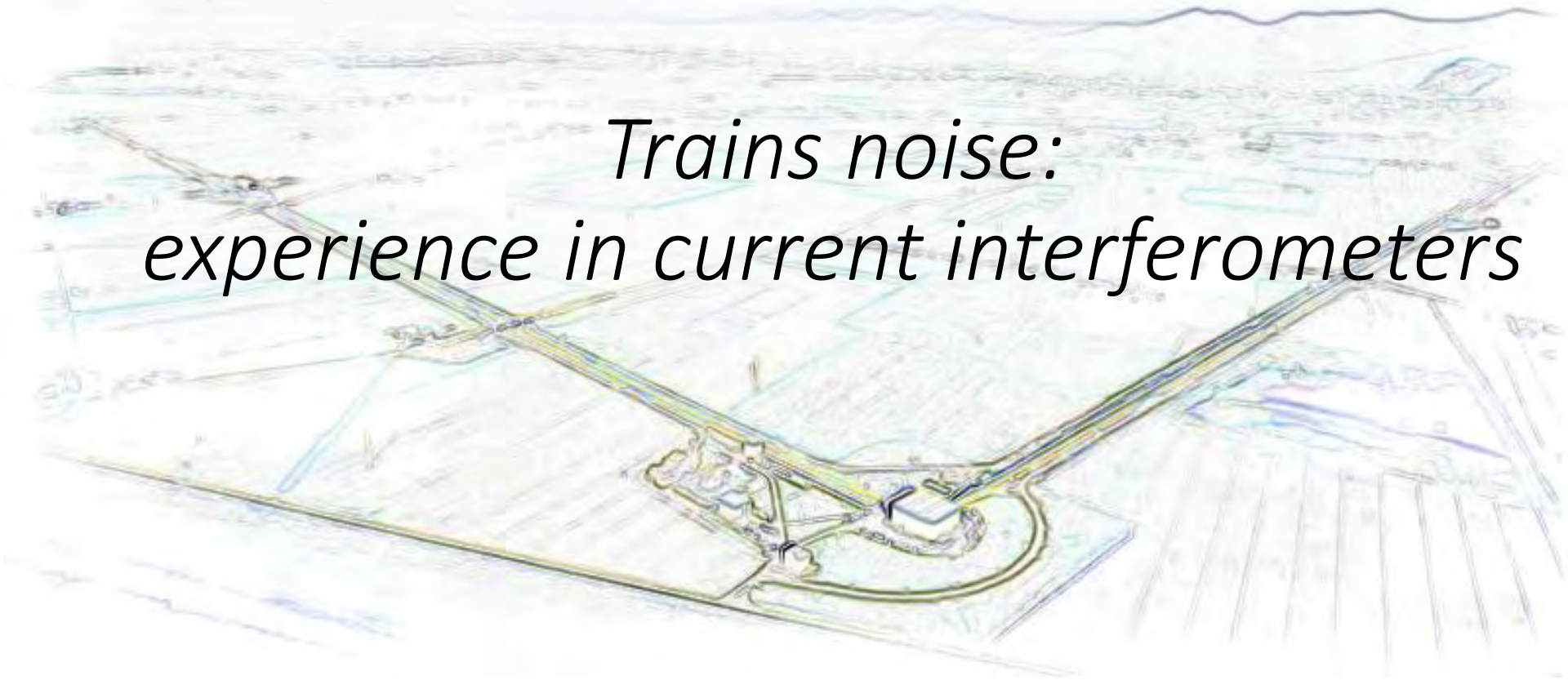


Trains noise: experience in current interferometers

Federico Paoletti, Irene Fiori, Maria Tringali, Renato Romero

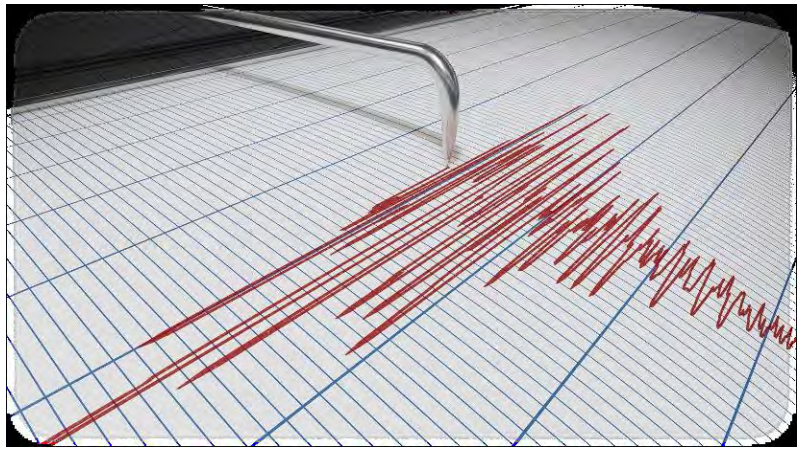
XIII ET Symposium - Cagliari 8-12 May 2023

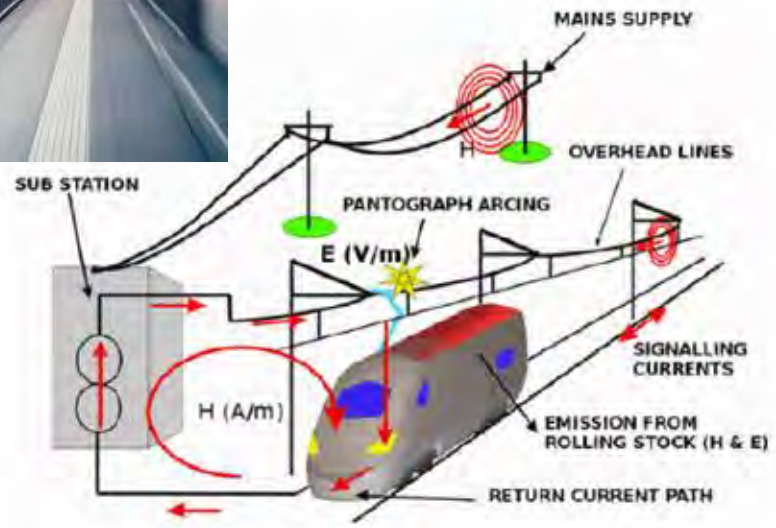
ET-0163A-23

Motivations

Trains are massive vehicles (>300 T) that use a lot of energy to move.
They can be a source of different types of noise, potentially impacting future underground interferometers:

- Acoustic
- Seismic
- Magnetic
- …

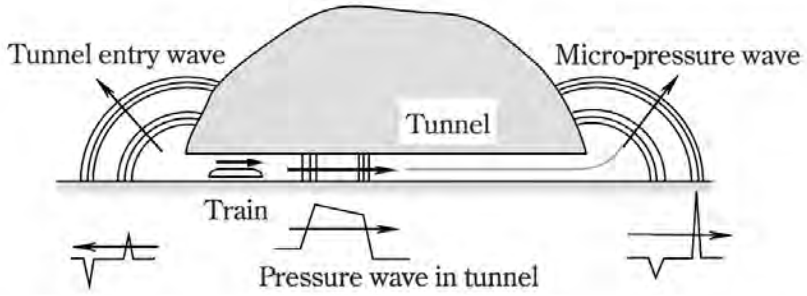




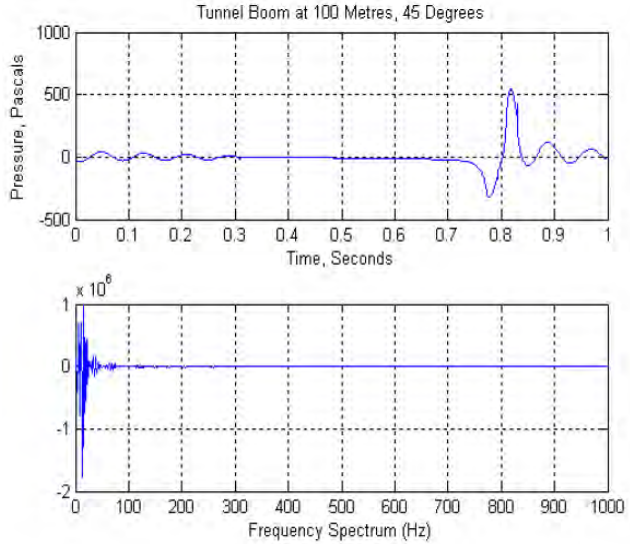
We report some preliminary measurements made near current ground-based interferometers

