ET: misure e caratterizzazione del sito in Sardegna

L. Naticchioni

INFN Roma & INGV Pisa

ET ITALIA, CAGLIARI

19/3/2025

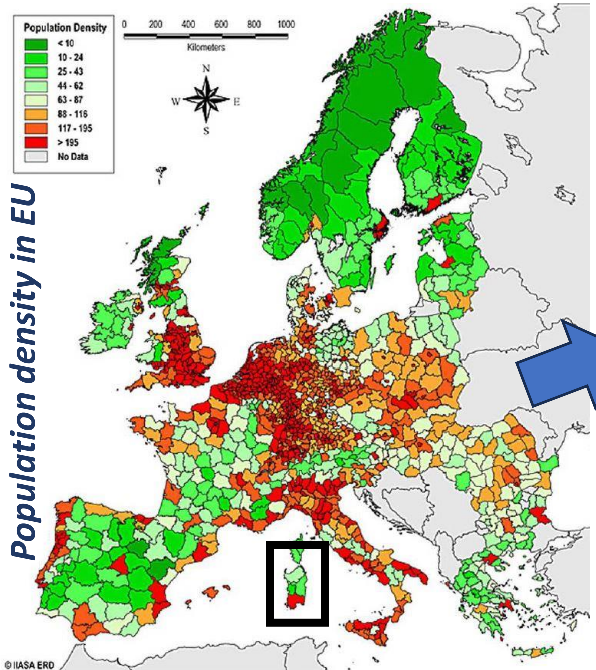
Site Characterization in Sardegna

Le attività di caratterizzazione del sito sono frutto della sinergica collaborazione di INFN e INGV sia per quanto concerne la strumentazione installata sul campo che per l'analisi dei dati prodotti.

Geological framework

Sardinia is made of:

- Quaternary alluvial deposits and minor intra-plate volcanism
- Tertiary sedimentary basins with volcanic units
- Deeply eroded Mesozoic sedimentary rocks
- Metamorphic basement widely intruded by Carboniferous-Permian Granitoids (Variscan orogenesis; 360-290 Ma)

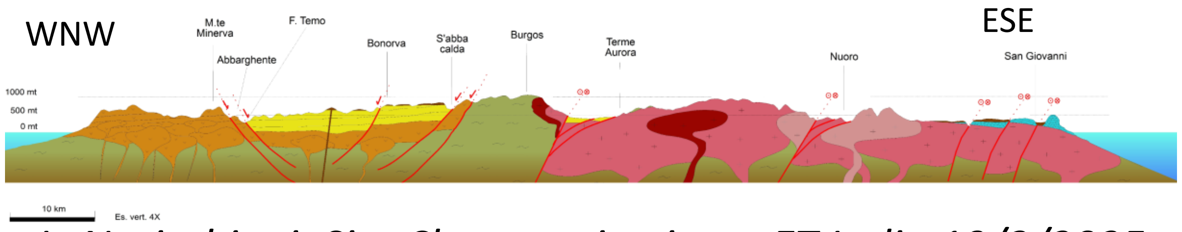


Population density in EU

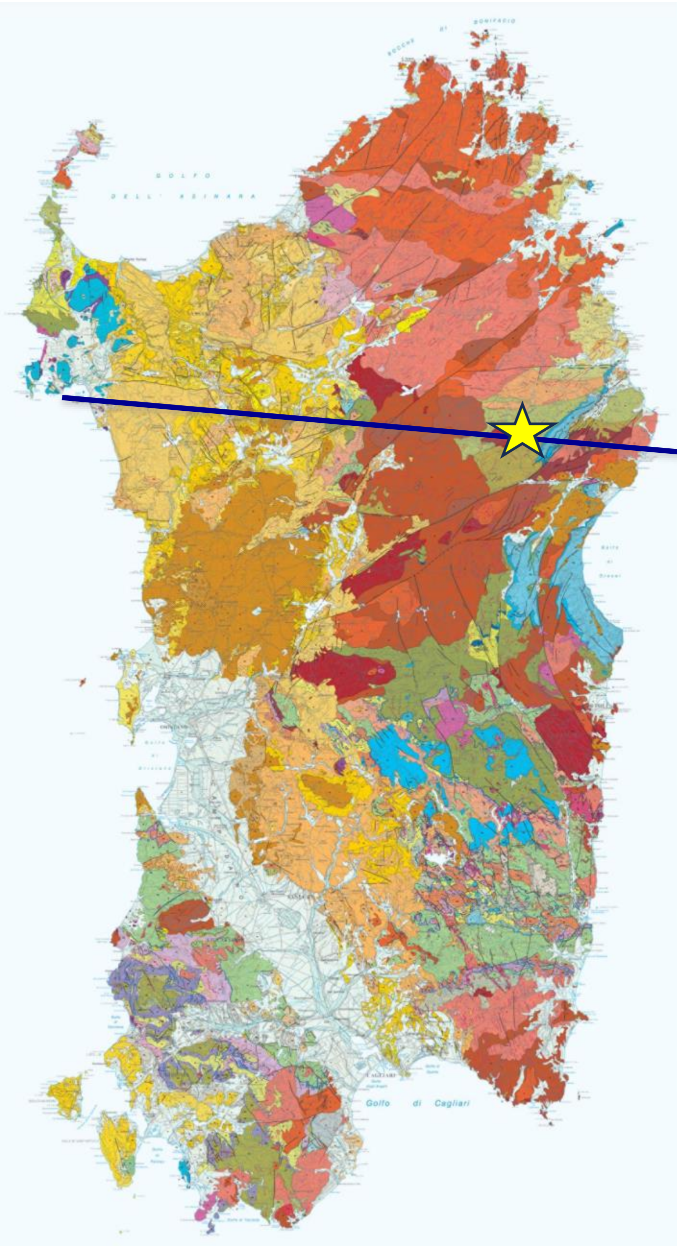
The ET Italian candidate site is located in the stable Variscan basement of Sardinia.

- Geodynamic quietness
- Low Anthropogenic noise
- Low E.M. noise

LOW SEISMIC NOISE!



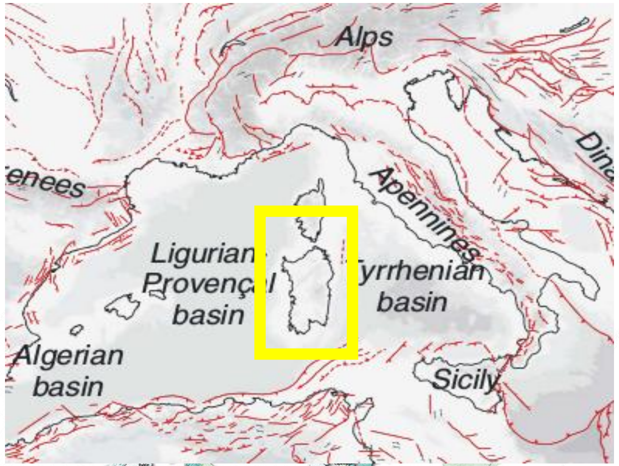
L. Naticchioni, Site Characterization – ET Italia 19/3/2025

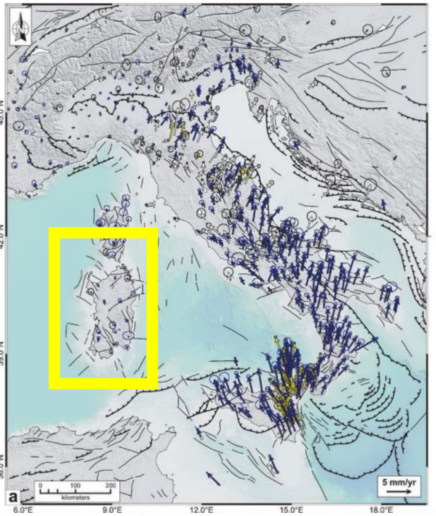


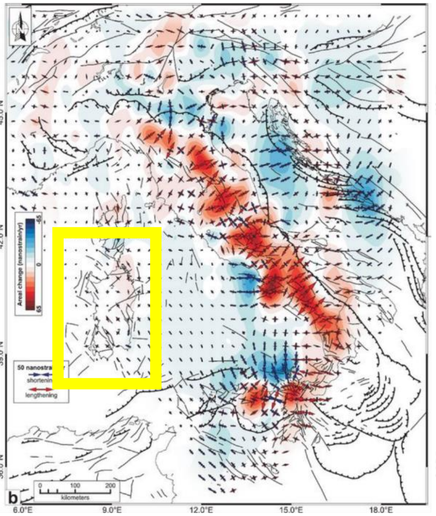
Geological framework

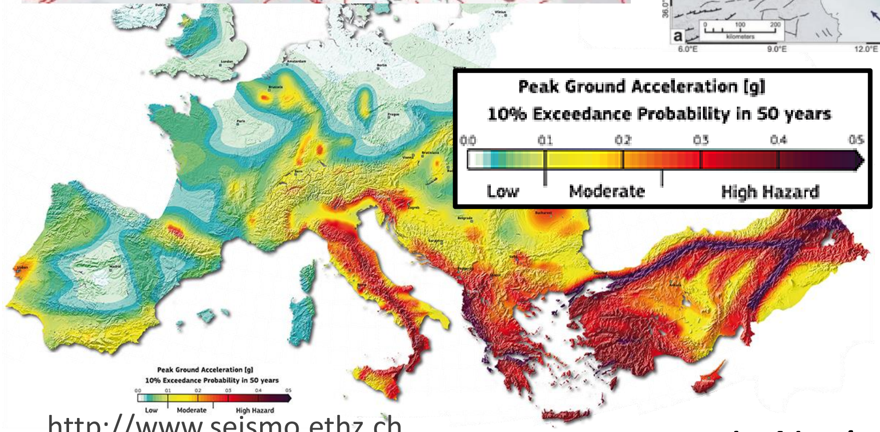
Sardinia, the geological framework

Far from active fault lines, the Corsica-Sardinia microplate is very stable → low crustal deformation.



