# Underground magnetic noise at the SoS Enattos site

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*We present an extended report on the magnetic noise at the SoS Enattos site, using data collected underground (-111 m) from 2020/09/22 to 2021/11/01 for the NS (north-south) magnetic component. To track the time evolution of the noise, we use the Band-Limited Root Mean Square (BLRMS) analizing different frequency bands. We show the diurnal and seasonal variability of the first Schumann resonances. The observed variability is compatible with other measurements performed in different observatories. We also report interesting results in the low frequency region between 1 Hz and 5 Hz where some disturbances were found during the spring and summer periods, and in the 50 Hz region showing a daily variability for the 50 Hz peak.*

## SoS Enattos site

The SoS Enattos site, in Sardinia, is one of the candidates for the Einstein Telescope.
The noise coming from natural or anthropogenic electromagnetic fields can affect the sensitivity of a gravitational wave interferometer directly coupling with magnet actuators of the mirror and suspension systems or coupling with electronic devices managing the interferometer.
To study the magnetic noise at the SoS Enattos site, we use an underground magnetometer (Metronix MFS-06 installed at -111 m at the SOE2 station) that measures the north-south (NS) magnetic field component.

## Methodology

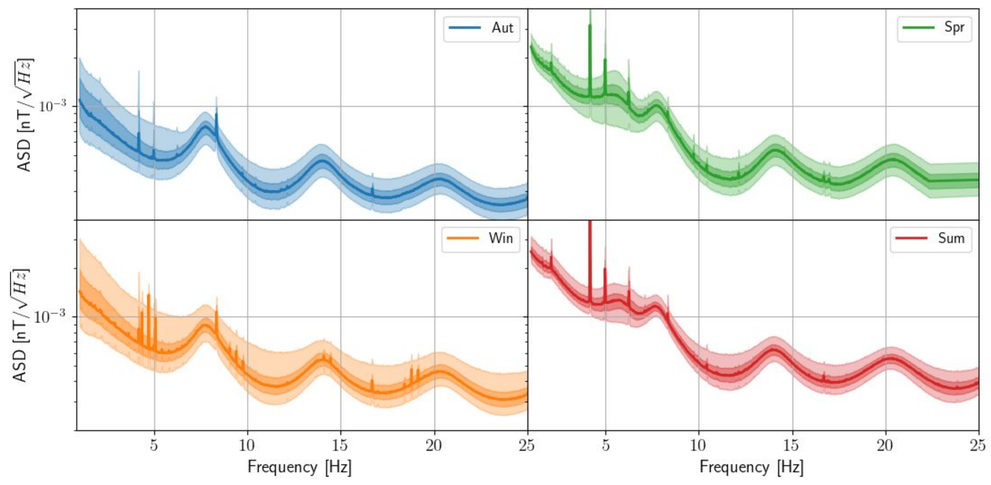
To perform quantitative analysis on the noise variations over time, we use the Band-Limited Root Mean Square (BLRMS). Since the root mean square value is linked to the autocorrelation function at zero delay, the BLRMS value of a signal in a frequency band $[\omega_1,\omega_2]$ is simply the integral of the power spectral density (PSD) in that band [1]:

$$BLRMS = \sqrt{\int_{\omega_1}^{\omega_2} PSD(\omega)d\omega}.$$

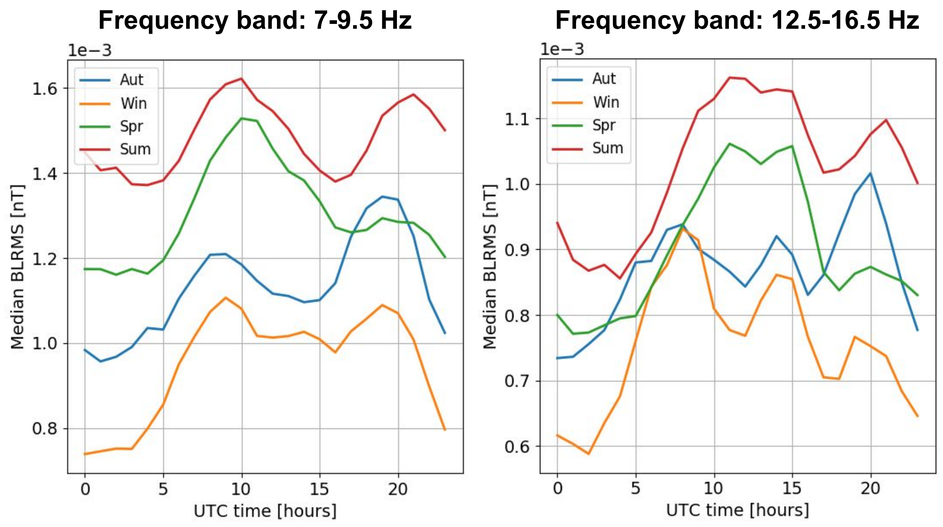
Using the PSD of the magnetic data and if the computation of the BLRMS is performed periodically, it is possible to track the time evolution of the magnetic noise.
The sampling rate chosen to compute the BLRMS is one hour. For the PSD computation, we use the Welch's Method dividing the one hour-long time data into overlapping segments (60 s long with overlap of 50%), computing a periodogram for each segment and averaging the periodograms.