Acoustic noise

Example of an infrasound "boom" generated when a train enters in a tunnel:



Pressure waves generated when a train enters a tunnel



Tunnel boom at 100m and 45 degrees to the exit portal

Distance from the portal, m	Peak sound pressure level, dB
50	152
100	149
200	145
400	139

Tunnel boom variation with distance from the portal

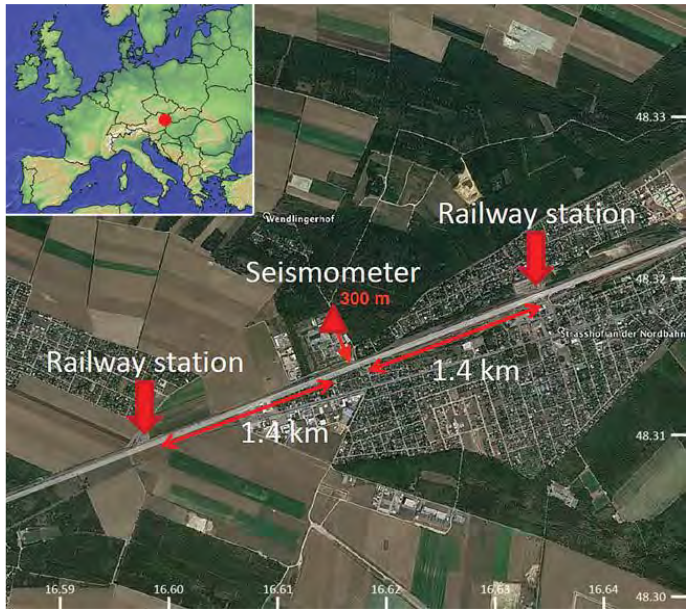
"… air shock waves generated by high-speed trains travelling in underground tunnels. This phenomenon, also known as 'tunnel boom', is associated with very loud and sharp noise, similar to that of cannon shots."
(*Krylov et al. (2015): Calculations of sound radiation associated with "tunnel boom'" from high-speed trains*)

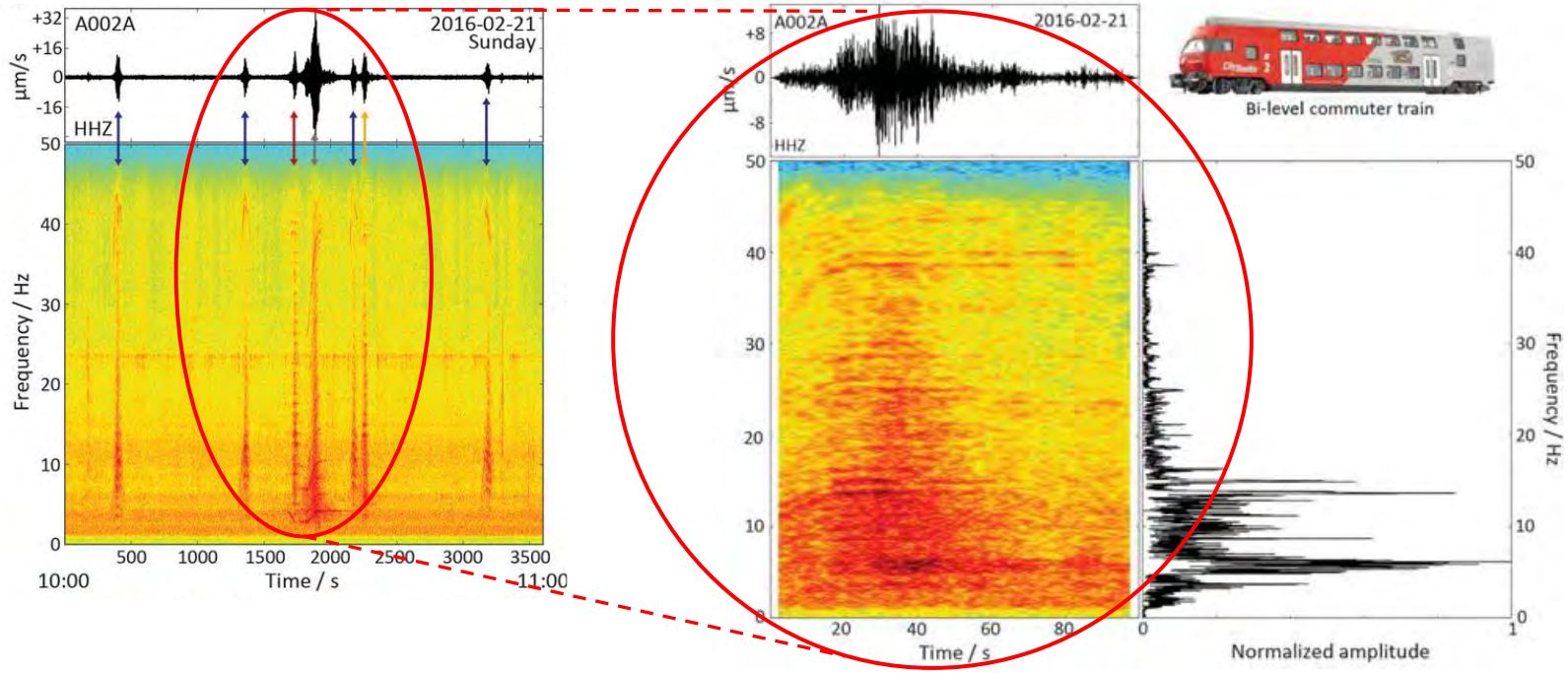
- This wave pressure can propagate into underground caverns.
- Infrasound are known to be a concern for ground-based interferometers (VIR-0412A-19: no-fly zone over Virgo).
- A study of underground pressure wave propagation is underway in Sardinia (ET-0013A-23).

There is not much information on infrasound emissions far (km) from trains railways (but see next slides)

Seismic noise

Seismic due to trains is a well studied topic, with detailed literature on the argument.





