The role of Magnetic noise in present GW detectors

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ET-0204A-26

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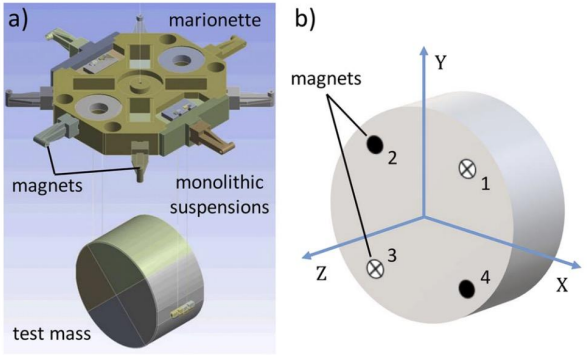
The Magnetic noise

$$h_{mag} = CF \cdot ASD_{mag}$$

$$\mathbf{F} = \nabla (\boldsymbol{\mu} \cdot \mathbf{B})$$

$$\tau = \mu \times \mathbf{B}$$



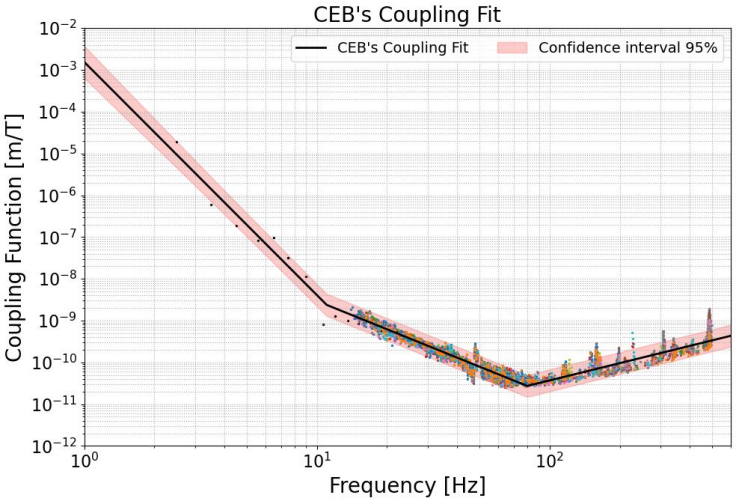
Contribution to interferometer sensitivity depends on <u>two multiplicative factors</u>:

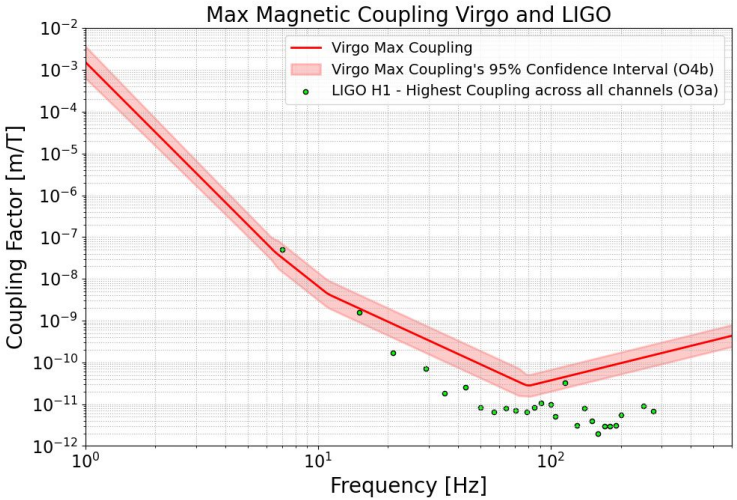
1. **Magnetic fields intensity** in the detector environment:
   - ❖ Natural sources - Earth magnetic field
   - ❖ Antropogenic sources - (see later in this talk)
   - ❖ Infrastructure (self-inflicted) sources - any device that poduces or carries currents (laboratory facility devices, electricity distribution, communication wires)

2. **Coupling strength** to “sensitive” points of the detector:
   - ❖ Magnetized components, especially if close to suspended optics and optical benches:
     - ➢ Actuation magnets on TMs and Suspension chains
     - ➢ Faraday isolator magnets
   - ❖ Electronics, by induction (in principle, but no evidence)

Measuring the Coupling to magnetic fields

We apply a controlled magnetic field in presence of witness sensors and measure the induced noise signal in the interferometer output. This was done periodically during the O4 observing run by both Virgo and Ligo.





