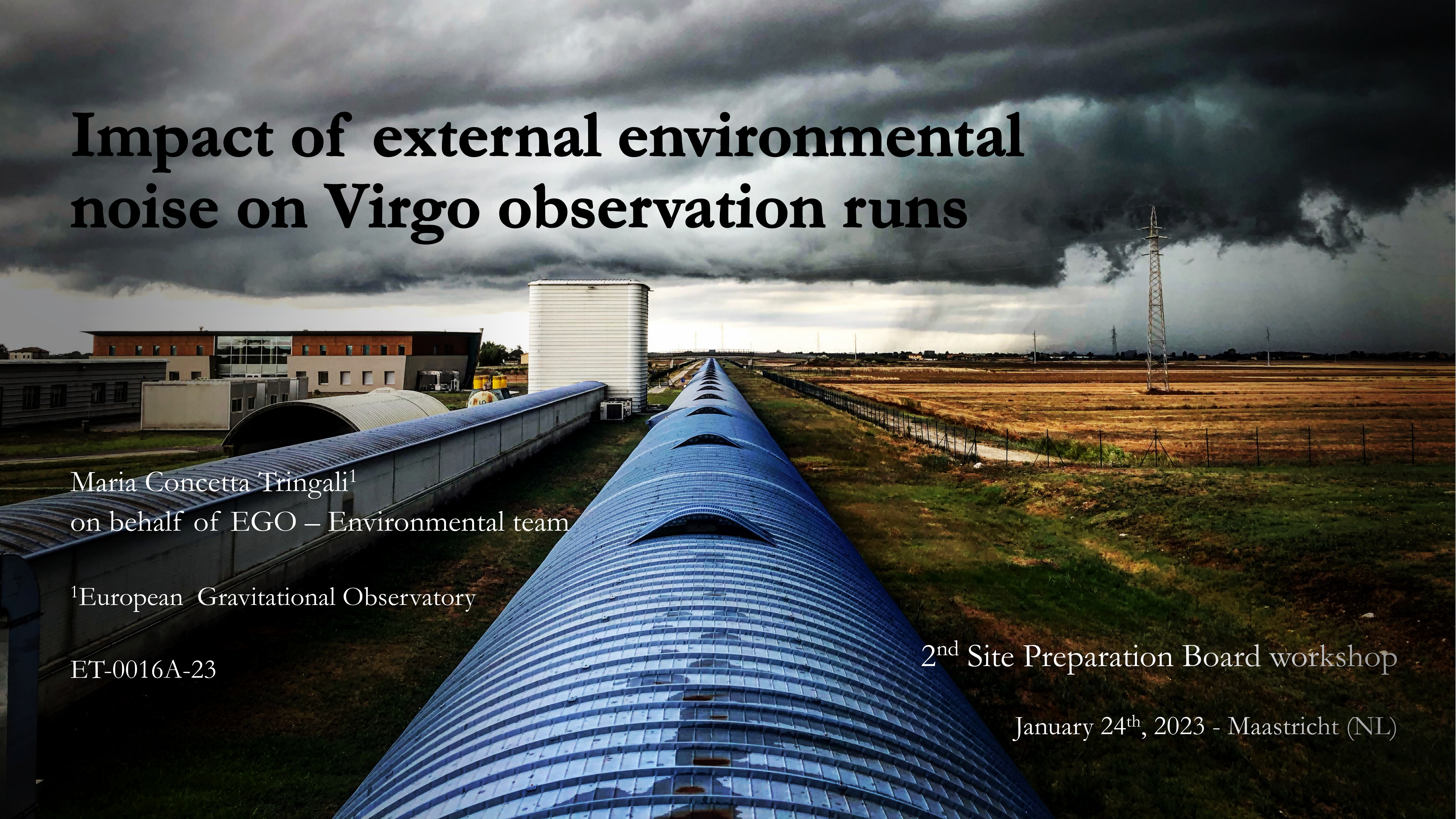


Impact of external environmental noise on Virgo observation runs

Maria Concetta Tringali[1]
on behalf of EGO – Environmental team

[1]European Gravitational Observatory

ET-0016A-23

2nd Site Preparation Board workshop

January 24th, 2023 - Maastricht (NL)

Outline

- Impact of external environmental noise on Virgo detector during O3 run:
    - natural noise: wind activity, sea activity and lightnings
    - anthropogenic noise

- Other noise studies:
    - wind farm
    - gas pipelines
    - site-wide low-frequency magnetic glitches

IOP Publishing Classical and Quantum Gravity
Class. Quantum Grav. **39** (2022) 235009 (40pp) https://doi.org/10.1088/1361-6382/ac776a

The Virgo O3 run and the impact of the environment

Class. Quantum Grav. 39 235009, https://doi.org/10.1088/1361-6382/ac776a

Environmental noise sources

The gravitational wave interferometers are influenced by environmental noise sources:

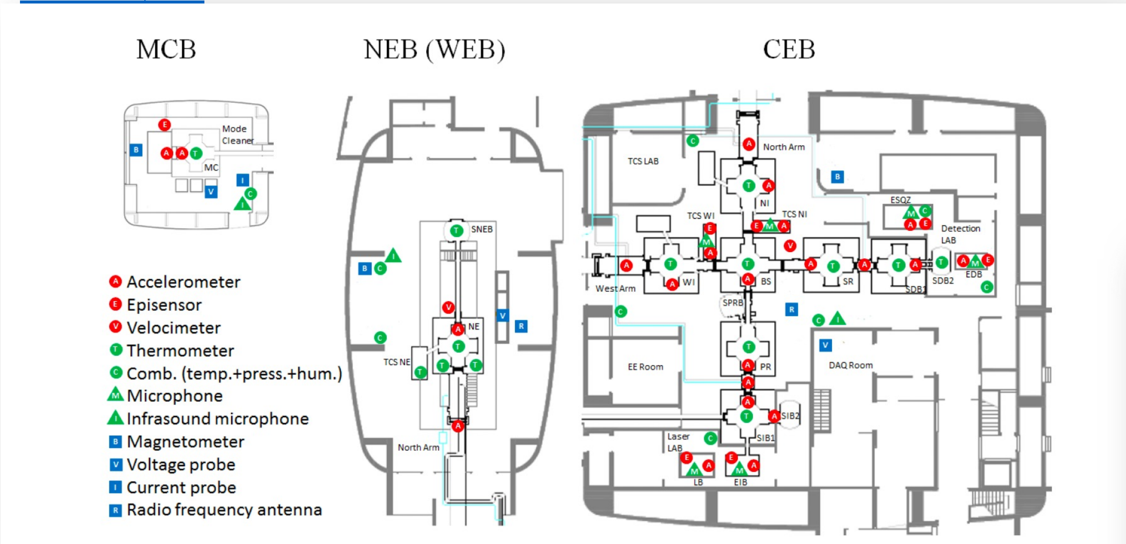
Natural
Sea activity, wind, earthquakes, lighting, Earth magnetic field etc