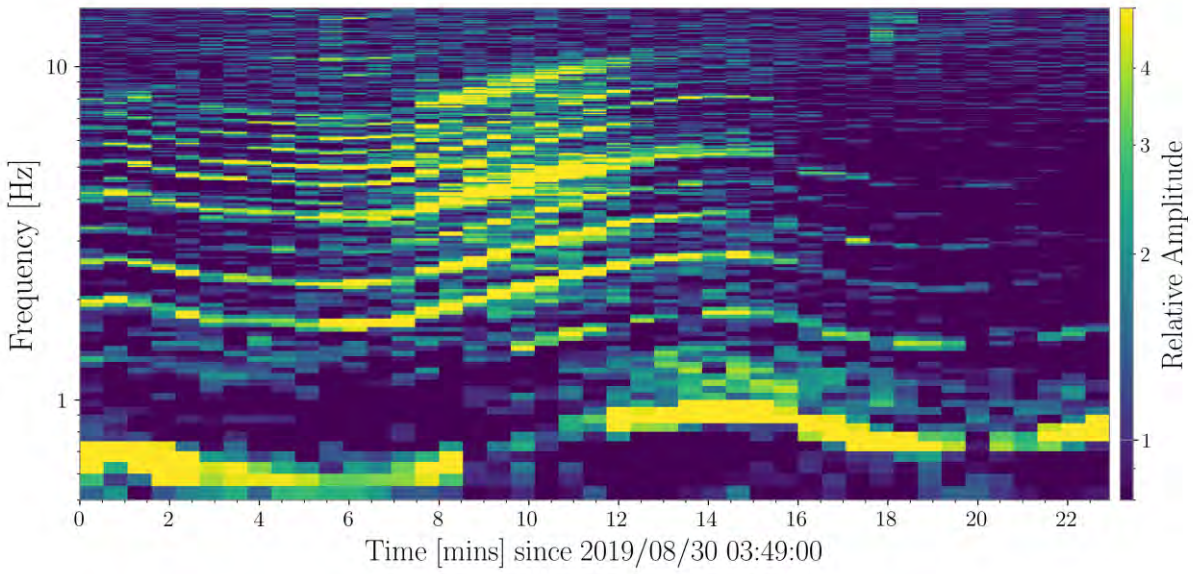
"All train-induced signals show the largest amplitudes around 10 Hz, with a secondary maximum that is sometimes observable around 40 Hz" *(Fuchs et al. (2016): Equidistant Spectral Lines in Train Vibrations)*

- The pattern is usually a broad noise from <1 Hz up to 40 Hz
- Propagation also depends on the composition of the soil

Seismic noise in LIGO site

LIGO made a study of seismic trains noise at LLO:

"Location of LLO relative to the train track in Livingston, Louisiana.
The track runs parallel to highway 190, which passes through Livingston.
*The **end of the Y arm** is approximately <u>two miles</u> (>3 km) from the track."*

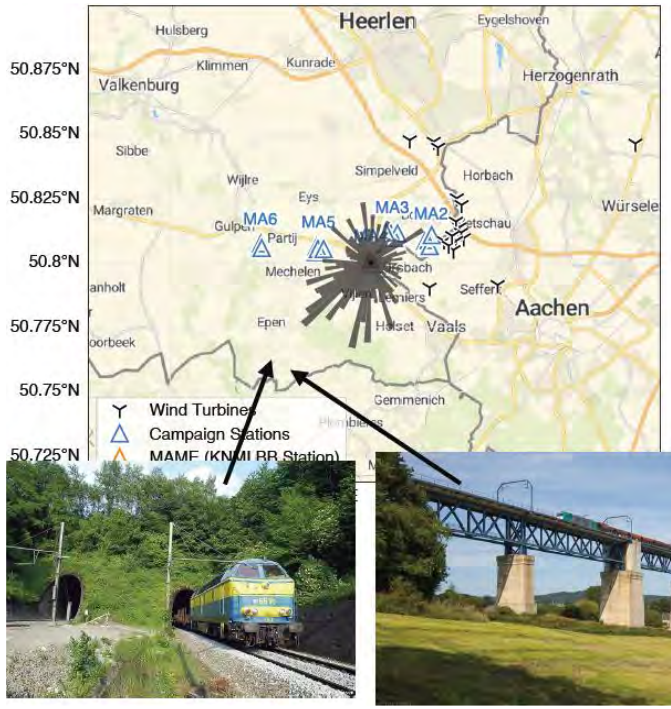


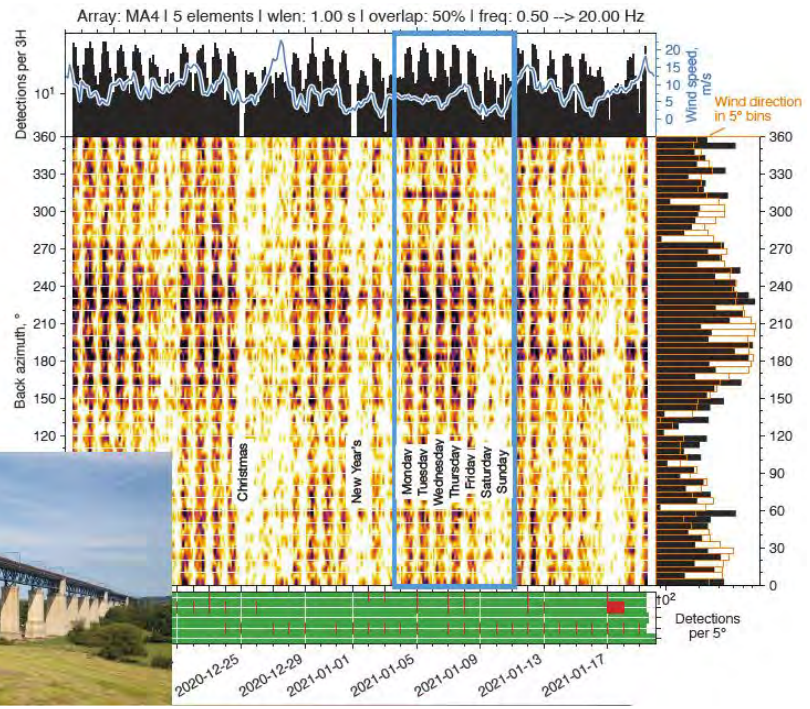
Ground motion produced by trains
*(spectrogram of data from Y channel of the seismometer at **ETMY**)*

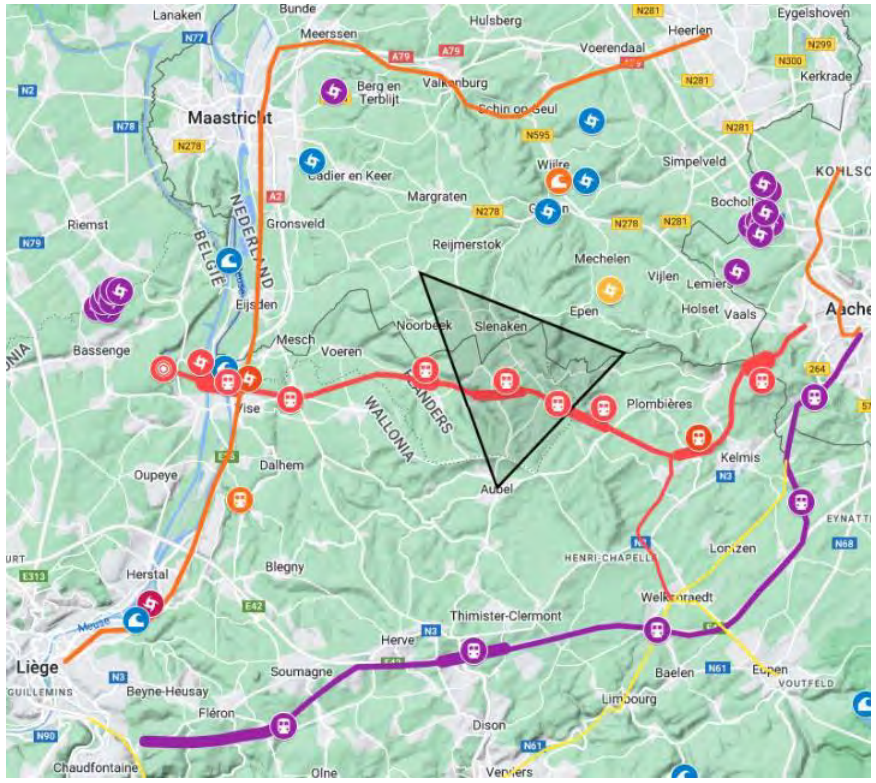
"Trains near the LIGO Livingston detector produce low frequency (0.5–10) Hz ground noise that couples into the gravitational wave sensitive frequency band (10–100) Hz through light reflected in mirrors and other surfaces."
(Glanzer et al. (2019): Noise in the LIGO Livingston Gravitational Wave Observatory due to Trains)

Seismic noise in EMR site

Similar study is ongoing in the Meuse–Rhine Euroregion:







The vertexes are located at 4-6 km from the ERWs.