What about ET?

An extrapolation of this coupling to the Einstein Telescope has been done, assuming the ET being an up-scaled version of Virgo, and that consequently magnetic coupling is dictated by the same physical mechanisms (ET-0058A-26):

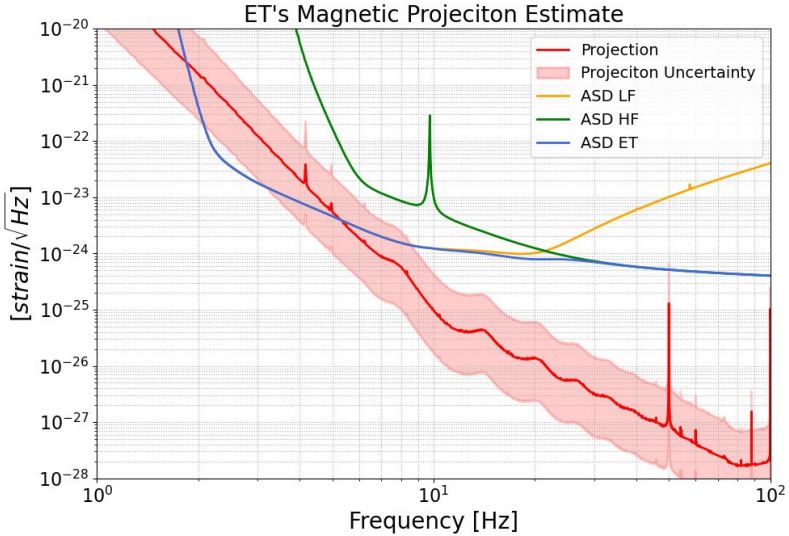
$$CF_{ET} = r \cdot CF_{\mathrm{Virgo}} \quad \text{where } r = \frac{m_{\mathrm{Virgo}}}{m_{\mathrm{ET}}}$$

The projected noise is estimated, for the Δ configuration with L= 10 km long arms, using as representative ambient noise, the very quiet spectrum - consistent with the Earth's geomagnetic field - measured underground at the Sos Enattos candidate site:

$$h_{\mathrm{MAG}}(f) = \frac{2}{L} \cdot CF_{\mathrm{ET}}(f) \cdot X_{\mathrm{med}}(f)$$

The noise produced by the Earth's magnetic field alone exceeds the ET design sensitivity by approximately a factor 10 at a few Hz.

… a somewhat concerning result.



How to achieve this mitigation goal?

We need a robust and comprehensive magnetic mitigation plan:

