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Abstract. In this work we report the ongoing characterization of the Sos Enattos former mine (Sardinia, Italy), one of the two candidate sites for the Einstein Telescope (ET), the European third-generation underground interferometric detector of Gravitational Waves. The Sos Enattos site lies on a crystalline basement, made of rocks with good geomechanical properties, characterized by negligible groundwater. In addition, the site has a very low seismic background noise due to the absence of active tectonics involving Sardinia. Finally, the area has a low population density, resulting in a reduced anthropic noise even at the ground level. This location was already studied in 2012-2014 as a promising site for an underground detector. More recently, in March 2019, we deployed a new network of surface and underground seismometers at the site, that is currently monitoring the local seismic noise. Most of the energy carried by the seismic waves is due to the microseisms below 1 Hz, showing a significant correlation with the waves of the west Mediterranean sea. Above 1 Hz the seismic noise in the underground levels of the mine approaches the Peterson's low noise model. Exploiting mine blasting works into the former mine, we were also able to perform active seismic measurements to evaluate the seismic waves propagation across the area. In conclusion we also give a first assessment about the acoustic and magnetic noise in this underground site.

1. Introduction

The Einstein Telescope will be the European third generation gravitational wave detector[1, 2]. It will be installed in an underground triangular infrastructure with 10-km long arms: indeed, since either anthropogenic or natural seismic vibrations are dominated by Rayleigh waves, whose amplitude decreases rapidly with depth, the underground installation will improve the detector sensitivity at low frequencies. Two European sites are currently under evaluation for this infrastructure, among them the area of the Sos Enattos former mine. This site is placed in the north-east of the Italian island of Sardinia, at about 50 minutes drive from the closest airport of Olbia. This area is a very stable area from the geodynamical point view, moreover it is also characterized by a low population density that implies a reduced anthropic noise impact. A first characterization of this site was made in 2012-2014 [3]. In March 2019 we installed the first part of a new evolving array of broadband seismometers and environmental sensors, placed at the surface and in the underground levels of the former mine, for a long-term qualification.

2. Geophysical features of the site

Sardinia is made of a metamorphic Paleozoic basement, intruded by Carboniferous-Permian granitoids [4]. In particular, the Sos Enattos site lies on a crystalline basement, made up with micaschist, quartzite, ortogneiss (*Lodé type*) and granitoids (*Bitti type*) rocks. All these rocks show good geo-mechanical parameters: perpendicular and parallel uniaxial compressive strength are respectively 92.60 MPa and 60.83 MPa for the orthogneiss, 68.68 MPa and 53.44 MPa for the quarzite, while the mean value for granodiorite is 72.09 MPa. These rocks have a low radioactive isotopes concentration (few ppm), compatible with the long-term operation of an underground laboratory. The absence of significant groundwater, due to the low porosity of these rocks, measured with ERT tomography, is also confirmed by the mine drainage, evaluated in 1 L/s on average along ~ 50 km of galleries. In addition, the site is located in a very stable area from the geophysical point of view, showing low seismicity due to the absence of active tectonics and significant earthquakes. Indeed the Sardinia microplate is practically not involved in present-day geodynamics of the Mediterranean domain [5].

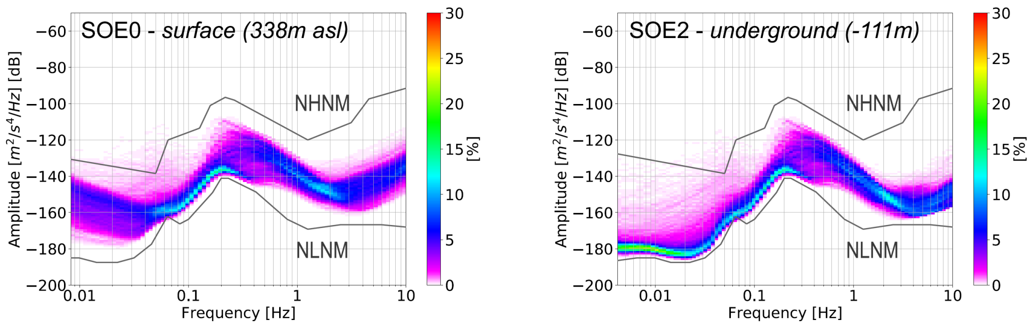

Figure 1. Power spectrum percentiles of seismic noise at Sos Enattos (vertical component), for the period April-August 2019. Left: surface measurement. Right: underground measurement below 111 m of rock. The continuous lines represents the Peterson models [6].