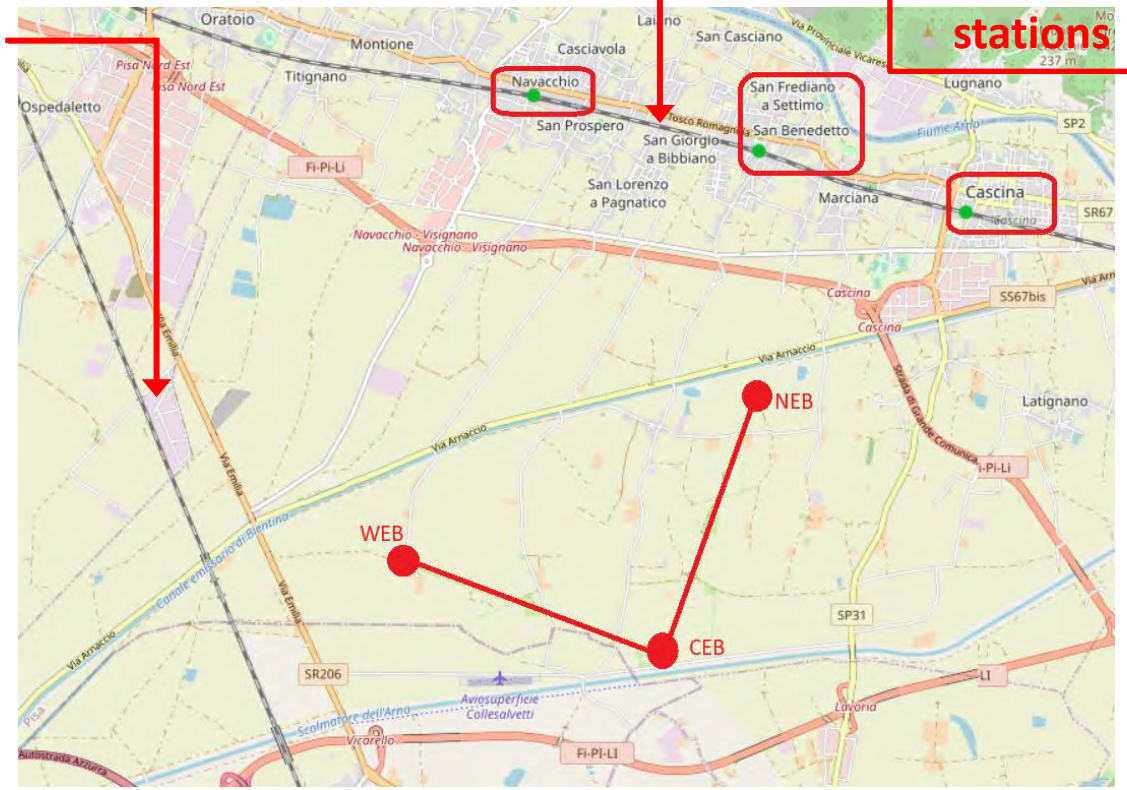
(*Shahar Shani-Kadmiel • ET SPB • March 29, 2023*)

- Distance of Vertex from ERWs is similar to the LIGO LLO situation.

Railways close to Virgo site

Virgo has two Electric Railways (ERW) close to terminal buildings:

- Passenger + freight 2km from **North End Building**
- Freight only 2km from **West End Building**

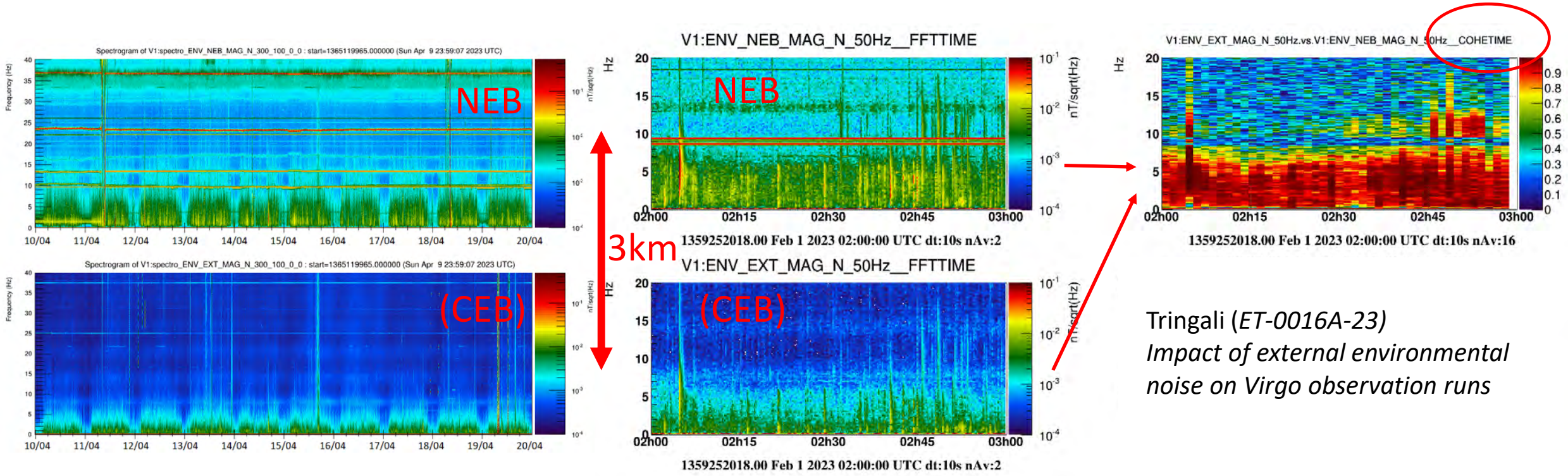


Available information (time-table) are on passenger trains only.
No info about freight trains.

Magnetic noise in Virgo site

We found site-wide low-frequency glitches correlated among distant magnetometers

- Clear a recurring daily pattern, but not weekly or holidays.
- It is anthropic but is not vehicles traffic.