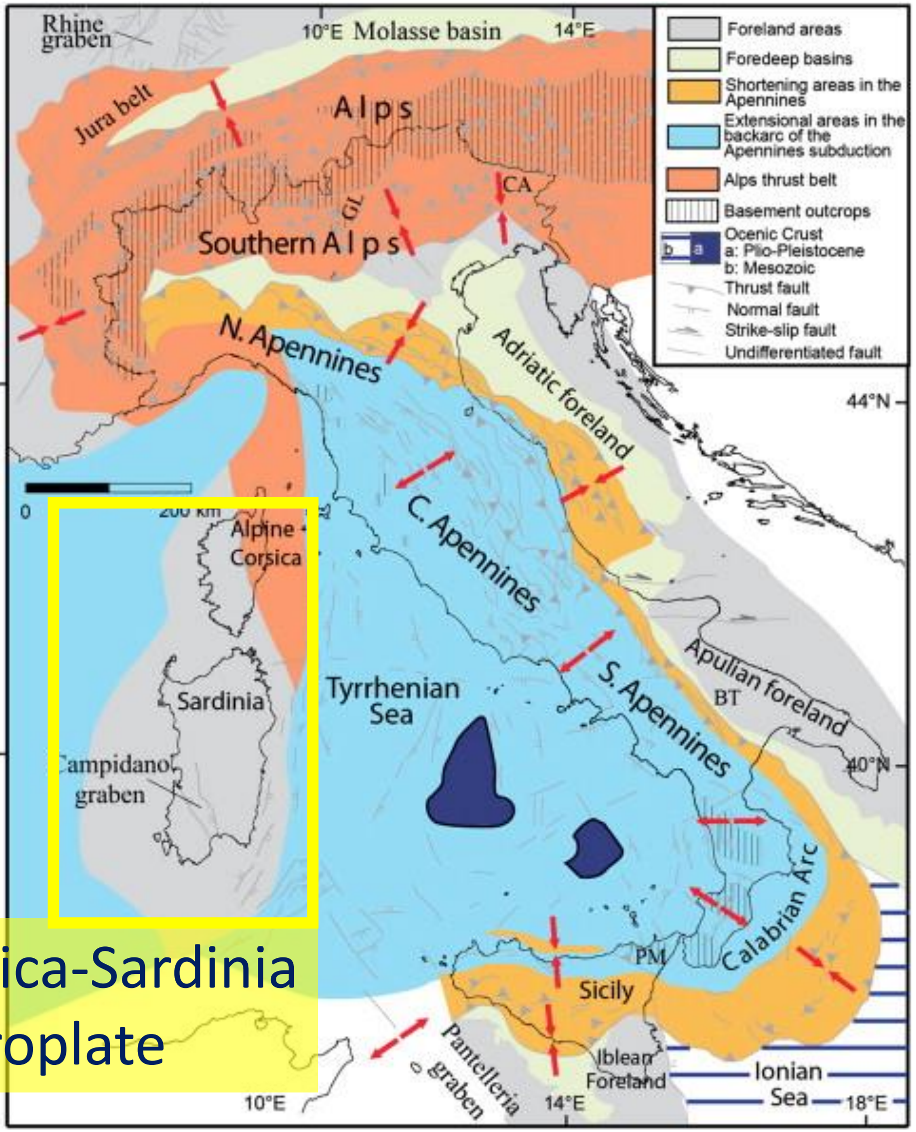






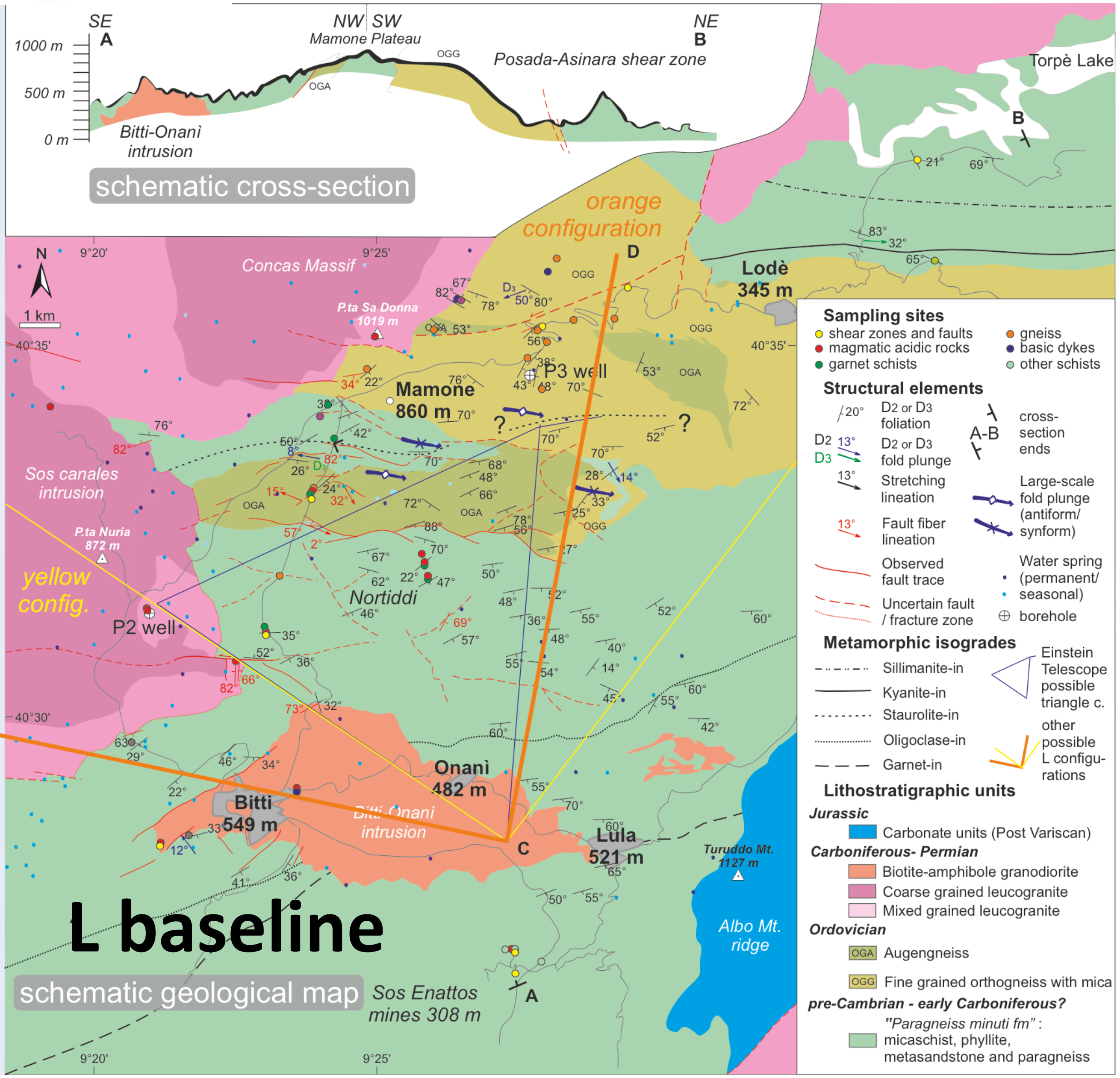
http://www.seismo.ethz.ch

Unaffected by significative seismic activity.