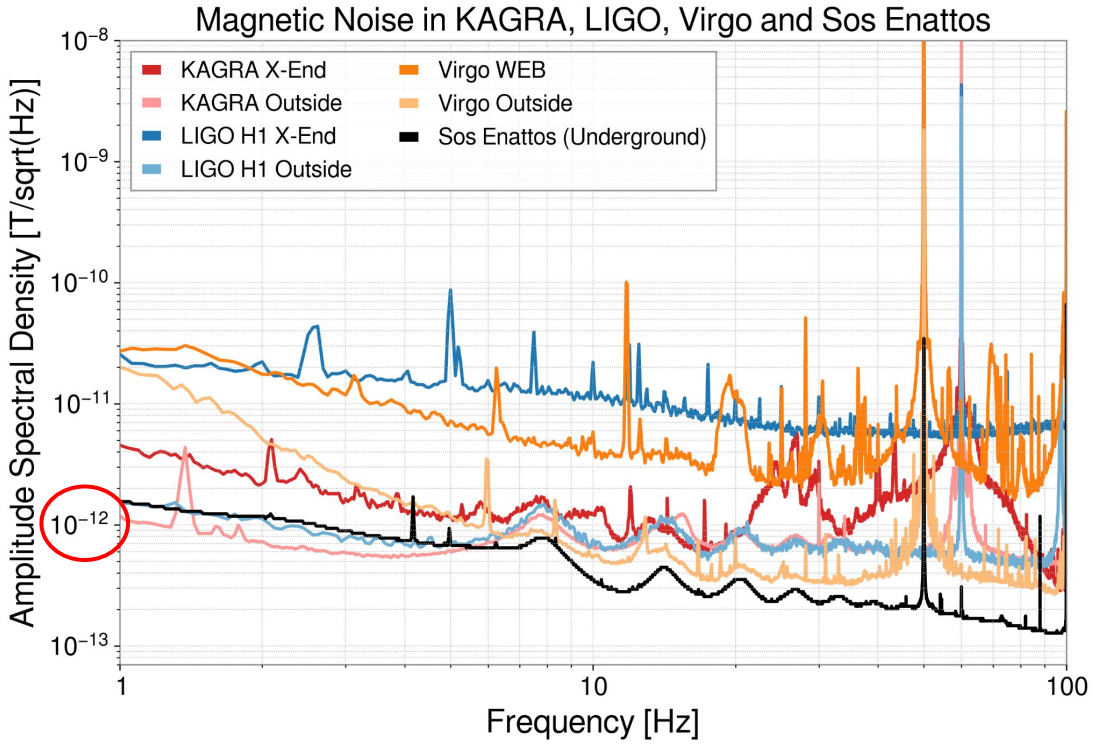
- **Reduce ambient noise of detector site** at the Earth magnetic field noise level
  - Minimize and control both anthropogenic and infrastructure noise sources
- **Shield sensitive detector locations** (further reduce ambient noise)
  - Magnetic shields (e.g. mu-metal, Eddy current, active shields)
- **Reduce coupling to the detector**
  - Reduce magnetic susceptibility of detector magnetized components (e.g. adopt actuation magnets in Halbach-like configuration, shields for Faraday isolators, avoid use of ferromagnetic materials …)

Activities ongoing within ANM-Magnetic Noise WP - see Barbara Garaventa ET-0248A-25

Magnetic noise at current GW detectors

Magnetic spectra at GW detectors sites are compared to Earth's geomagnetic field:

pT/√ Hz



Magnetic noise at Virgo

Transient noise glitches are seen in magnetometers site-wide

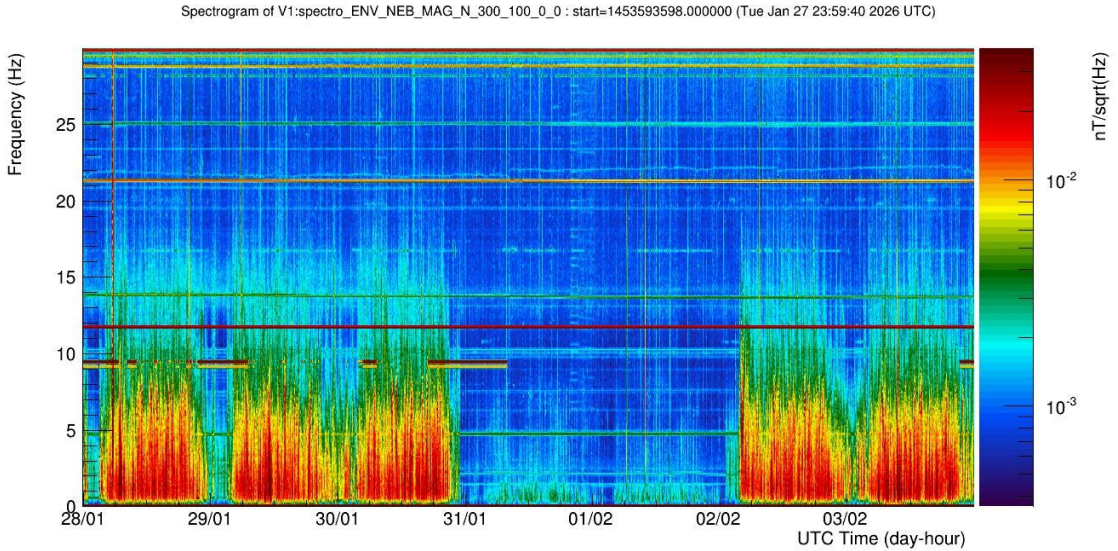
- **Frequency range: 0-15 Hz**
- **Typical intensity: a few tens of pT**
- **Clear daily modulation, with minima between 00:00–03:00 LT**

Significant reduction observed on January 31 and February 1st.