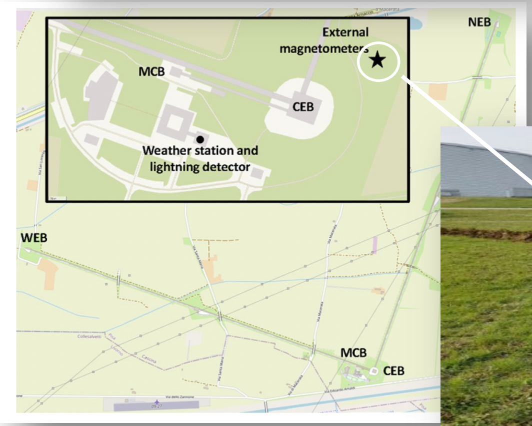
Anthropogenic
highways, railway tracks, wind turbine, airplanes, tractors etc

Virgo site facilities and infrastructures (I. Fiori, ET-0164A-22)
air conditioning systems, vacuum devices, electricity, experimental equipment, power supplies etc

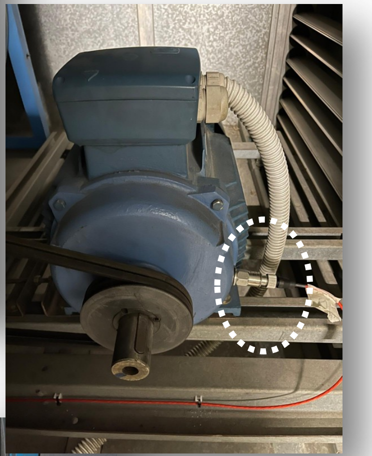
Environmental monitoring

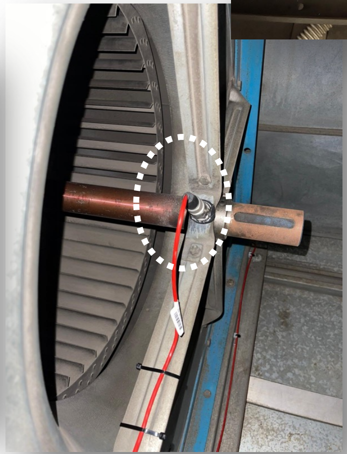
I. Fiori et al, 2020





External magnetometers





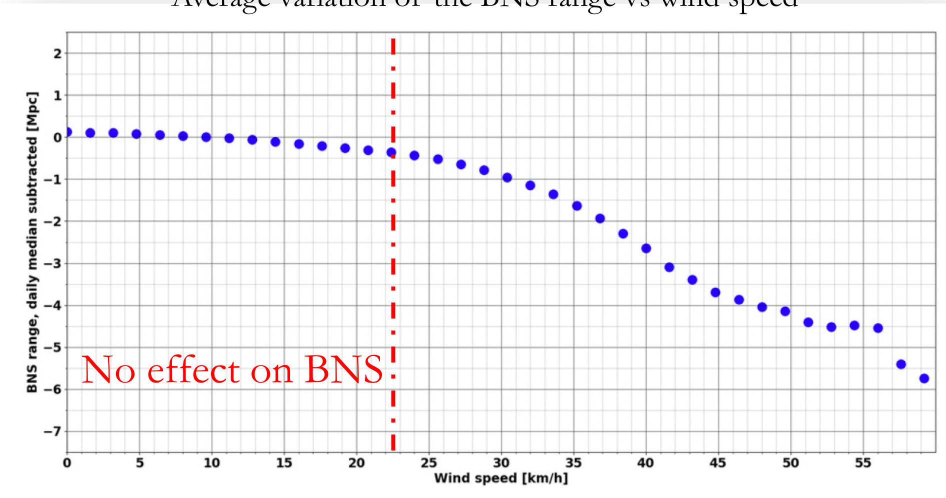
Monitor of AHU devices

- A distributed network of probes are used to monitor the conditions of the surrounding environment.
- There are two categories of sensors
  - **fast sensors**, f_s=1 kHz to 20 kHz: seismometers, accelerometer microphones, magnetometers (internal and external), voltage and current sensors, radio-frequency antenna.
  - **slow sensors**, f_s=1 Hz: wind, temperature, humidity, pressure, air and water flux probes, weather station, lightning detector.

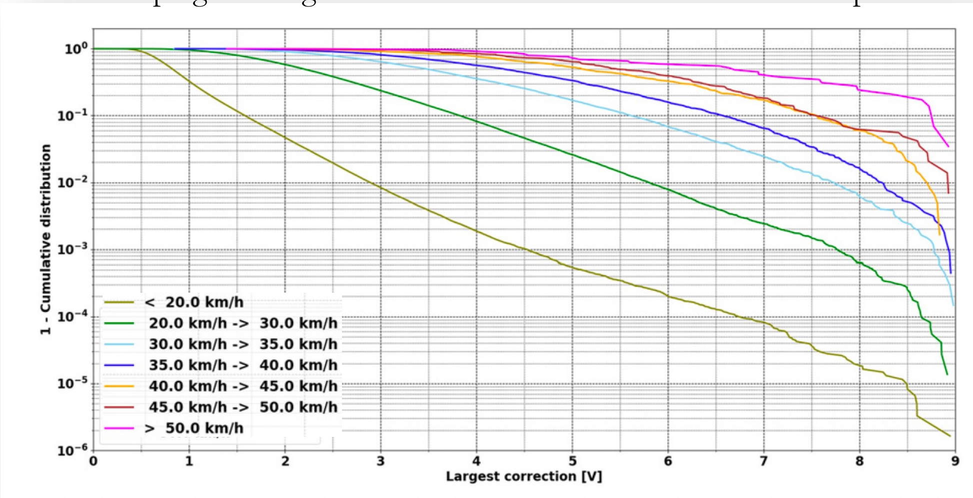
Natural noise

Impact of the wind

Average variation of the BNS range vs wind speed



Cumulative distribution of the maximum longitudinal corrections keeping the Virgo arm cavities resonant for different wind speeds



- Through O3, the Virgo interferometer performed worst during days with winds and intense sea activity.
- These periods were generally associated with increased non stationary noise in the GW signal below about 100 Hz and with some difficulties in maintaining the interferometer in its controlled state, resulting in reduced duty cycle.
- The impact of the wind:

BNS range

- the sensitivity is unaffected until a wind speed of ~20-25 km/h;
- the BNS range decrease exceeds ~4 Mpc for a wind speed above 50 km/h.