Tringali (*ET-0016A-23)*
Impact of external environmental noise on Virgo observation runs

This triggered an (ongoing) analysis on the trains magnetic noise

- we decided to put a magnetic sensor at the nearest *railway station*

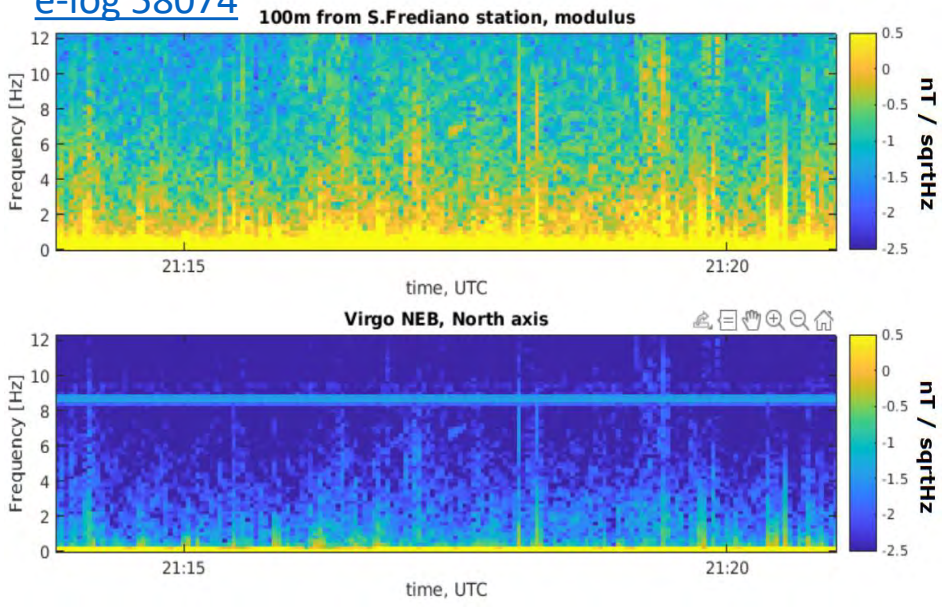
Magnetic noise pattern

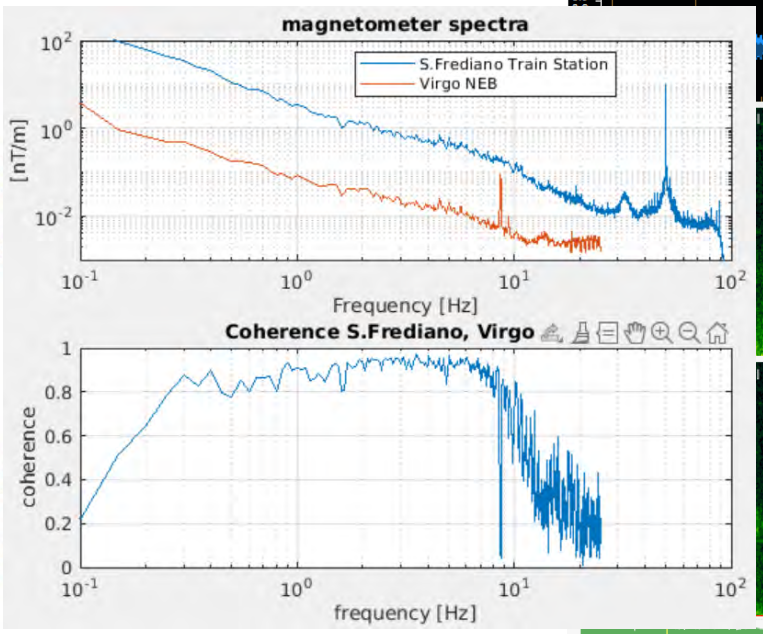
We found two kinds of noise

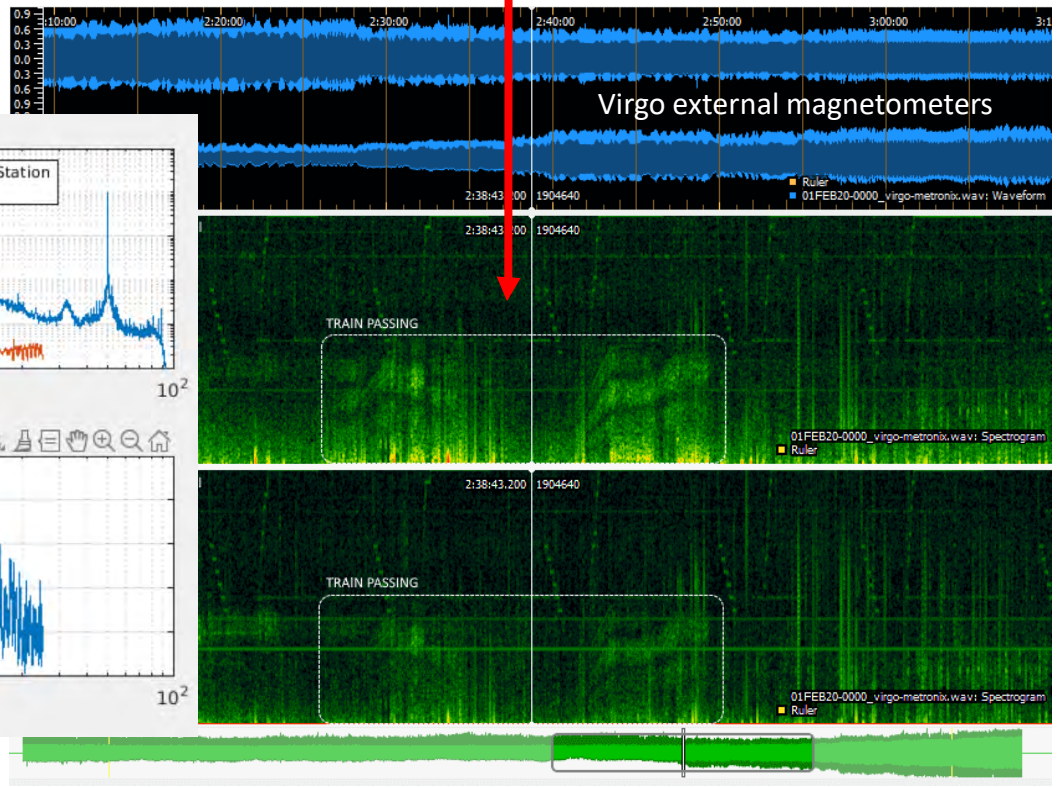
- Correlated "butterfly" pattern
- Site-wide low-frequency magnetic glitches

Credit: Renato Romero (www.vlf.it)

e-log 58074





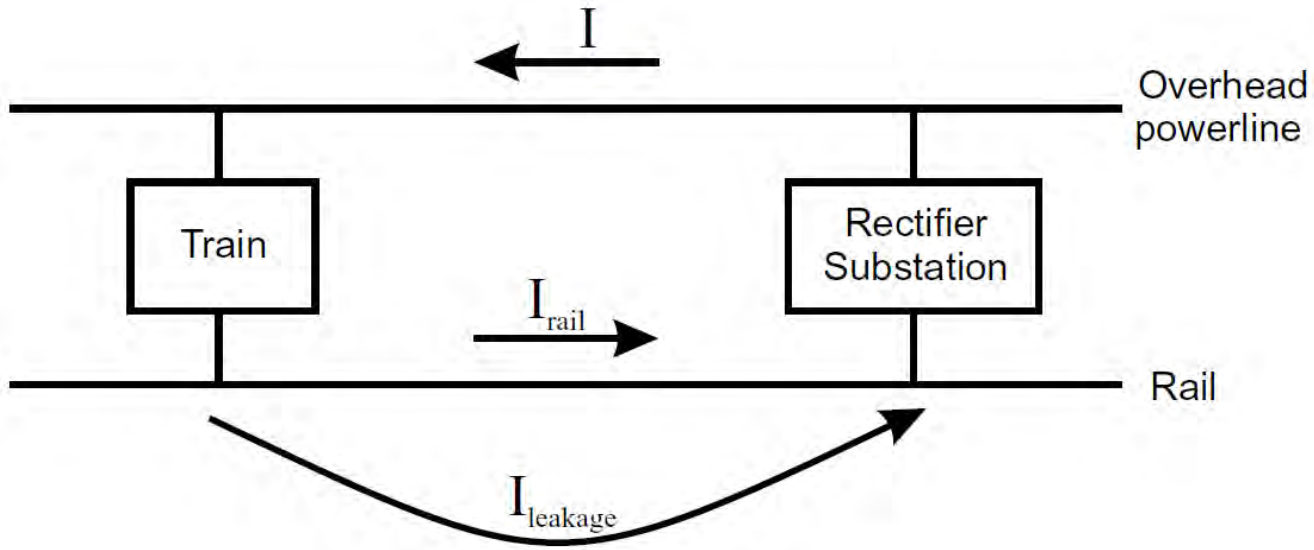


- The "butterfly" is the magnetic pattern of the train change of speed while approaching the station.
- The glitches are spikes of current travelling on the overhead line and returning to ground via railways and trough the soil (F. J. Lowes, 2009)