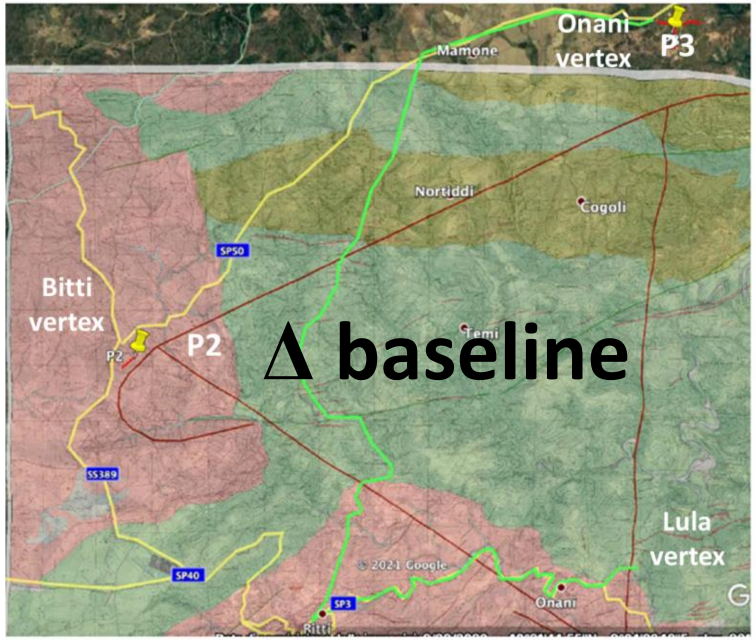
Corsica-Sardinia Microplate

Geological framework



Good rock quality

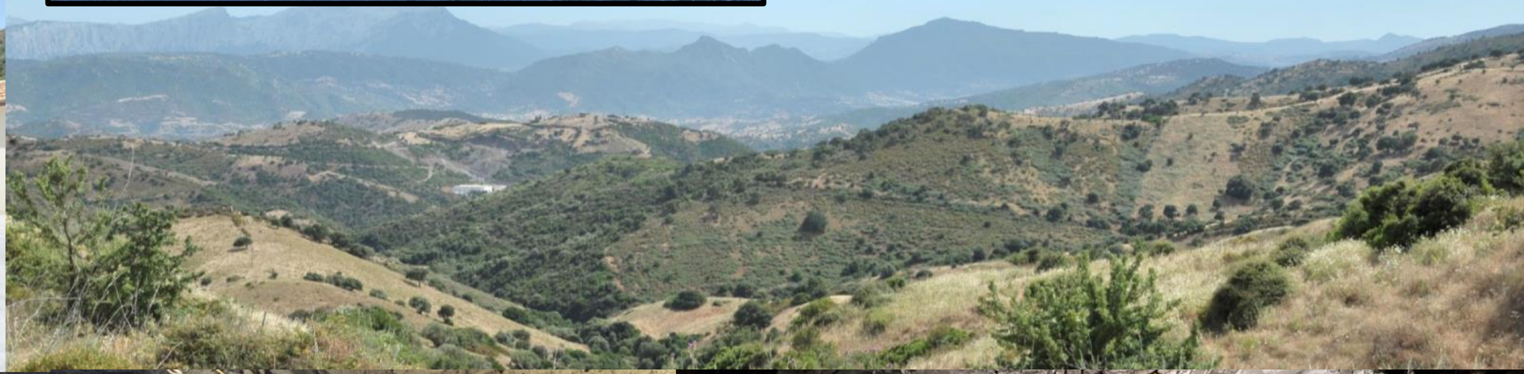
Lithologies: Orthogneiss, granitoids, micaschists. The red triangle represents the hypothetic Δ underground trace of ET. One of the possible L traces is also shown. P2 and P3 are the borehole locations. **Ongoing geological survey of the area and review of the geological maps**.



L. Naticchioni, Site Characterization – ET Italia 19/3/2025

The Sos Enattos site

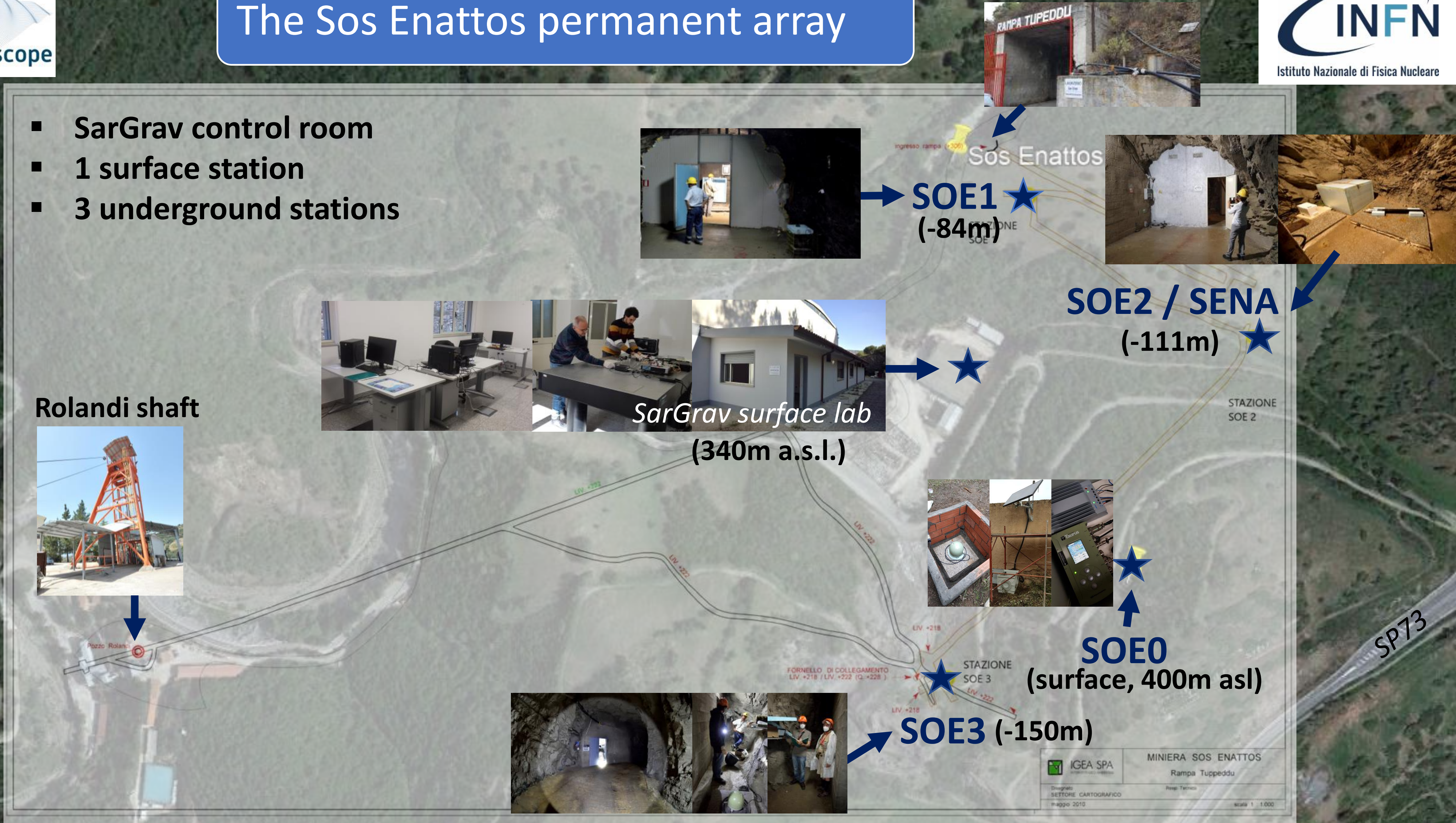
Sos Enattos former mine



- **First seismic characterization in 2010-2014**
- **ET full site characterization started in 2019**

The Sos Enattos permanent array

- SarGrav control room
- 1 surface station
- 3 underground stations



Nel 2025 inizieranno i lavori per lo smantellamento del vecchio edificio (capannone «Rimisa») ospitante il laboratorio di superficie SarGrav e la control room a Sos Enattos, che sarà sostituito dal nuovo edificio **SUNLAB**.

Le attività di misura in loco (ex miniera Sos Enattos) risentiranno del cantiere, sia in termini di acquisizione dati (control room) che data quality (science data a SOE0,1,2,3 solo in orario notturno)

The Sos Enattos site

Site characterization of the former mine

- **SarGrav surface Lab + Control Room**;
- **SOE0** (surface);
- **SOE1**, **SOE2**, **SOE3** (-86m, -111m, -160m underground).

Instrumented stations

Sensors currently installed:

- 5 broadband triaxial seismometers (*Nanometrics Trillium 360, 240, Guralp 360 CMG-3TD*);
- 3 magnetometers (*MF6-06*, N-S at surface, N-S & E-W underground);
- Several infrasound microphones and microbarometers (surface & underground);
- 8 short-period triaxial seismometers (*Nanometrics Trillium 20PH,* movable array);
- High Precision Tiltmeter (part of the *Archimedes* experiment @ SarGrav) *it must be relocated in another site during 2025 due to SUNLAB construction*;
- Radon sensors along the mine.
- Weather station.
- 2 GNSS stations.
- A gravimeter (INGV)