Fabry-Perot cavity longitudinal corrections

- the larger the wind speed, the higher the correction to keep the instrument at nominal working point (L. Trozzo, VIR-0379A-18);
- for wind speeds above 50 km/h (purple curve) the physical correction gets often very close, and sometimes encompasses, the saturation value which is 9 V.

Sea activity and scattered light

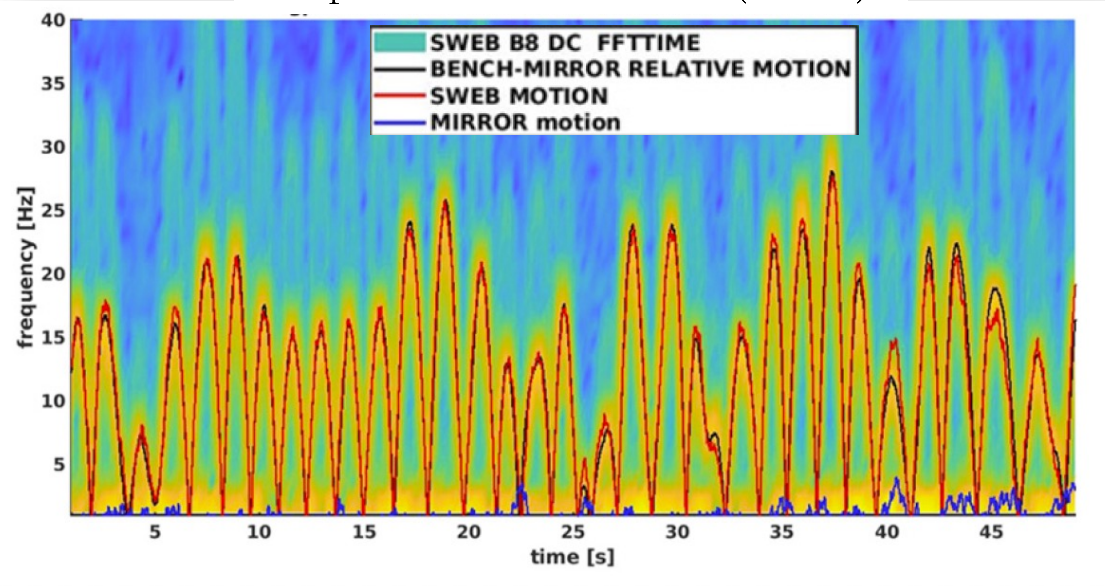
- Interferometric GW detectors have their sensitivity affected by scattered light, especially when microseism ground motion is elevated at times of rough seas.

- In O3 run, the main sources of scattered light affecting the Virgo sensitivity in the low frequency were the suspended optical benches placed beyond the end test masses in the terminal buildings.

- Scattered light noise appears as a series of arches in the arm power spectrogram.

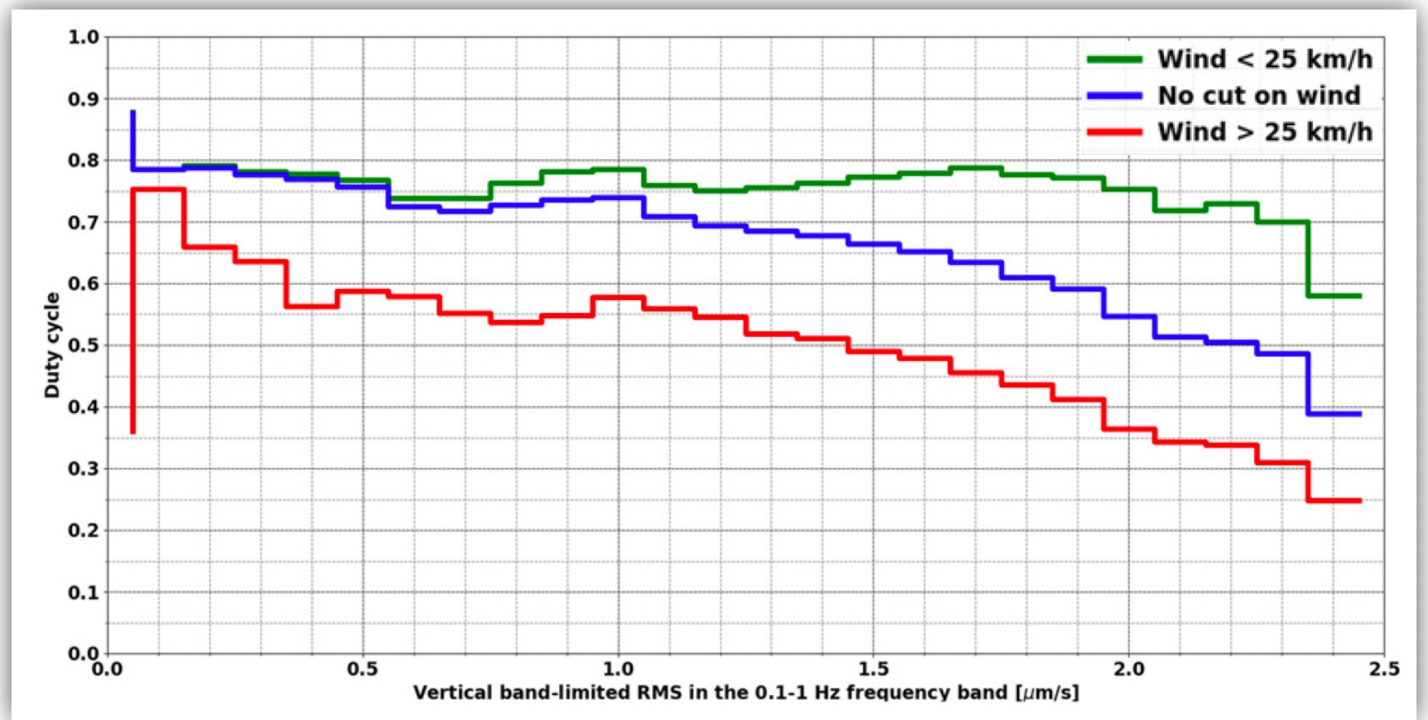
- Due to a malfunctioning of the mechanical setting of the SWEB suspension, it was observed ([M. Was et al, 2021](#)):
    - arches due to large amplitude slow motion of the bench (red curve) at the microseism peak at ∼0.35 Hz;
    - arches entered in the detection band when the ground motion exceeded a threshold during the run.