Overhead line: a brief description

DC electric railways near Virgo use an overhead 3kV line, with the rails as current return path

- Power involved can be as high as few MW, with current up to 1 kA



Mean distance between Rectifier Substations is usually ~20 km

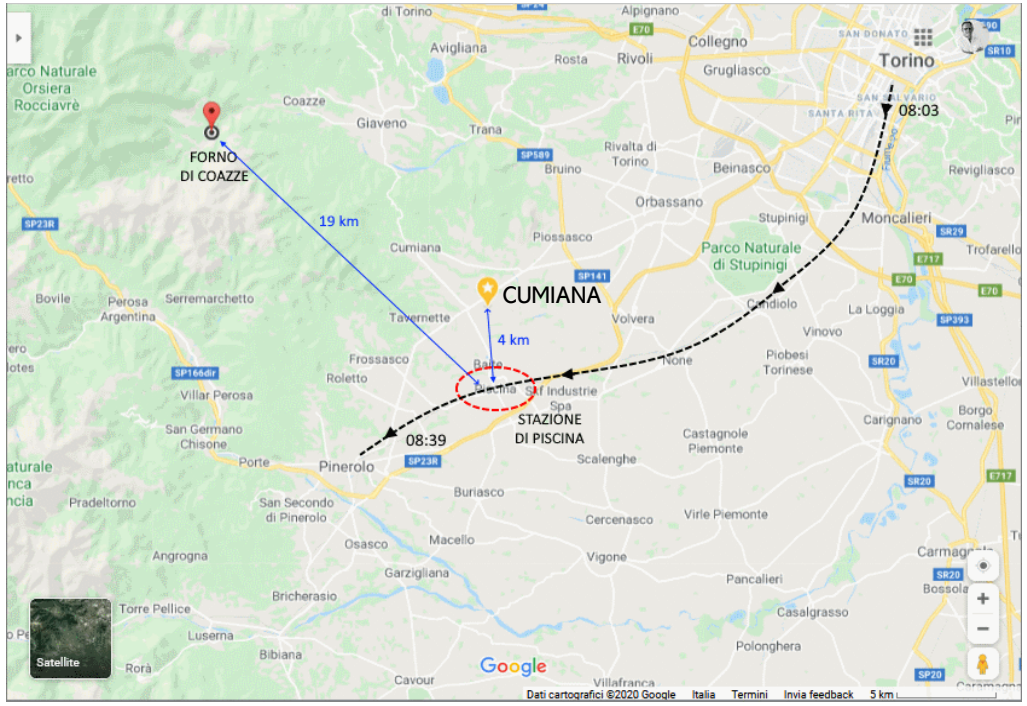
Pàdua et al. - Disturbances on magnetotelluric data due to DC electrified railway

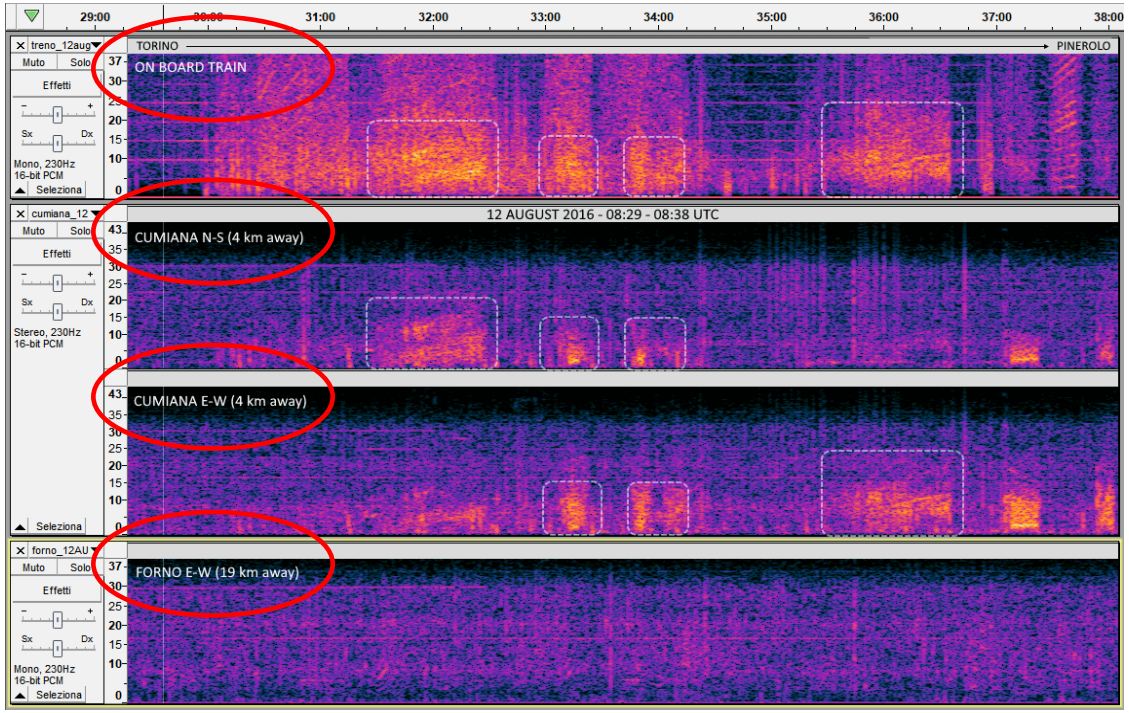
DC electric railways produce magnetic fields, not only from the intended traction currents, but also from unintended earth-leakage currents as the rails are not perfectly isolated from ground, producing large EM fluctuations.

Magnetic noise outside Virgo

We also have further confirmation looking at a test done by our collaborator Renato Romero in Aug. 2016.