3. Seismic noise in Sos Enattos

The seismic power spectral density (PSD) in Sos Enattos approaches the Peterson's New Low Noise Model (NLNM) [6] as shown in figure 1, in particular we observe in the underground levels (84 and 111 m deep) of the former mine a significant attenuation for frequencies above few Hertz (anthropic noise) and below 80 mHz (temperature and pressure slow fluctuations). Below 1 Hz the main features of the seismic PSD measured in Sos Enattos are the microseismic peaks, whose generation is strictly related to the waves in seas and oceans [7, 8]. The seasonal evolution of these spectral structure in the site was already studied in ref. [3]; using the new data measured underground in Sos Enattos from April to August 2019, we were able to correlate the seismic PSD amplitude with the wave height provided by Copernicus Marine Environment Monitoring Service (CMEMS) [9] in the western Mediterranean sea and in Biscay bay (Atlantic Ocean), confirming that the dominant contribution comes from the closer Mediterranean sea, in particular the Tyrrhenian sea (see fig. 2). The best correlation between microseism and sea waves was found for waves with a period of 4.5 s. Above 1 Hz the seismic spectrum is dominated by the anthropic noise: since the population density in this part of Sardinia is one of the lowest in Europe, this background is low even at the Earth's surface. An underground installation provides a further and significant attenuation of this background, as shown in fig. 3.

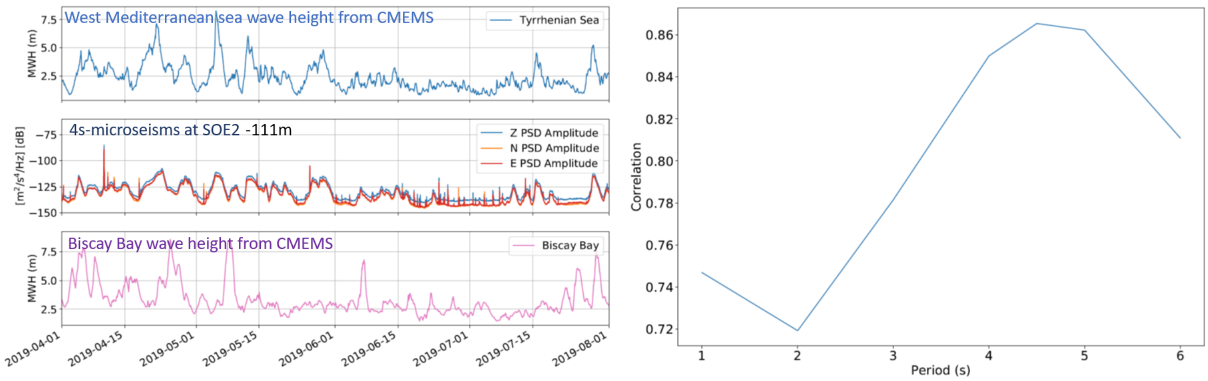

Figure 2. Left: time evolution of west Mediterranean and Biscay bay sea wave height (CMEMS data [9]) compared to the average amplitude of 4s-period microseisms measured underground in Sos Enattos. Right: frequency correlation between west Mediterranean sea waves and seismic waves, the maximum correlation is obtained for 4.5s-long microseism.

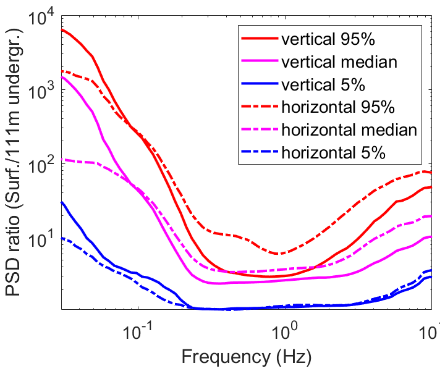

Figure 3. Ratio between surface and underground (-111m) seismic PSD, percentiles of 4 months of data.