Suspended West end bench (SWEB)



Disentangle of sea and wind activity

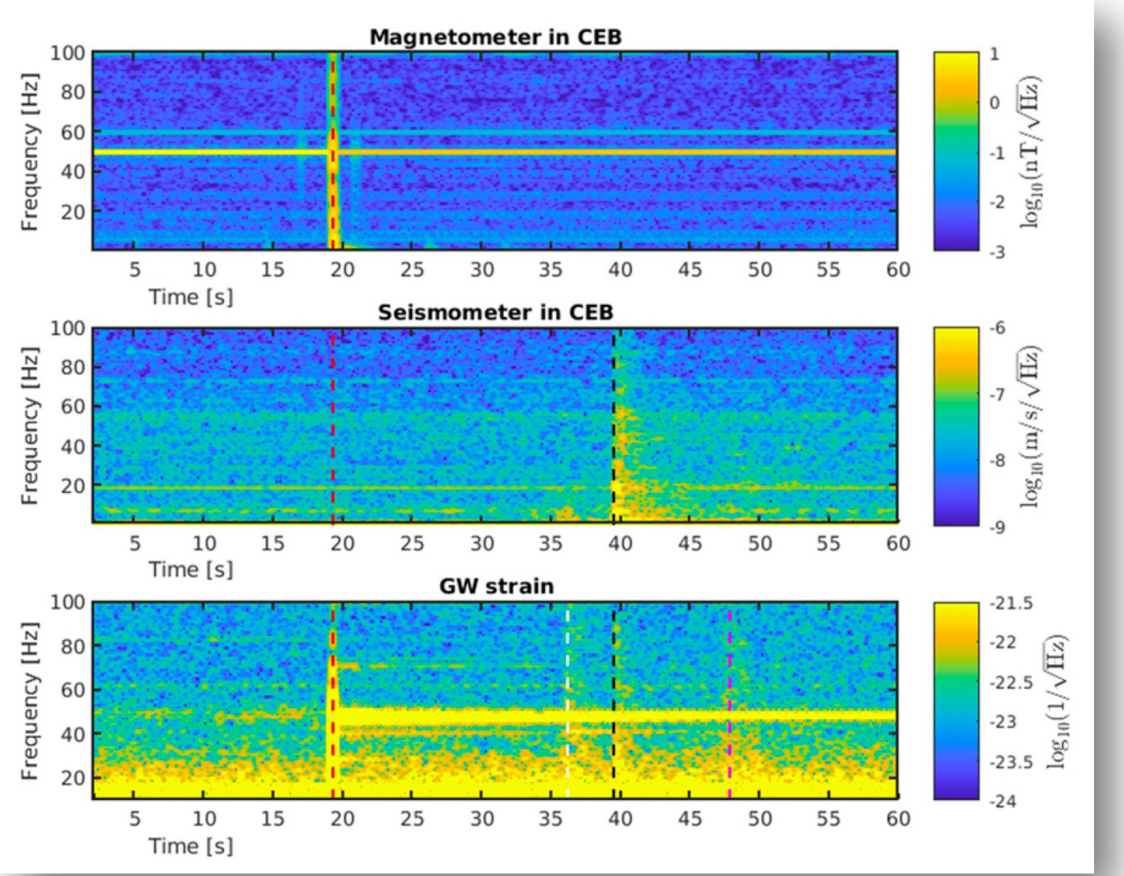
O3 duty cycle vs microseism activity (0.1-1) Hz



- Because of the wind action on the sea surface, high winds and rough sea often occur together.
- A statistical approach was used to disentangle their effects on the interferometer.
- During O3 run, Virgo detector was robust against microseism but more sensitive to wind:
  - for low wind conditions (v_{wind}< 25 km/h, green curve), the duty cycle seems to be independent from microseismicity;
  - the duty cycle is lower and decreases more quickly when the wind level increases (red curve).

Lightnings

- Lightning strikes produce prompt electromagnetic waves and much slower air pressure waves which induce vibrations of the ground and of the detector mechanical components.