Credits:
Renato Romero,
Claudio Re, Fabrizio Francione





Black dot line: the railway with an ON-BOARD sensor; other sensors at CUMIANA (4km) and FORNO (19km)

The train magnetic pattern is clearly visible 4 km far from it (not visible "by eye" at 19 km)

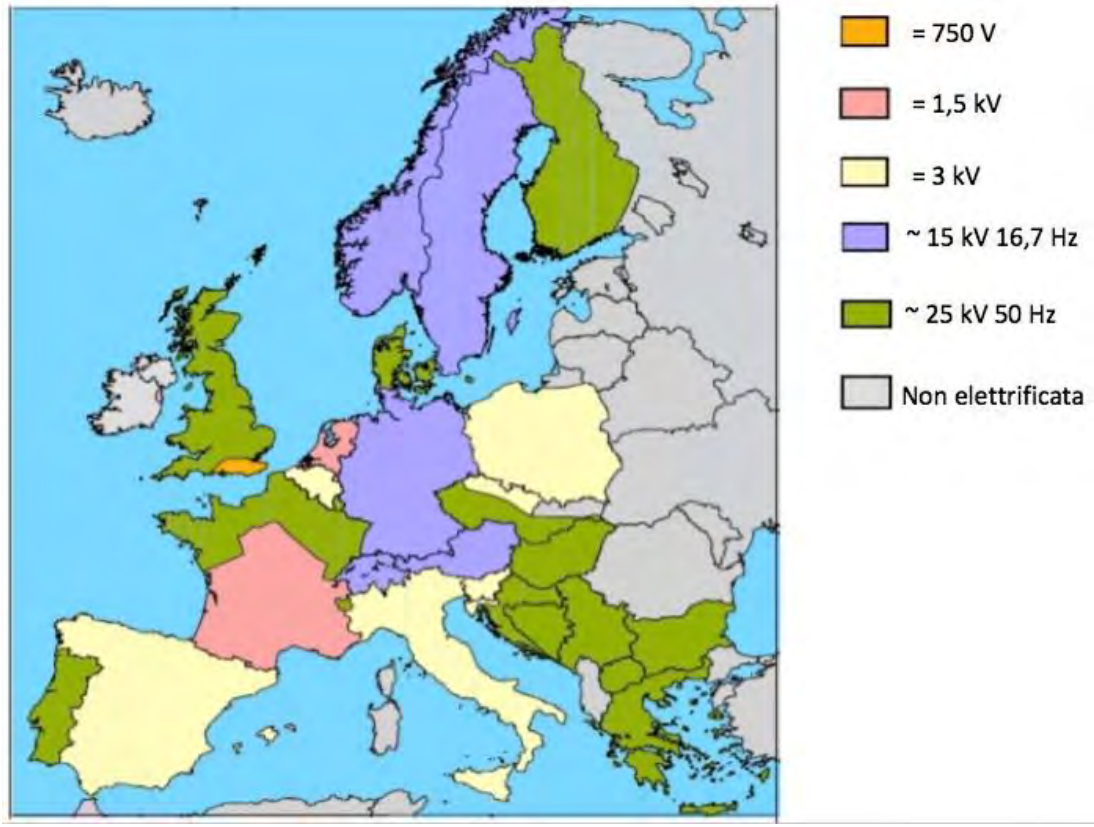
- It consists in a noise from DC to ~20Hz (depending on speed)

CAVEAT: The test was carried out on a small three-cars passenger train.

Power supply of EU railways

Other types of railways use 25 kV - 50 Hz AC voltage

- Magnetic pattern could be different (e.g. PWM with sidebands all around 50 Hz)
- In EU there are also railways with $16.\overline{6}$ Hz (Swiss, Deutschland, *Österreich*) or 16.7 Hz (Sweden, Norway) AC voltage



Kind and distribution in EU of overhead trains supply

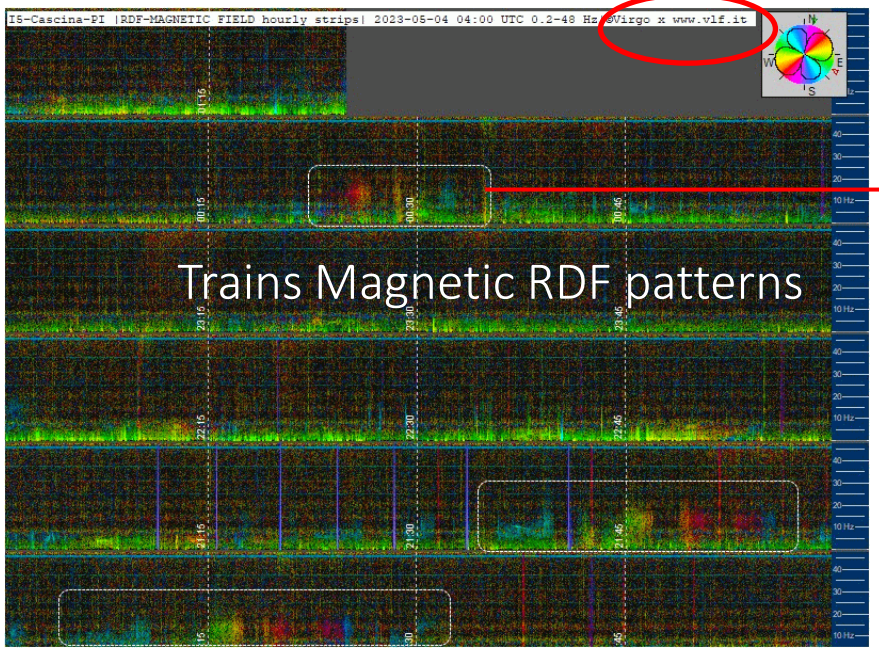
We need a wide measurement campaign to assess the effect of trains magnetic emission

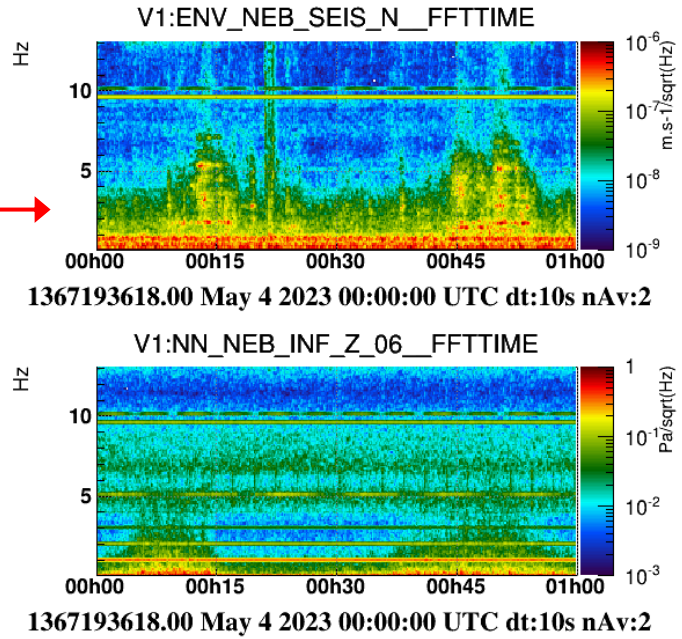
Magnetic + Seismic + Acoustic

Magnetic RDS (Radio Detection Finder) technique combining the two external Virgo magnetometers.