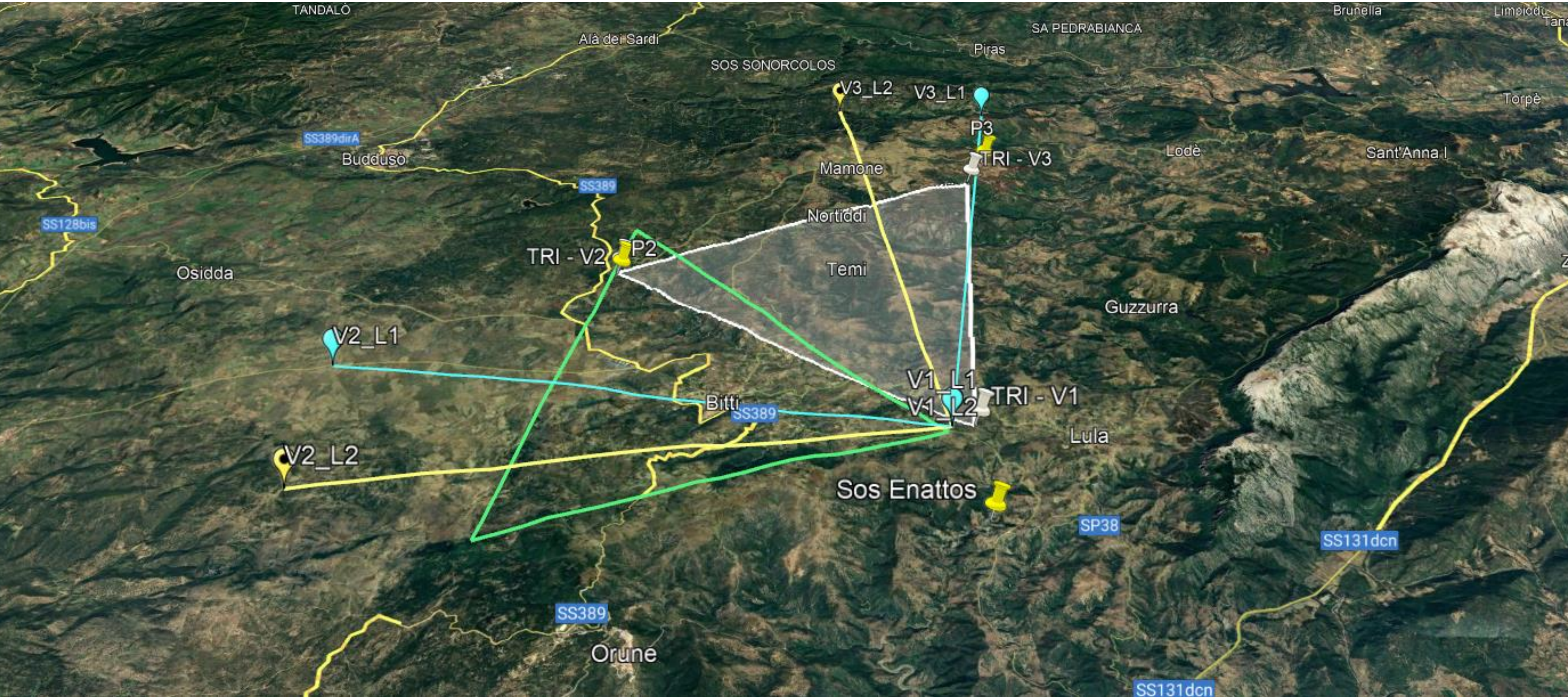
The Sos Enattos site

Site characterization of the former mine

Station code	Depth WRT surface	Sensor installed	Period	Digitiser
SOE0 (old location)	0 (338m a.s.l.)	Guralp 3EPSCD 120	2019/3-2019/12	Embedded
SOE0	400m asl	Nanometrics Trillium 240	2019/12-...	Nanometrics Taurus
SOE1	-84m (254m asl)	Nanometrics Trillium 240	2019/3-2020/7	Nanometrics Taurus
SOE1	-84m (254m asl)	Nanometrics Trillium 120H	2020/7-2021/8	Nanometrics Centaur
SOE1	-84m (254m asl)	Guralp CMG-3TD 360	2021/7-...	Embedded
SOE1	-84m (254m asl)	Nanometrics Trillium 360 vault	2022/4-...	Nanometrics Centaur
SOE2	-111m (227m asl)	Nanometrics Trillium 240	2019/3-2021/6	Nanometrics Centaur
SOE2	-111m (227m asl)	(2x) Nanometrics Trillium 360 GSN	2021/6-...	Nanometrics Centaur
SOE3	-160m (178m asl)	Nanometrics Trillium 240	2020/8-...	Nanometrics Centaur
Control Room	340m asl	Nanometrics Trillium 20	2020/11-...	Nanometrics Centaur

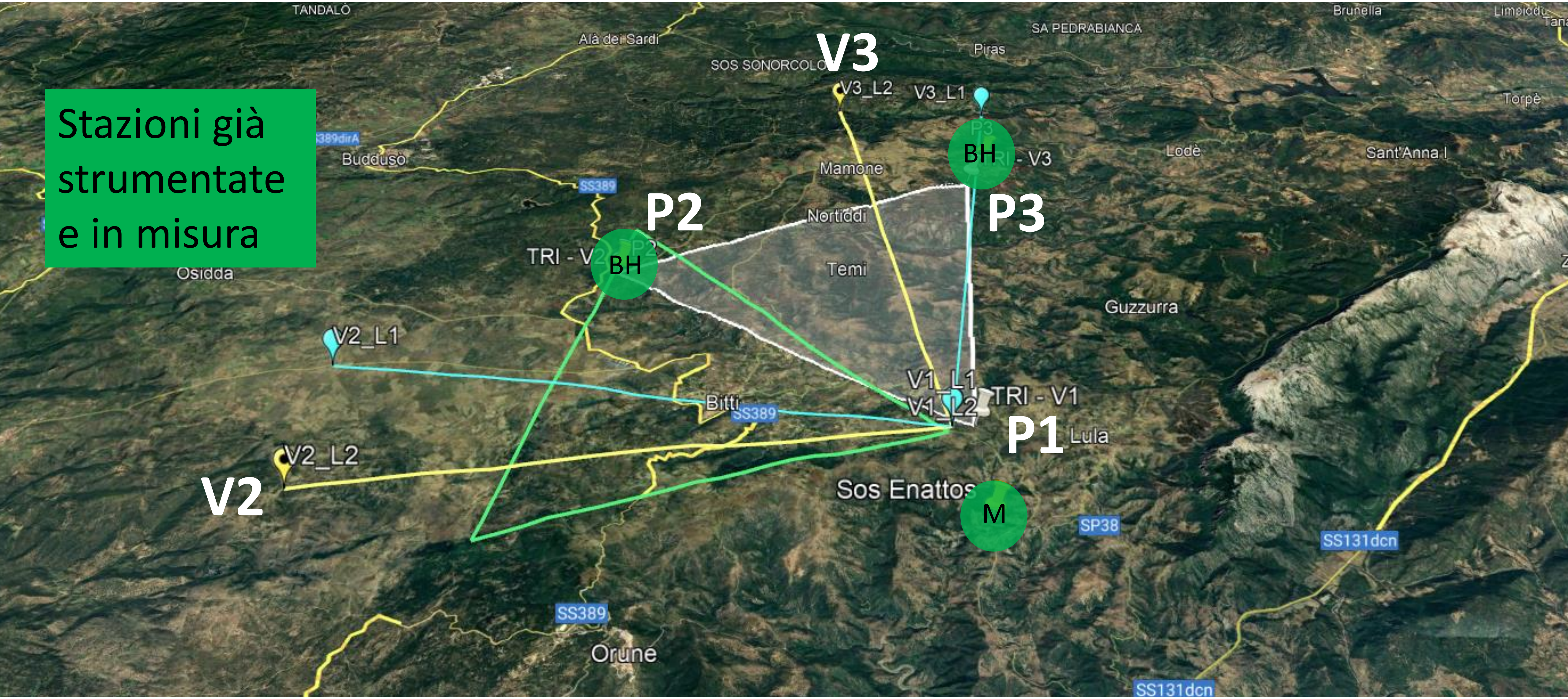
ET-0151A-22, https://apps.et-gw.eu/tds/?content=3&r=17920