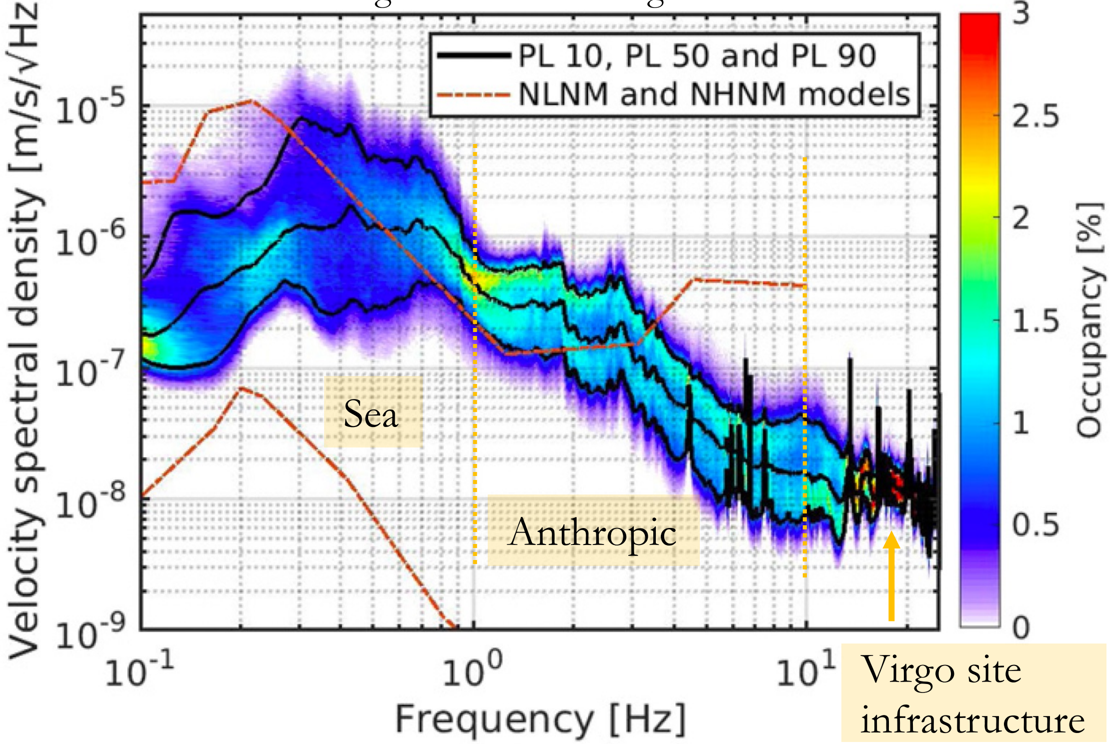
Lightning strike occurrence ---
Seismic transient occurrence @ WEB (white), CEB ---, NEB ---

- A distinctive feature of lightning strikes is a coincident transient noise in all magnetometers.
- The magnetic impulse is followed by the slower sound shock wave detected by seismometers in the experimental buildings (WEB, CEB, NEB).
- In the GW strain signal:
  - prompt broadband low-frequency noise in coincidence with the magnetic spike;
  - this spike acts directly on magnets (e.g., suspension actuators) and perturbs the GW strain;
  - the onset of a 48 Hz narrow spectral noise, with a minute-long decay time (~30% drop of BNS range) is due to the excitation of one structural mode of West end test mass suspension.

Anthropogenic noise

Seismic spectrum at Virgo site

Horizontal velocity variability of the Virgo NEB ground floor during O3

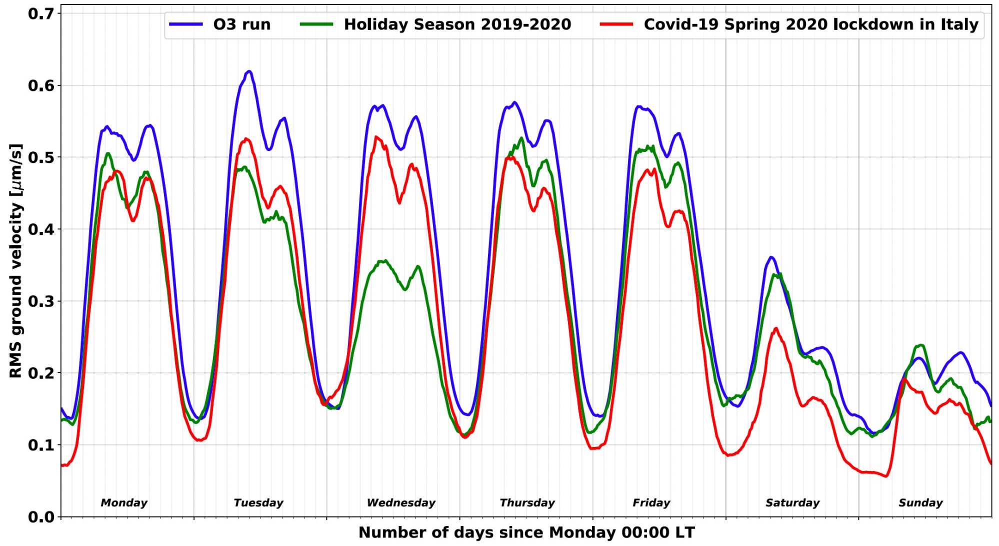


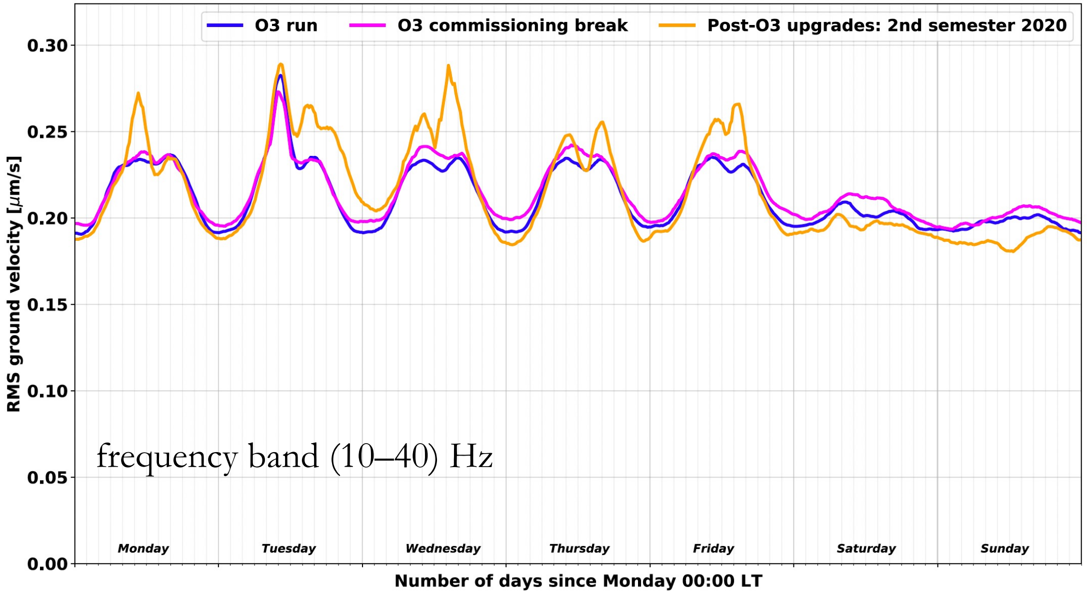
- Virgo seismic wave-field is the sum of several sources whose contribution dominates in a specific frequency band:
  - Microseism frequency band (0.1-1) Hz: the largest contribution to seismic ground motion is due to the interaction between shallow water sea waves and the bottom of the sea (M. S. Longuet-Higgins, 1950, Robert K. Cessaro, 1994).
  - Frequency band 1-10 Hz, anthropogenic sources dominate the spectrum. Heavy vehicles (trucks and alike) on ~1 km distant elevated roads (S. Koley, 2017) are the prevailing source (variation due to day/night cycle).
  - Above 10 Hz, the dominant seismic contribution is generated locally: Virgo infrastructures, vehicles in nearby and on-site roads, agricultural work on neighbouring land.