- It helps detect trains on ERWs near Virgo, making it easier to look for them in other sensors

Credit: **Wolfgang Büscher DL4YHF** (SpectrumLab)





Seismic

Infrasound

Virgo Central Building external magnetometers

3 km

Virgo North End Building sensors

Magnetic

2 km

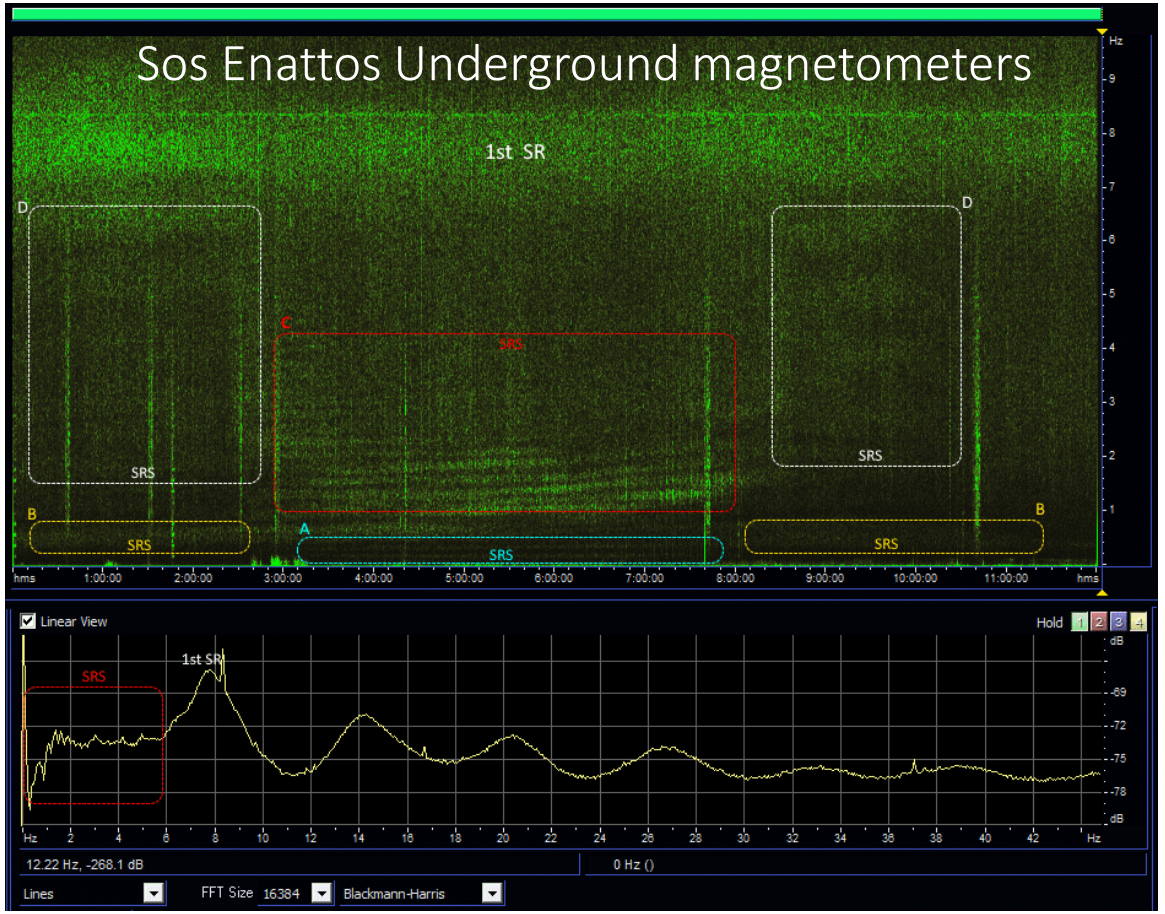
Pisa – Firenze ERW

<u>Preliminary</u> analysis suggests that we can observe all these three noises in Virgo sensors.

- Magnetic patterns is well visible 5 km far from the Pisa – Firenze railway

Noise at Sos Enattos site

Sos Enattos is quite distant from railways (~30 km from the nearest ERW)



- Indeed, the region 0 to 40 Hz is magnetically clean enough to clearly detect up to the sixth Schumann resonance, and the SRS (Alfvén *Spectral Resonance Structure*)

Conclusions

- Initial measurements suggest that trains could be sources of noise:

  acoustic, seismic, magnetic.

- Open question:

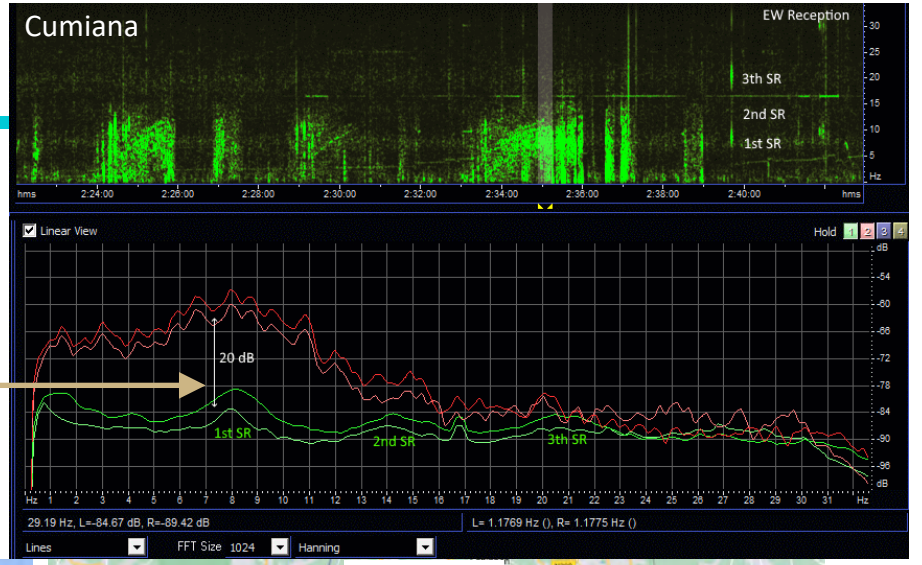
  how some of these noises propagate underground

- Could trains play a role for Newtonian Noise?

  leave the floor to the experts

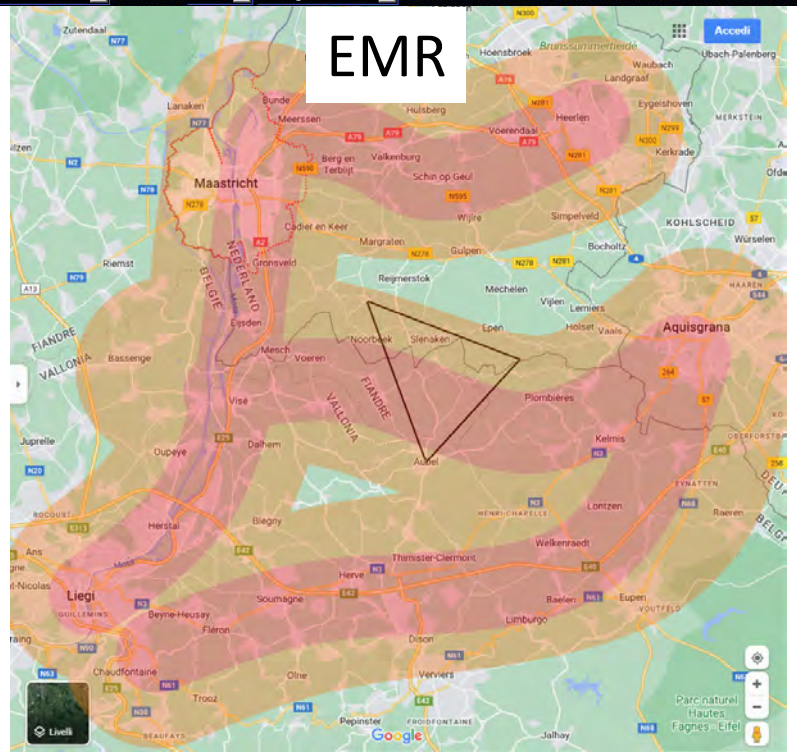
Thank you for your attention

Backup slide



Presumed train magnetic noise using data of Cumiana test:

- light pink: 2km from ERW (38dB over Schumann resonances)
- light orange: 4km from ERW (20dB over Schumann resonances)



(note: **maps are not in scale**)

Credit: Renato Romero (www.vlf.it)