ET in Sardegna: area di indagine

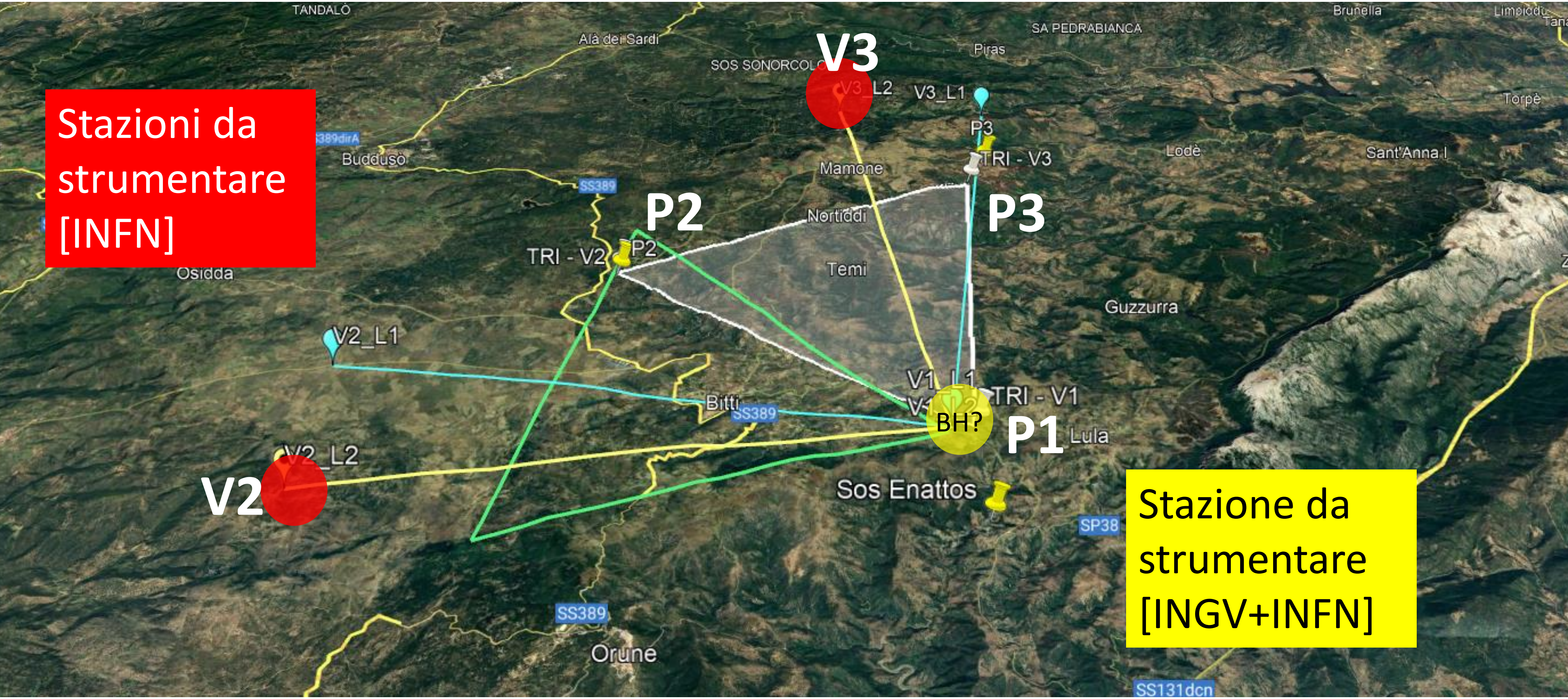


L. Naticchioni, Site Characterization – ET Italia 19/3/2025

ET in Sardegna: area di indagine



ET in Sardegna: area di indagine

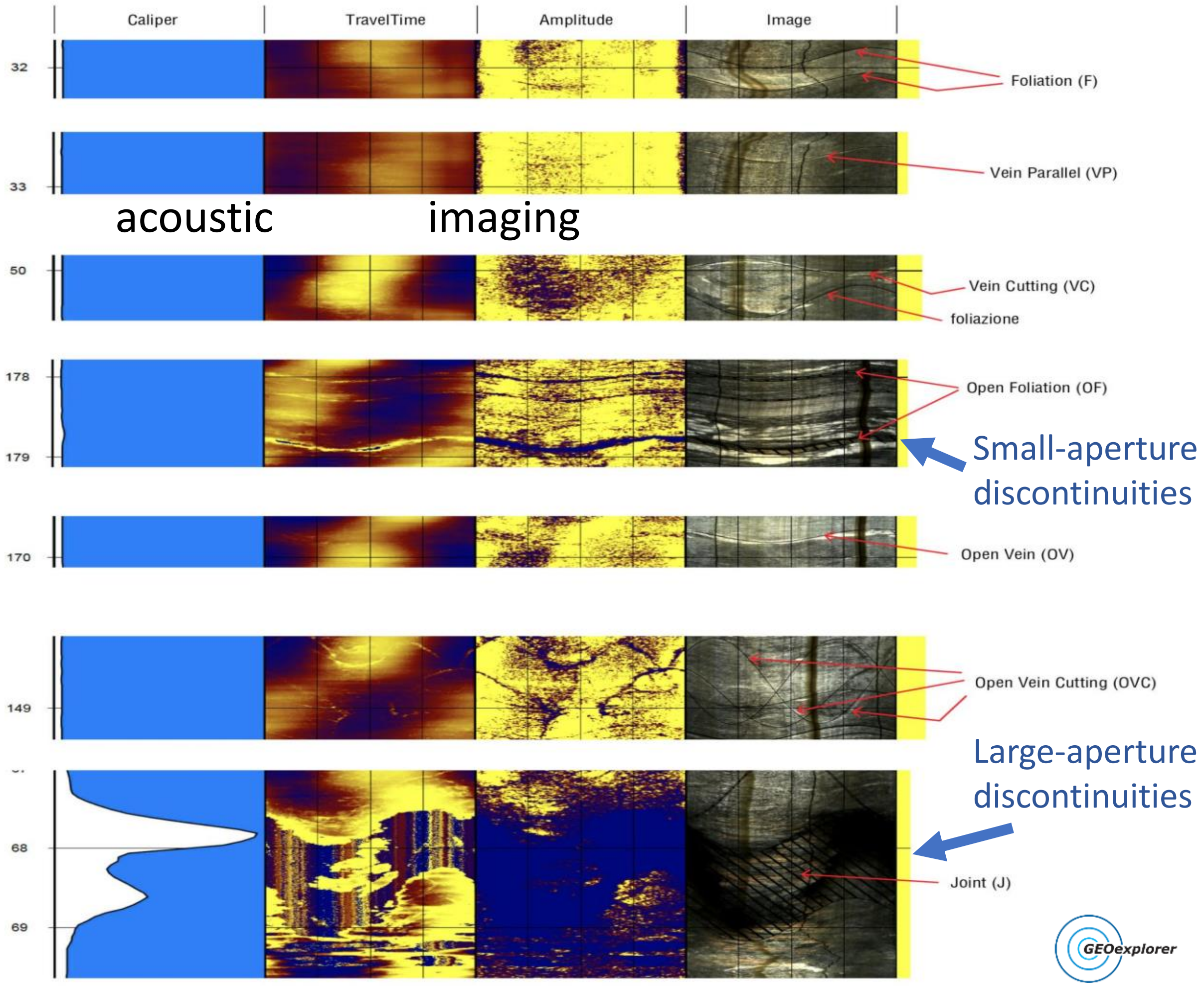


L. Naticchioni, Site Characterization – ET Italia 19/3/2025

Characterization of the (original) Δ corners

The boreholes at P2 and P3

Borehole drilling in 2021 down to 270m within 3° inclination, and geophysical logs

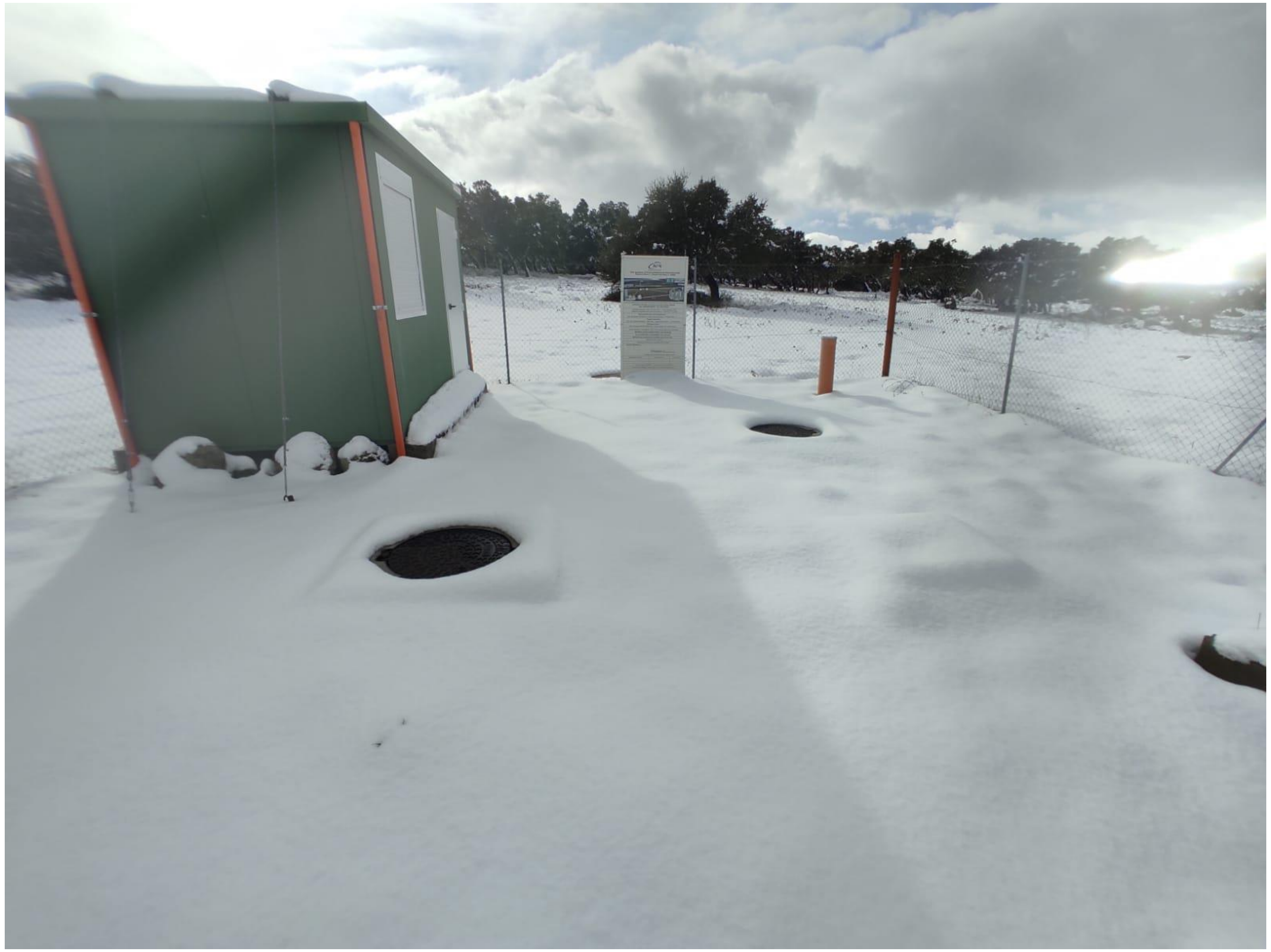


L. Naticchioni, Site Characterization – ET Italia 19/3/2025

Characterization of the (original) Δ corners

The boreholes at P2 and P3

Measurement stations at the corners



Einstein Telescope ITALY

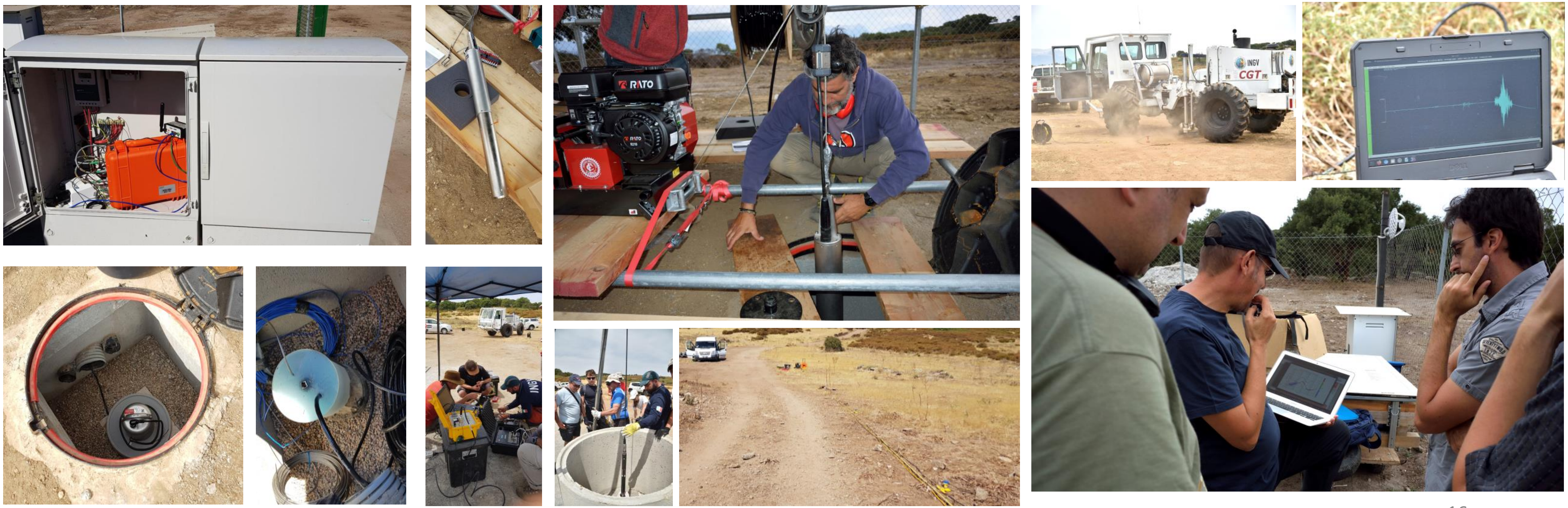
Characterization of the (original) Δ corners