[1] https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=48668

## Schumann resonances

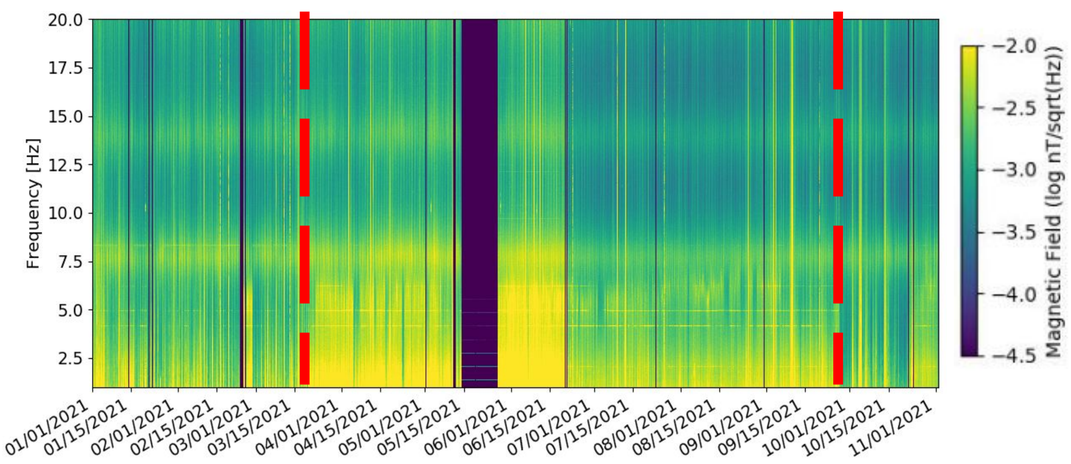



The top plot is the amplitude spectral density (ASD) of the NS magnetic component for the four seasons starting from Autumn 2020. The continuous lines are the median for the ASD values while the coloured areas display the 10th, 30th, 70th, 90th percentile.
In the bottom plots, we show the diurnal time evolution of the BLRMS considering the median value for each hour in the four seasons.
The obtained results (in the plots, the frequency bands of the first two Schumann resonances) are in agreement with several works that used diverse methodologies to track the noise evolution in different sites [2,3].

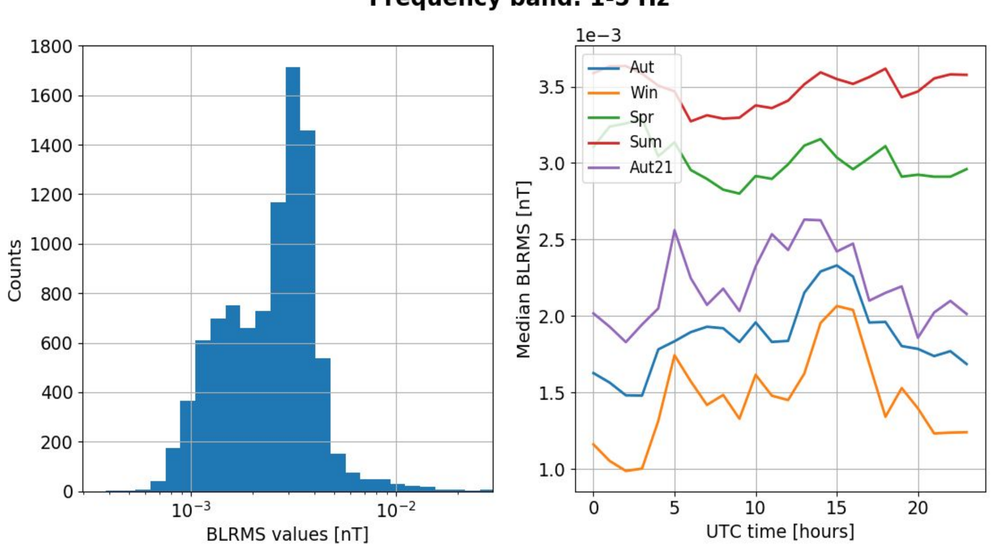



[2] https://doi.org/10.1016/0021-9169(95)00146-8,
[3] Sátori G., Mushtak V., Williams E. (2009) "Schumann Resonance Signatures of Global Lightning Activity"

## 1-5 Hz region




The shown spectrogram covers 1 Hz - 20 Hz frequency band and almost one year (from the 1th January to the 1th November 2021) of data. It is computed considering one hour-long data chunks (FFT length is 60 seconds with overlap of 50%). The dashed line correspond to the start-date and to the end-date of a clear disturbance in the region 1 Hz - 5 Hz.
As shown in the bottom plots for the 1 Hz - 5 Hz region, the BLRMS highest values are in Spring and Summer. The disturbance seems to disappear in the first part of the Autumn 2021. More data need to be collected to track and explain the noise evolution in this frequency region.




## 50 Hz region

To indicate possible correlations with BLRMS values at low frequency bands, we also track the time evolution of the magnetic noise in the 50 Hz region using the BLRMS.
The median BLRMS evolution computed in the frequency band 49 Hz - 51 Hz (top plot on the right) show an important diurnal variability.
This variation is of the order $10^{-2}$ nT with a first peak at 6:00/7:00 UTC time and a second higher peak at 17:00/18:00 UTC time.
The observed variation slightly depends on the considered season. The highest BLRMS values are reported in Winter. This result is in contrast with the observed seasonal variability of the Schumann resonances.
In the bottom plot on the right, we also report the diurnal BLRMS variation considering the frequency band 48 Hz - 49 Hz, excluding the 50 Hz peak.
The variation is of the order $10^{-4}$ nT without the peaks observed in the top plot and in agreement with the seasonal variability of the Schumann resonances.
Further analysis are needed to better quantify and explain the observed 50 Hz peak variability.