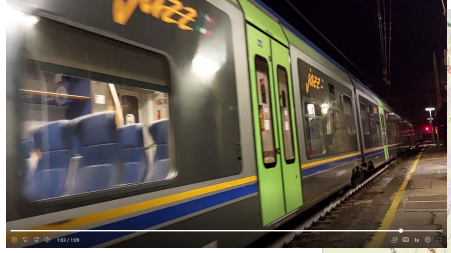
According to *Trenitalia*, the Pisa–Empoli railway line was de-energized on those days due to maintenance (no train traffic)

https://logbook.virgo-gw.eu/virgo/?r=68641

Magnetometer Virgo NEB, one week.

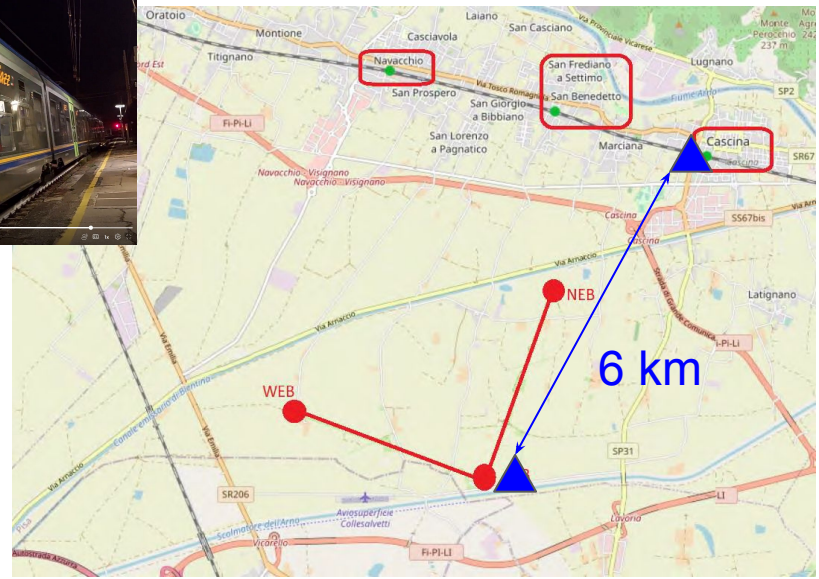


Trains noise @Virgo

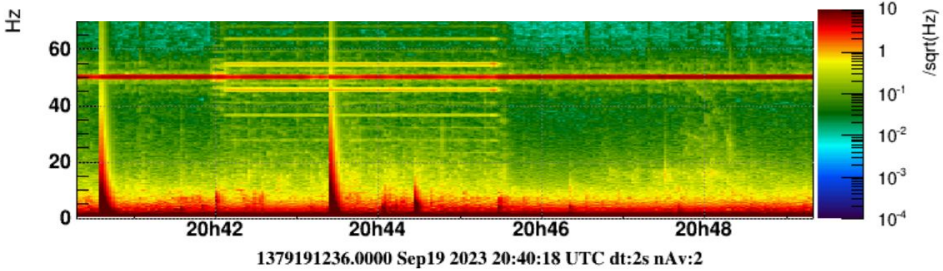


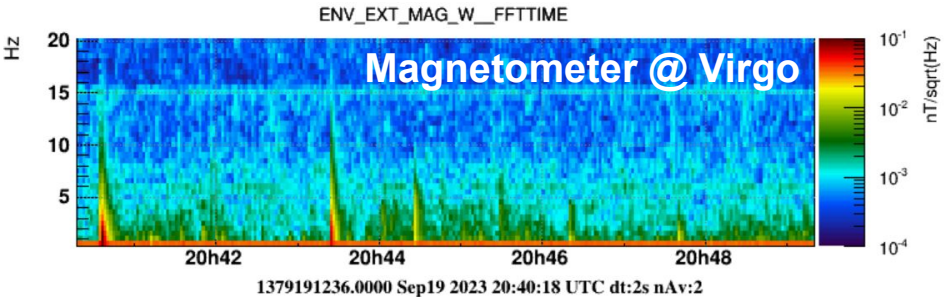
Credits: Olivier Nauwelaers, Max Lalleman (Antwerpen U.)