Anthropogenic noise at Virgo site

- RMS of seismic noise in the 1–5 Hz band follows a day/night cycle with higher levels during working hours, small reduction during lunch break and minima during week-ends and holidays.
- Significant reduction of the anthropogenic noise during the Spring 2020 lockdown in Italy, due to the COVID-19 pandemic (red curve).

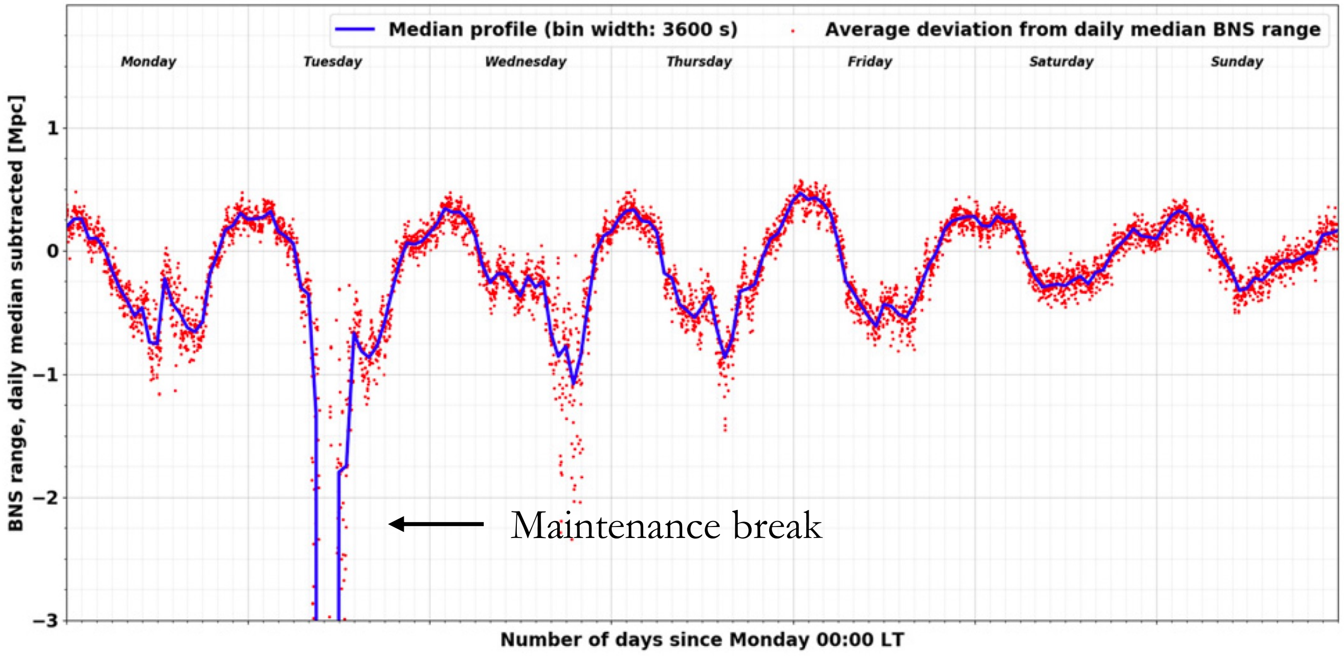
Average evolution of the seismic anthropogenic noise in frequency band (1–5) Hz





- The on-site seismic noise level was slightly higher during the commissioning break (purple curve) compared to the O3 run with lowest activities during the weekend because of site access restrictions, enforced because of the pandemic.

Impact of the anthropogenic noise



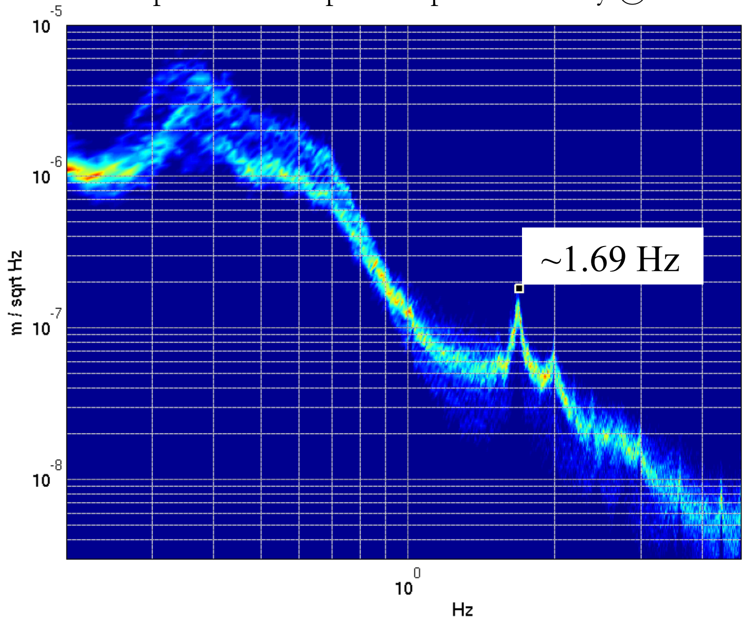
- The BNS variations are of anthropogenic origin, with a day–night pattern and a reduced spread during the weekends.
- Variations are ∼1 Mpc compared to an average BNS range of about 50 Mpc during the O3 run.
- Tuesday morning: weekly maintenance period of the Virgo detector.
- Wednesday and Thursday afternoons: these times have often been used for calibration or detector activities.