Istituto Nazionale di Fisica Nucleare INFN

Seismometer installations & active seismic campaign

ET-0426A-21, https://apps.et-gw.eu/tds/?content=3&r=17710

- Surface & borehole seismometer installed in Sept. 2021. Stations were improved during 2022, also with the installation of 2 magnetometers (P2). Optical fiber strainmeter deployed along both boreholes.
- Temporary surface array for passive and active seismic measurement at both corners.



ET: Δ or L …

- **La collaborazione sta valutando entrambe le configurazioni:**
  - Δ-10km, un solo sito.
  - 2L-15km, due siti.
  - La collaborazione ha nominato due comitati dedicati per studiare le performance scientifiche (**COBA**) e il rischio (**ETRAC**) nelle due configurazioni.
  - Chiara evidenza da entrambi gli studi che la soluzione a **2L è favorita**. Tuttavia, **una decisione definitiva non è stata ancora presa** e ci sono ancora resistenze (poco «scientifiche») ad adottare la soluzione 2L dal lato olandese.
  - A fine 2024 è stata presentata la candidatura di un terzo sito in Germania (Lusatia)...
  - Verosimilmente, la decisione su configurazione e sito/i non sarà presa prima di **fine 2026**.
- **L'appalto della «garona» di progettazione finanziata da ETIC prevede entrambe le soluzioni per la Sardegna.**
- **È necessario «strumentare» i vertici per la soluzione L-15km e il P1 (~3km da Sos Enattos) come già fatto con successo in P2, P3 per avere un quadro completo su tutta l'area dell'osservatorio.**
  - *Non ci aspettiamo grosse differenze nel fondo sismico, ma localmente possibili differenze* (**sorgenti locali**, p.e. Budussò windpark signature in P2 data)

The Sos Enattos site

Site Characterization publications #1/2

- L. Naticchioni et al., ***Microseismic studies of an underground site for a new interferometric gravitational wave detector***, **CQG**, 2014, https://doi.org/10.1088/0264-9381/31/10/105016
- L. Naticchioni et al., ***Characterization of the Sos Enattos site for the Einstein Telescope***, **JPCS** 1468, 2020, https://doi.org/10.1088/1742-6596/1468/1/012242
- M. Di Giovanni et al., ***A seismological study of the Sos Enattos Area – the Sardinia Candidate Site for the Einstein Telescope***, **SRL**, 2020 https://doi.org/10.1785/0220200186
- A. Allocca et al., ***Seismic glitchness at Sos Enattos site: impact on intermediate black hole binaries detection efficiency***, **EPJP**, 2021 https://doi.org/10.1140/epjp/s13360-021-01450-8
- Allocca *et al.* **Picoradiant tiltmeter and direct ground tilt measurements at the Sos Enattos site**, **EPJP 136**, 1069 (2021). https://doi.org/10.1140/epjp/s13360-021-01993-w
- M. Di Giovanni et al., ***Temporal variations of the ambient seismic field at the Sardinia candidate site of the Einstein Telescope***, **GJI 234**, 2023, https://doi.org/10.1093/gji/ggad178
- G. Saccorotti et al., ***Array analysis of seismic noise at the Sos Enattos mine, the Italian candidate site for the Einstein Telescope***, **EPJP 138**, 793 (2023). https://doi.org/10.1140/epjp/s13360-023-04395-2.

[…]

Site Characterization publications #2/2

- L .Naticchioni et al., ***Results of the site characterization in Sardinia for the Einstein Telescope***, *PoS Proc. Sci.*, Vol. **441**, 2023, https://doi.org/10.22323/1.441.0110
- F. Villani et al., ***Subsurface characterization of crystalline rocks at the Einstein Telescope candidate site (Italy): Insights from seismic tomography, geoelectrical and morphostructural surveys***, SSRN, https://dx.doi.org/10.2139/ssrn.5063240 (2024)
- M. Di Giovanni et al., ***Impact on signal SNR of local ambient noise recorded at the ET candidate sites***, submitted to CQG (2025) https://www.arxiv.org/abs/2503.02166
- G. Diaferia et al., ***Characterization of the seismic signature of a wind park in Sardinia (Italy) near the candidate site for Einstein Telescope (ET), the third-generation gravitational wave detector***, ready for submission to journal (2025)
- R. De Rosa et al., **Magnetic noise characterization of the ET candidate site in Sardinia**, in preparation.

+ several internal notes, reports and talks

The Sos Enattos site

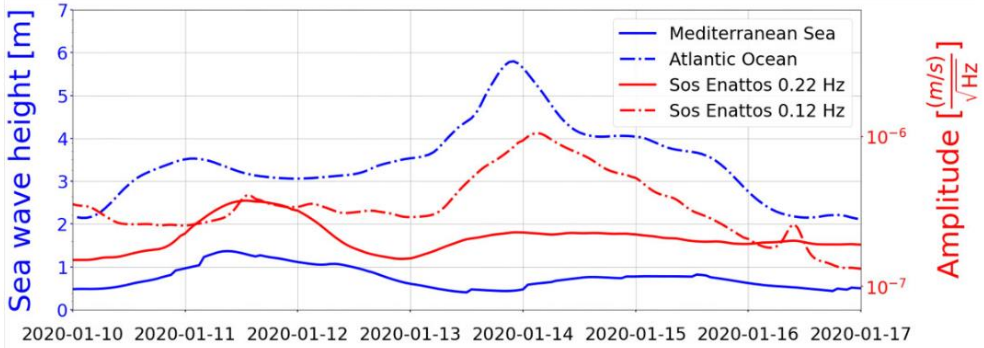
Main results

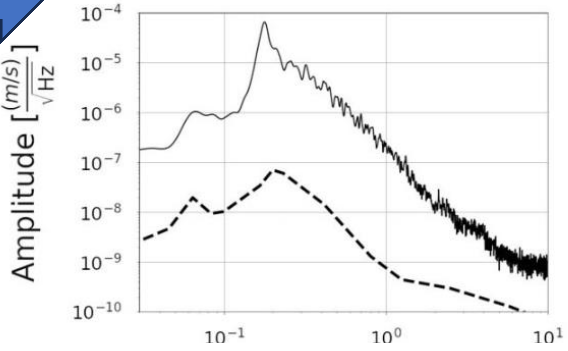
Geophysical Journal International
Geophys. J. Int. (2023) 234, 1943–1964
Advance Access publication 2023 April 26
GJI Seismology
https://doi.org/10.1093/gji/ggad178

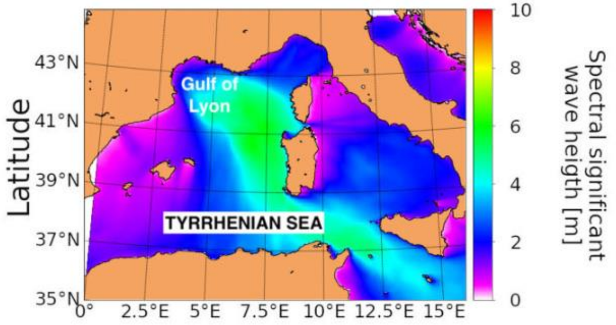
Temporal variations of the ambient seismic field at the Sardinia candidate site of the Einstein Telescope

M. Di Giovanni,[1,2] S. Koley,[1,2] J. X. Ensing,[3] T. Andric,[1,2] J. Harms,[1,2] D. D'Urso,[4,5] L. Naticchioni,[6,7] R. De Rosa,[8,9] C. Giunchi,[10] A. Allocca,[8,9] M. Cadoni,[11,12]

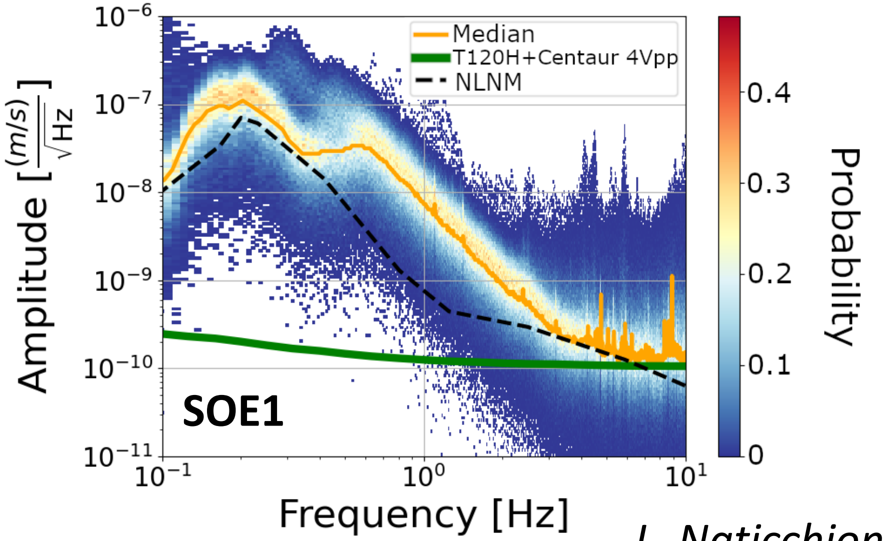
In the microseismic band (0.05-1Hz) the main spectral feature at ~0.22Hz is produced by the waves in the Gulf of Lion (NW Mediterranean sea). Depends on weather conditions → seasonal pattern.