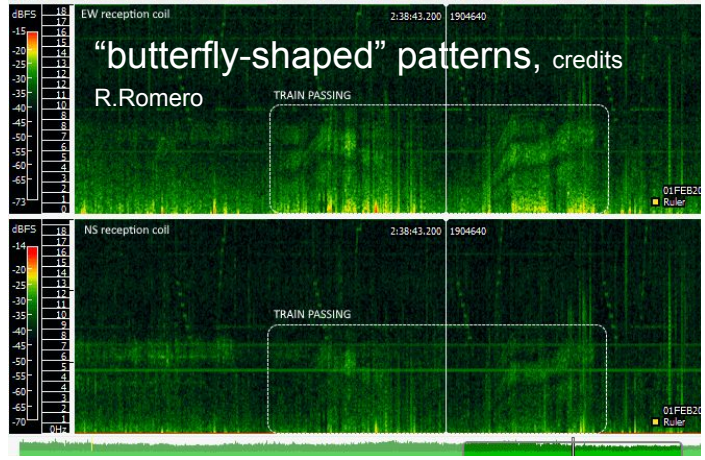
Measurements at Cascina station
Coincident signals are detected



Magnetometer @ Cascina train station







How the noise is produced?

Credits F.Paoletti - ET-0163A-23

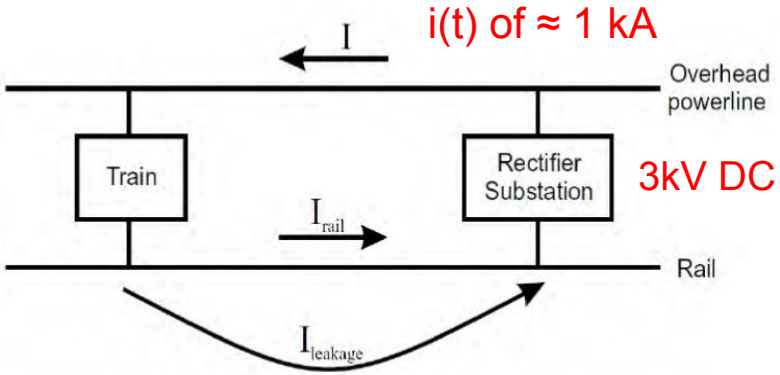
Possible mechanisms:

- Large currents (~1 kA) flow in the loop between the overhead power line and the rail
  - Current leakages propagate through soil (magnetotelluric currents) >> magnetic field
  - Induction from the railway current loop
- What happens underground? (to be investigated)

Fast glitches - when trains are crossing powering substations (every ~20 km) or when pantographs have bad contact (jumps) with the overhead powerline

Butterfly shaped patterns - due to variable power surging by the engine when the train accelerates or decelerates.

Railway electric scheme:



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

Trains noise @Virgo

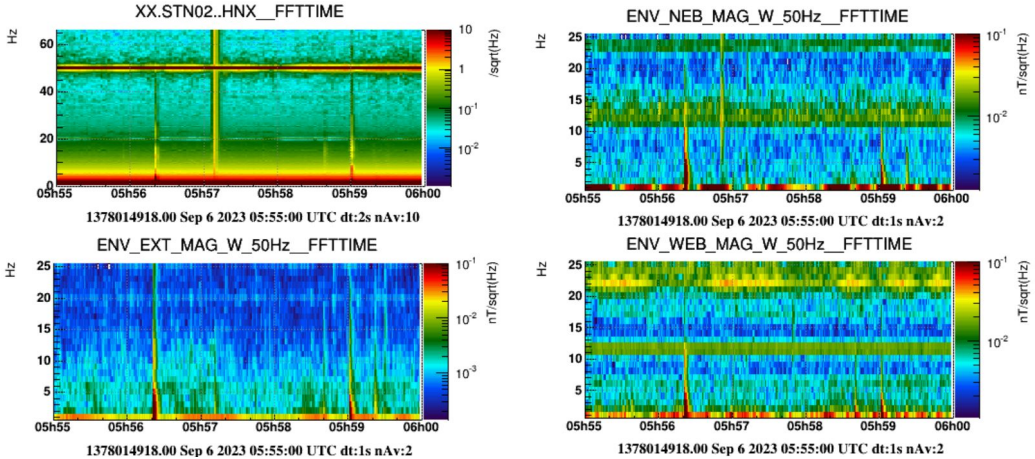
Magnetic signal is amplified in close proximity of Virgo arm tubes