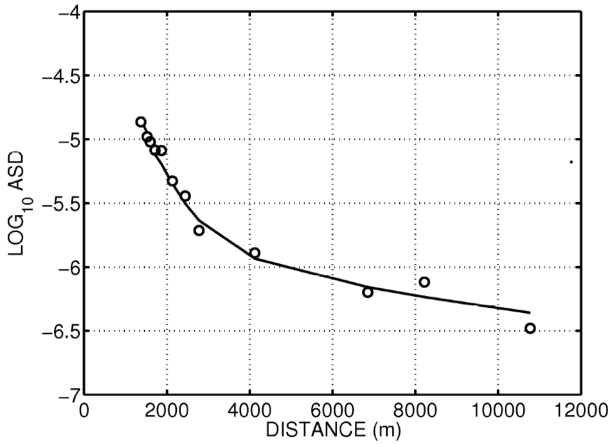
Other selected noise studies

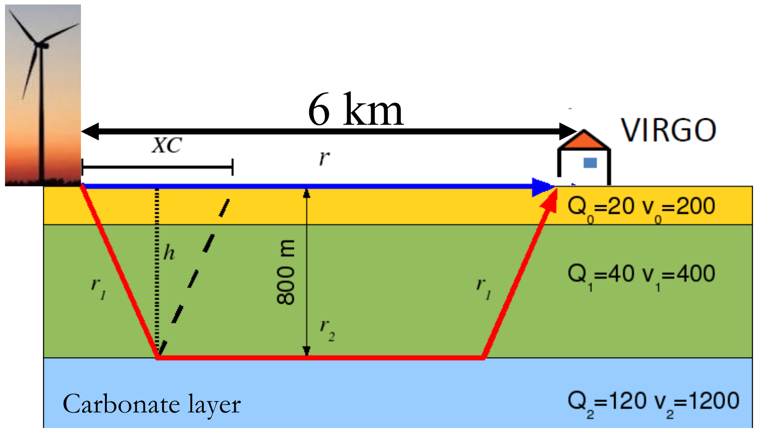
Noise from a wind farm

- A wind farm composed of four 2-MW turbines is installed ~6 km east of Virgo North end building.
- The observed impact at Virgo is a seismic peak at frequency 1.7 Hz (first mode of cylindrical tower) with a spectral amplitude of few 10^{-7} m $Hz^{-1/2}$ at North end building.
- No evidence so far of acoustic or magnetic noise associated to this wind farm.
- Study of a seismic wave (surface and body) propagation model to interpret the amplitude attenuation with distance → large distance for amplitude peak reduction.

Displacement amplitude spectral density @ NEB





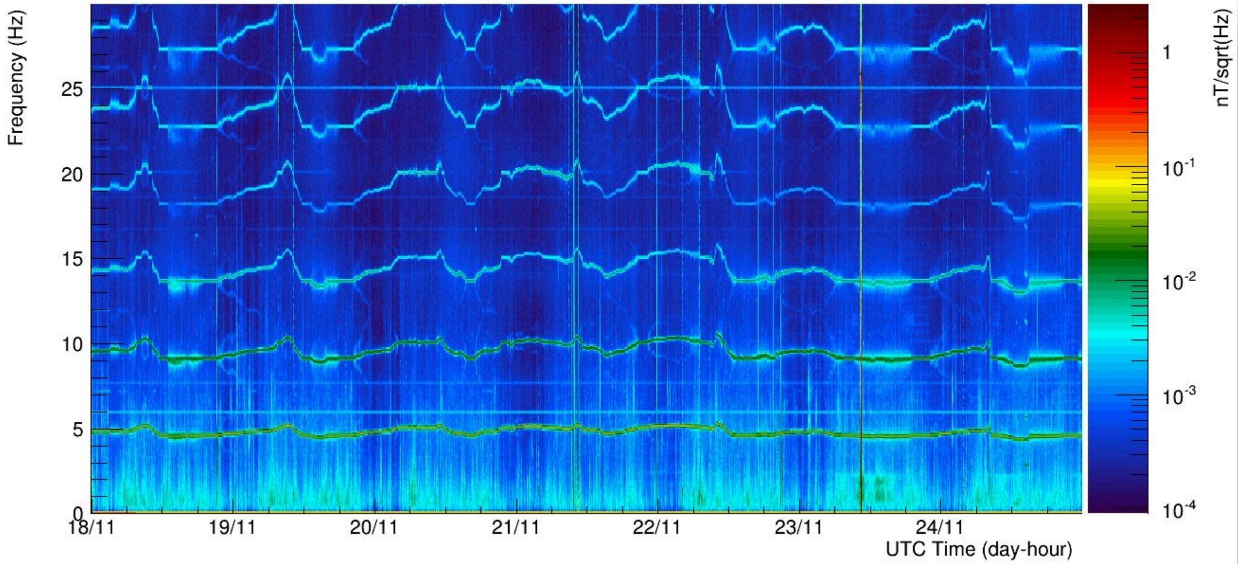


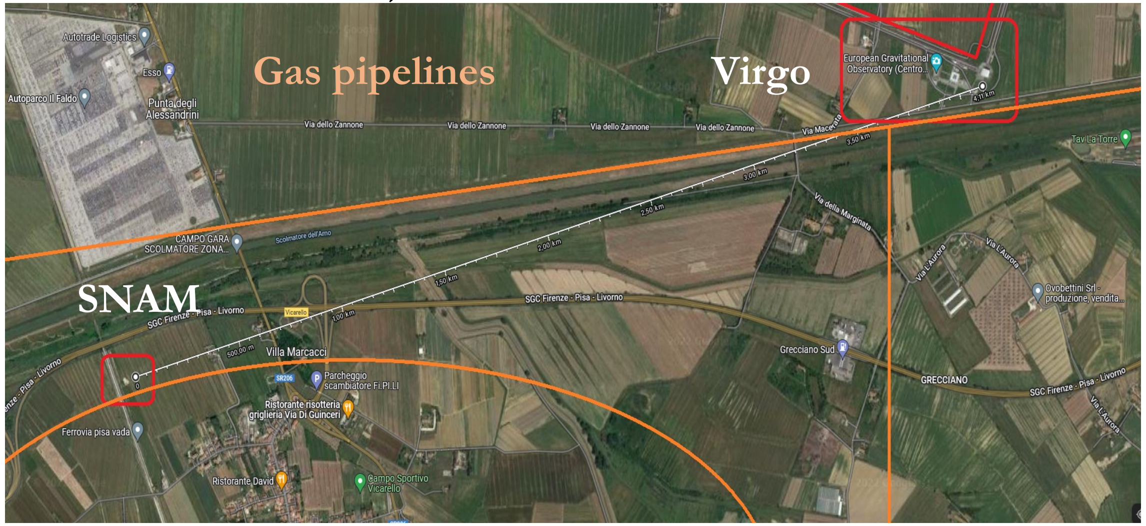
G. Saccorotti et al, 2011
https://doi.org/10.1785/0120100203

Magnetic noise from gas pipeline

- Since July 2021, a magnetic noise at low frequency ~5 Hz and harmonics is polluting Virgo magnetic environment→ Schumann resonances blinded in the external magnetometers.
- No coherence was found with other Virgo sensors→ external source.
- Extensive measurement campaign was carried out around the interferometer site (L. Pierini, VIR-0310A-22).