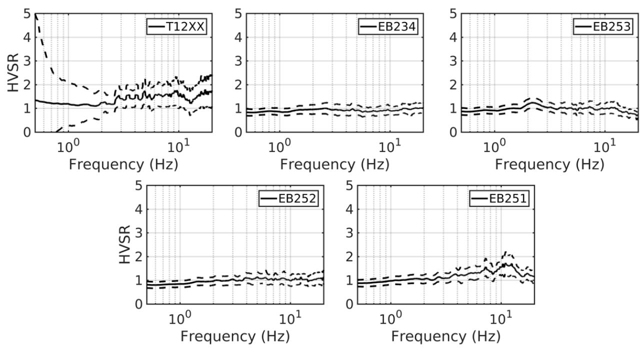

Figure 4. Horizontal-to-Vertical spectral ratio from active seismic measurement: peaks indicate resonance effect, but are significant only when amplitude is higher than 2.

An active seismic measurement was done for the evaluation of the seismic wave velocity in the rocks around the former mine: we deployed an array of five short-period seismometers, spacing each other 500 m, during a mine blast in an underground tunnel. The results of these measurements indicate a velocity of P-waves of $v_P = 4.61 \pm 0.23\ km/s$, consistent with the local lithology and Rayleigh-waves group velocities ranging from 1.66 km/s to 2.30 km/s over the 2-5 Hz frequency band. Horizontal-to-vertical spectral ratios (fig. 4) indicate the lack of significant site amplification effects related to shallow impedance contrasts.

4. Acoustic and magnetic background

In the existing main tunnel of the former mine the ventilation is ensured by a natural air flow between the entrance ramp and the vertical shaft at the end of the ramp, therefore the acoustic noise is currently not affected by artificial ventilation systems. Indeed we measured with a B&K 4193 microphone a very low acoustic background, with a spectral amplitude of $\sim 10^{-4} Pa/\sqrt{Hz}$ at $10Hz$ and $1.5 \times 10^{-5} Pa/\sqrt{Hz}$ at $100Hz$.

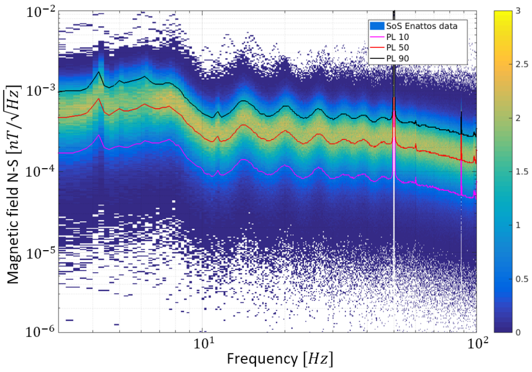

Figure 5. PSD percentiles of the magnetic field measured $111m$ underground in Sos Enattos in one week of data in April 2019, along N-S direction. Continuous lines indicate percentiles for 10%, 50% and 90% of the observing time. Schumann resonances are visible at $7.8Hz$ and higher harmonics.

The magnetic background noise was measured at 111 m underground with a Metronix MFS-6 magnetometer aligned along the North-South direction and its spectrum is shown in fig. 5. The main spectral feature is related to the Schumann resonances of the Earth magnetic field [10]. The average magnetic noise background can change up to a factor ten, in particular when a thunderstorm approaches to the site.

5. Conclusions and perspectives

The first results of the ongoing site characterization of the Sos Enattos area in Sardinia demonstrate that this site is particularly promising for the construction of an underground infrastructure such as the Einstein Telescope. In particular we observe a very low seismic noise, even at surface, that underground approaches the NLNM [6], due to the fact that Sardinia has a negligible earthquake activity, and to the very low population density of the area. Also the geomechanical properties of the rocks are good for the excavation of an extensive underground infrastructure. Finally, the limited groundwater found in the area represents a favorable condition for the construction and operation of a large underground detector.

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