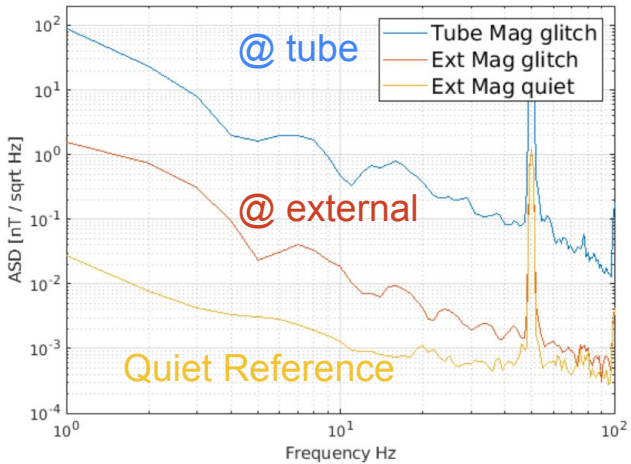
Field direction is consistent with a noisy current flowing along the tube

What is happening?

- noisy ambient fields induce currents in the tubes
- the tube is a low resistance path for telluric currents

To be further investigated.





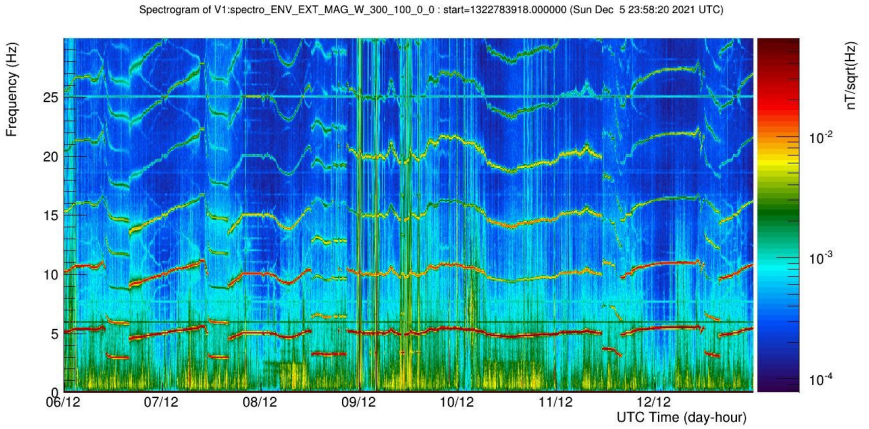
Other anthropogenic sources of magnetic noise

Noise from methane gas pipelines

Anti-corrosion currents flowing in the subsurface gas pipes, generate magnetic fields

Normally DC, but power supply malfunctionings might generate LF noise

One such noise affected the Virgo site from Nov 2021-Apr 2022



Credits: Lorenzo Pierini, Jean-Loup Raymond VIR-0310A-22 and Virgo elog 55542

Concluding remarks

- **Ambient magnetic noise at 1–10 Hz is identified as critical for ET performance.**
- **The target is to reduce the site ambient noise at the Earth magnetic noise level,**
  a. **addressing both anthropogenic and detector infrastructure sources**
  b. **further mitigate with proper shielding and minimizing the coupling at sensitive locations**
- **Anthropogenic magnetic noise is a critical challenge for ET site qualification.**
- **Railway infrastructure is a potential source of magnetic noise in the future ET site, which requires an accurate assessment.**