External magnetometer

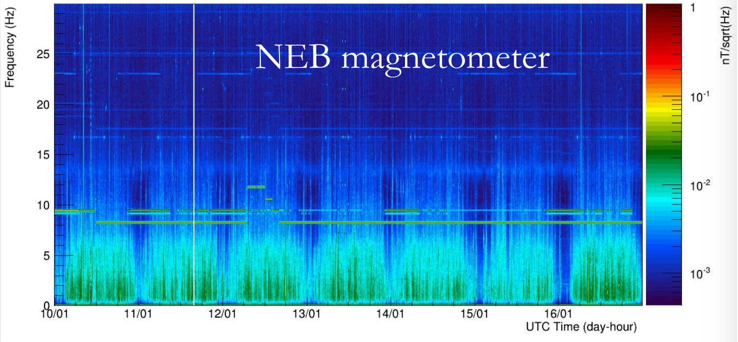


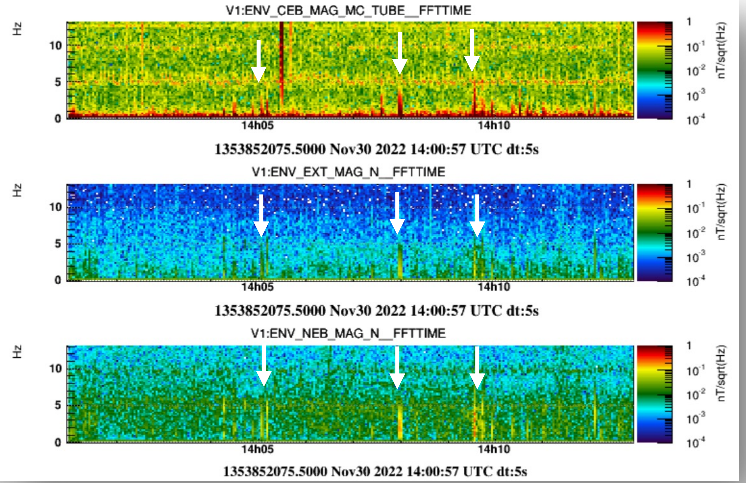


- The noise was tracked down to some cathodic protection power supplies 4 km far from CEB, used in SNAM gas pipelines to avoid corrosion → since January 2023, the noise is not present.
- The noise path could be the telluric currents.
- In touch with the SNAM company for performing tests if/when the noise will appear again.

Site-wide low-frequency magnetic glitches

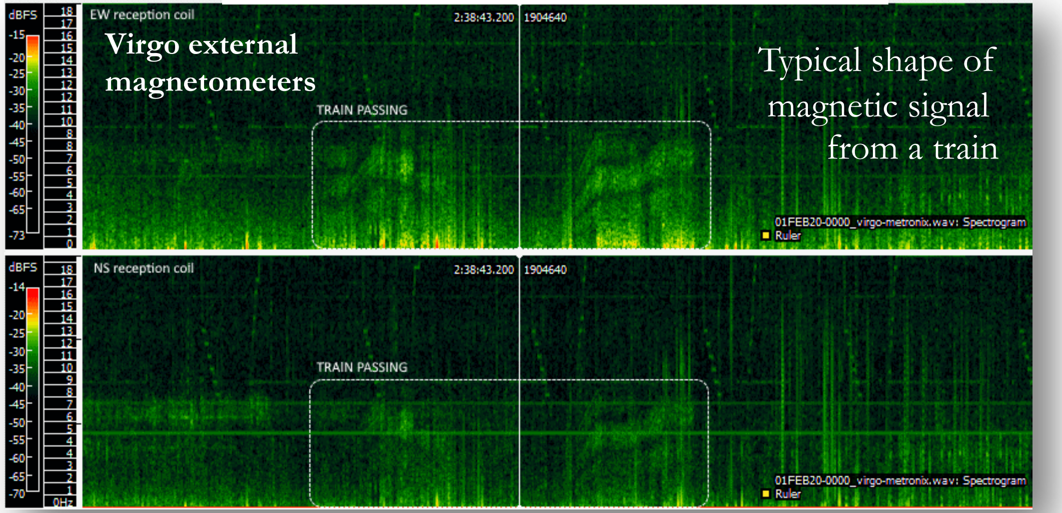
- Below 10 Hz, environmental magnetic noise on the Virgo site is dominated by transients with quiet periods occurring daily between roughly midnight and 4 a.m. (elog 58074).
- Magnetic glitches are visible in all magnetometers in Virgo.
- The noise comes from the external environment (no correlation with Virgo signals and devices).





- Hypothesis: Earth-leakage currents can be generated by railway power stations (F. J. Lowes, 2009).
- Two railway lines are close-by Virgo end buildings: one passenger line (~2.5 km from NEB) and one commercial line (~2 km from WEB).
- In touch with F. Garufi and R. Di Maio (Università di Napoli Federico II) to discuss about a possible measurement of telluric currents.

Credit: Renato Romero (www.vlf.it)



Conclusions

- Despite the external environment conditions slightly affected the detector performances during O3 run , the Virgo interferometer proved to be a robust apparatus.

    - The Virgo global control proved robust against microseism activity while it was less effective against strong wind (v_{wind}> 50 km/h).
    - Anthropogenic seismic noise slightly impacted the BNS range by less than 2% .

- There are other external environmental sources potentially critical for the detector:

    - wind farms vibration noise can propagate to large distances
        - some faced sources: quarries, photovoltaic installations, shooting plant, motor racing track, military aircrafts, agriculture work (tractors).
    - gas pipelines and railway lines are sources of low frequency magnetic noise, possibly through Earth-leakage currents
    - planned investigation of telluric currents.