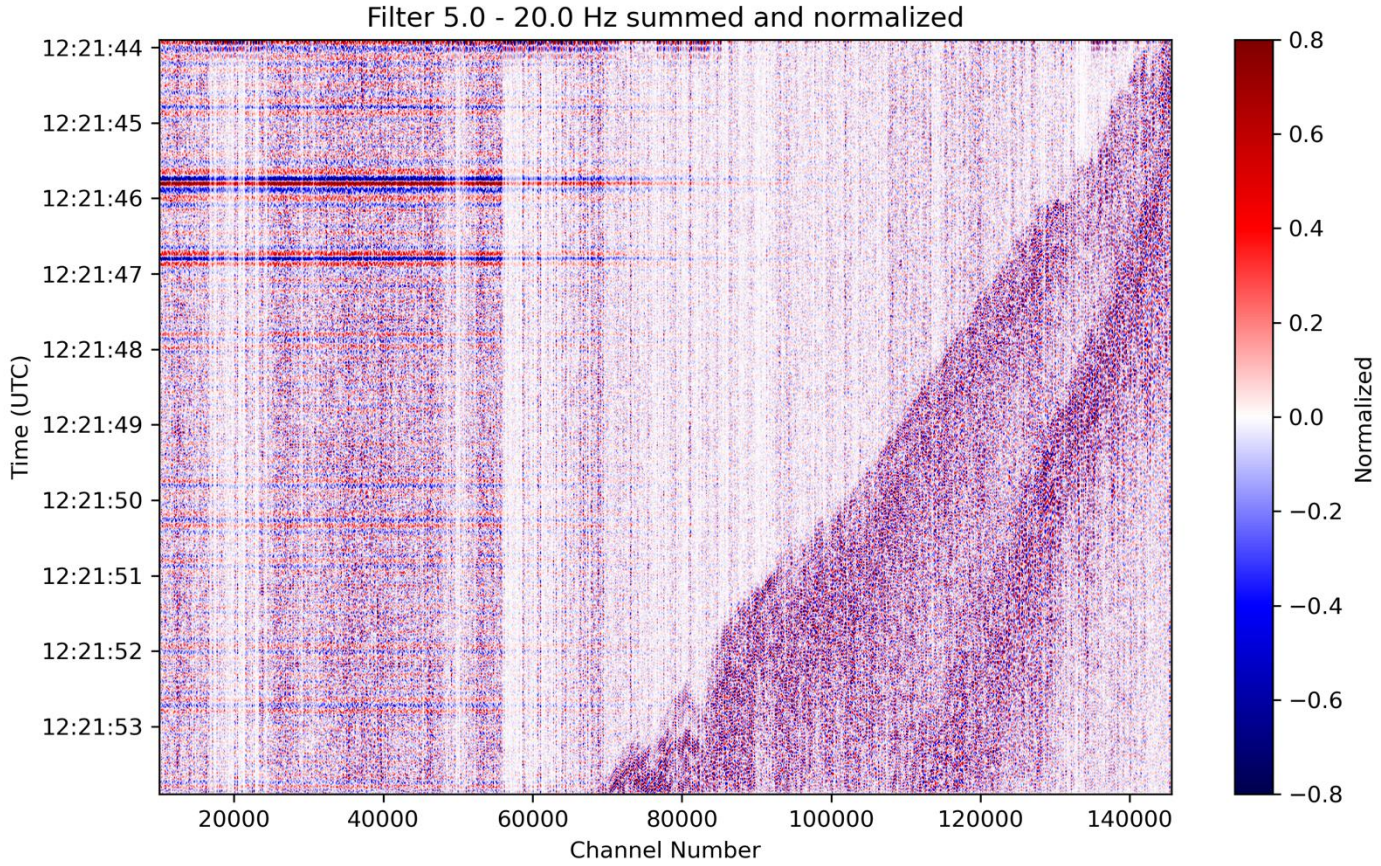


Image: Björn Lund

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Absolute amplitude

So far, we have only measured differences in amplitude.

But what is the absolute amplitude of the signal?

It changes depending on the type of cable.

In water, sound behaves the same over distance as long as the temperature is constant – unlike soil, which varies by type.

Cable:

- Dual-armored
- 26 mm diameter
- 15-ton strength
- 192 fibers





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Transfer function of the fiber





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Questions?



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