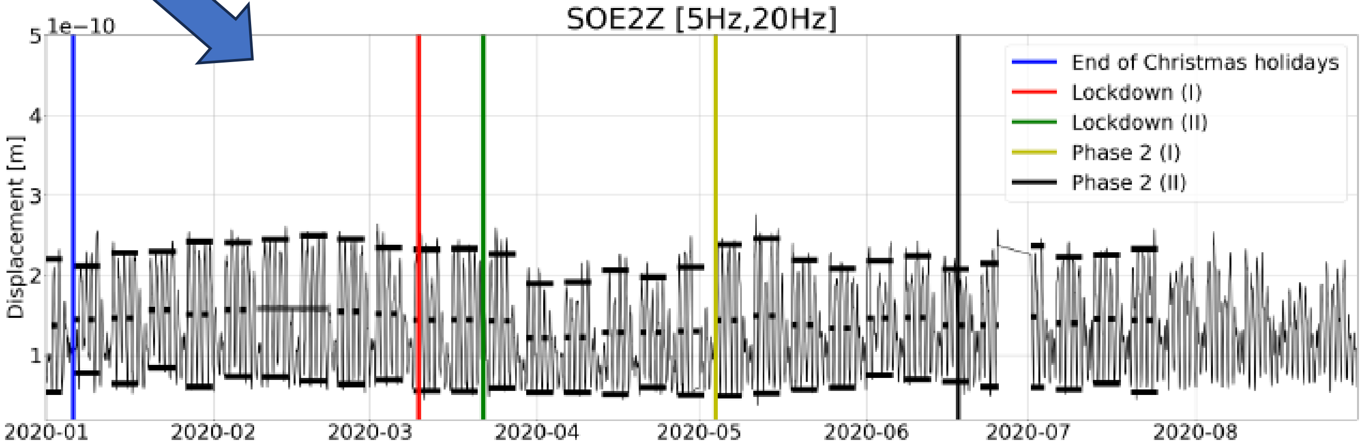






At higher frequencies, anthropic noise pattern observed.

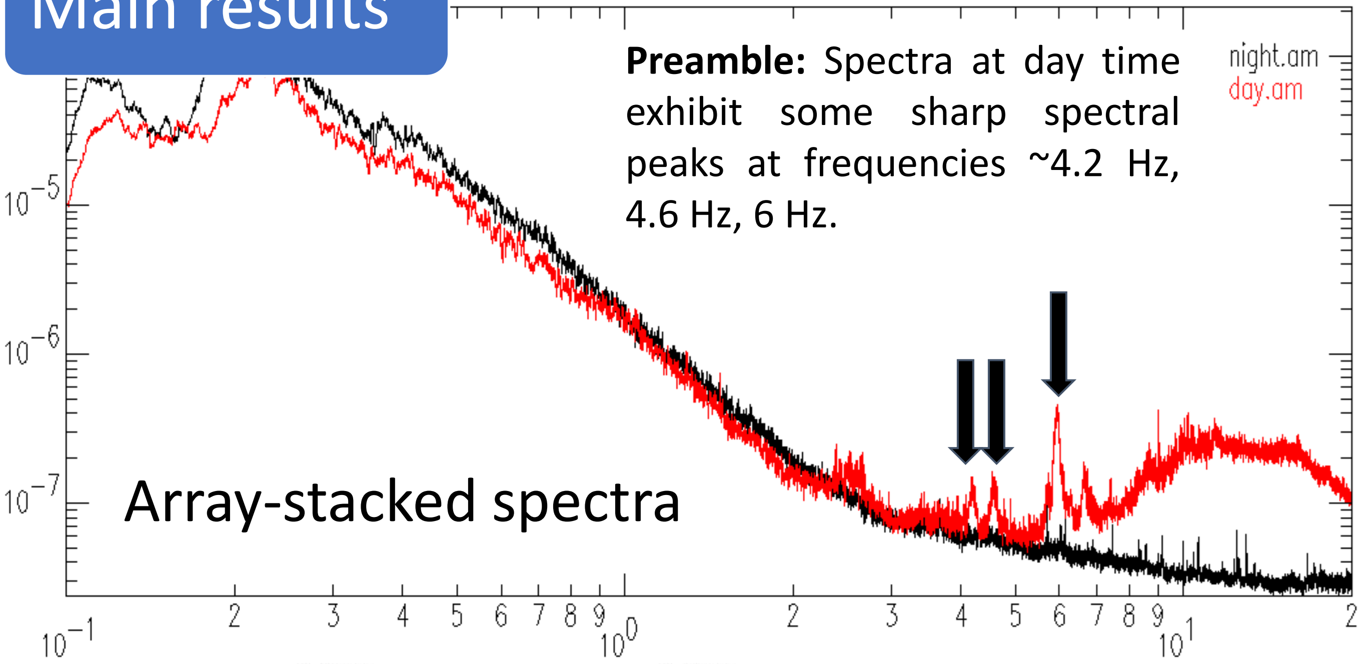




The Sos Enattos site

Seismometer array results

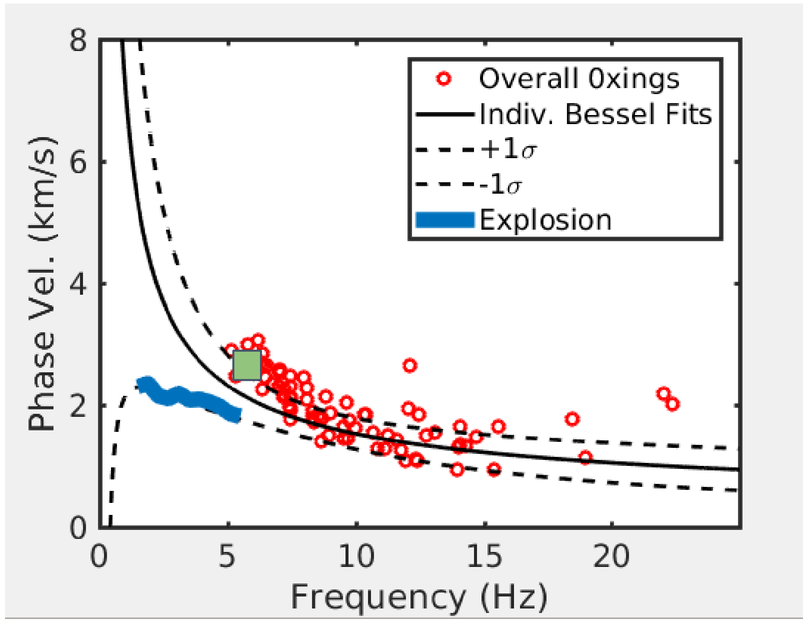
Main results



Preamble: Spectra at day time exhibit some sharp spectral peaks at frequencies ~4.2 Hz, 4.6 Hz, 6 Hz.

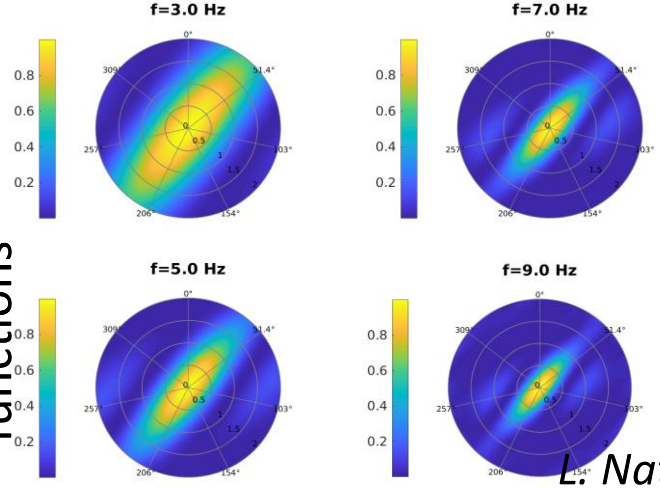
Array-stacked spectra

SPatial AutoCorrelation:

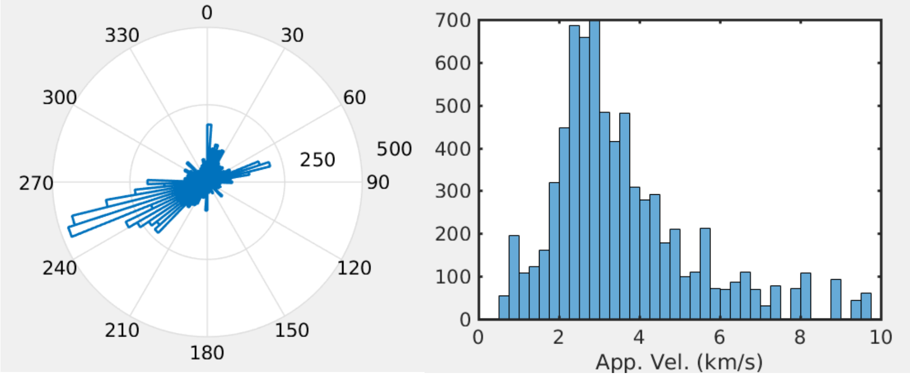


G. Saccorotti et al., 2023, Eur. Phys. J. Plus

Array response functions



FK-Analysis



Not-isotropic wavefield
Peaks at f = 4-5 Hz
Propagation azimuths directed WSW (i.e., main sources located ENE of the array)
High velocities (~2.5 km/s)

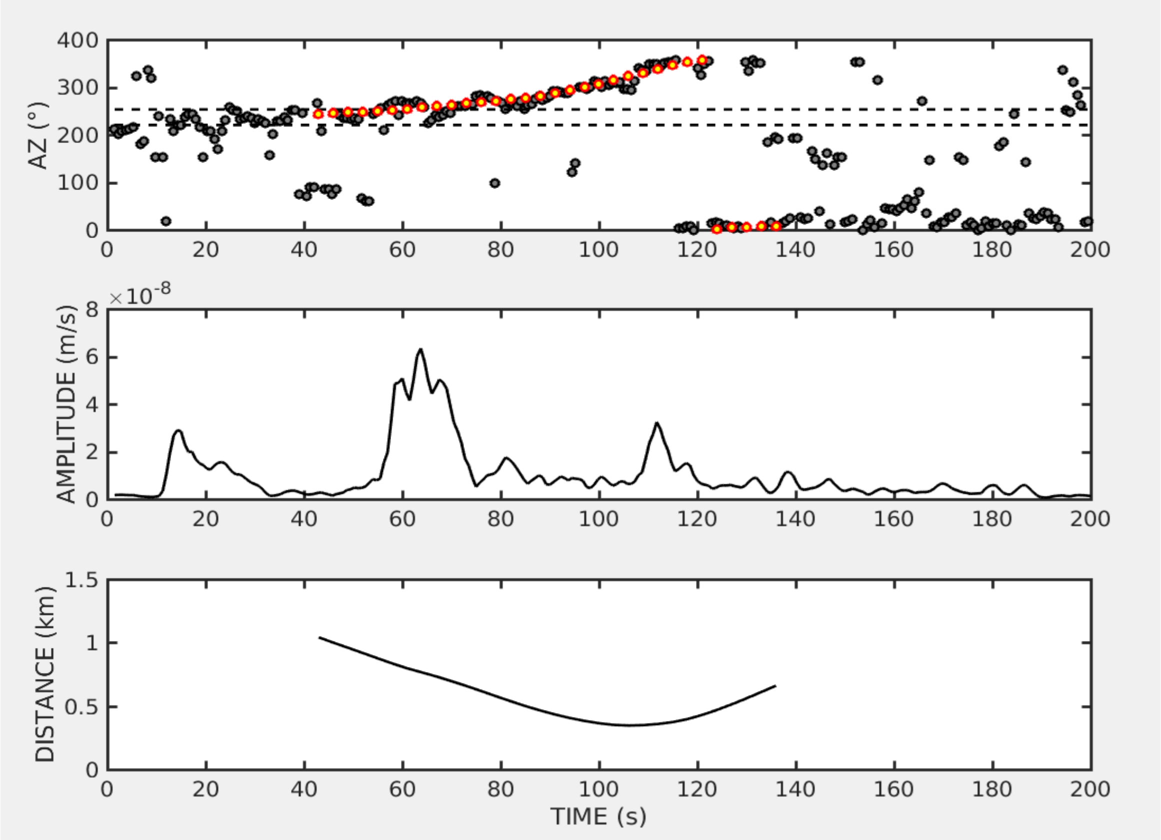
The Sos Enattos site

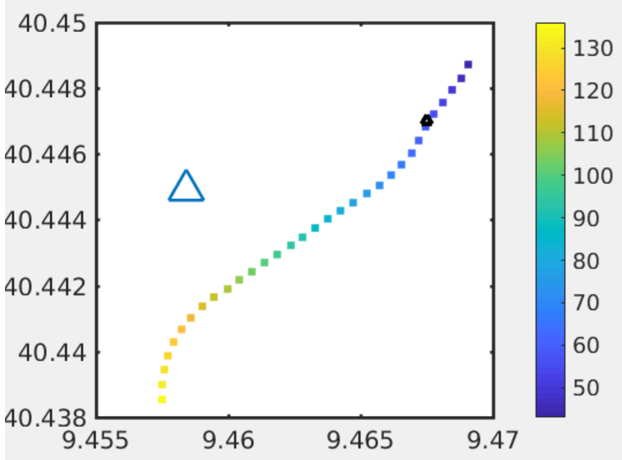
Main results

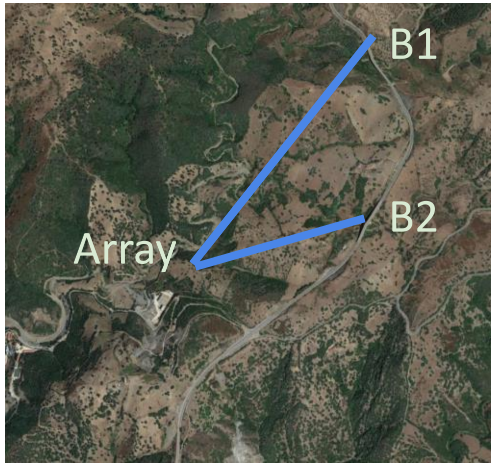
Seismometer array results

Vehicle Tracking close to the site

G. Saccorotti et al., 2023, Eur. Phys. J. Plus







Time evolution of azimuth compatible with a vehicle traveling at 60 km/h southward along road SP73.

Largest signal amplitude is NOT associated when the vehicle is closest to the array, but when it traverses bridge B2

Confirmed in another study: Geophys. J. Int. 234, 3 2023

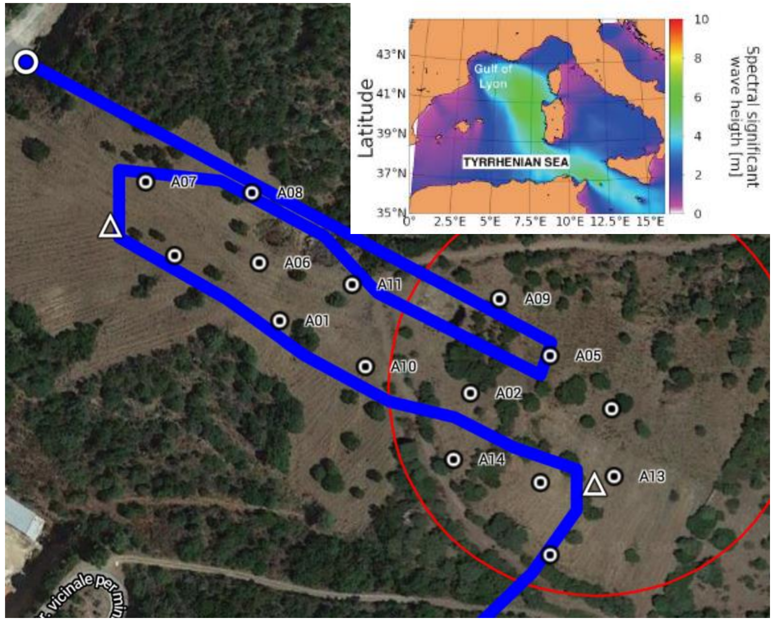
The Sos Enattos site

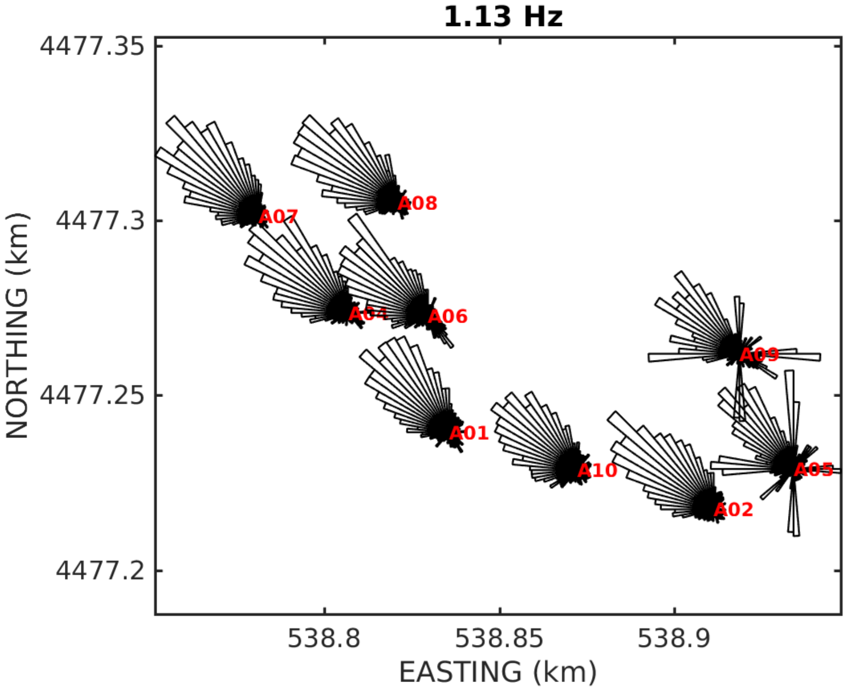
Main results

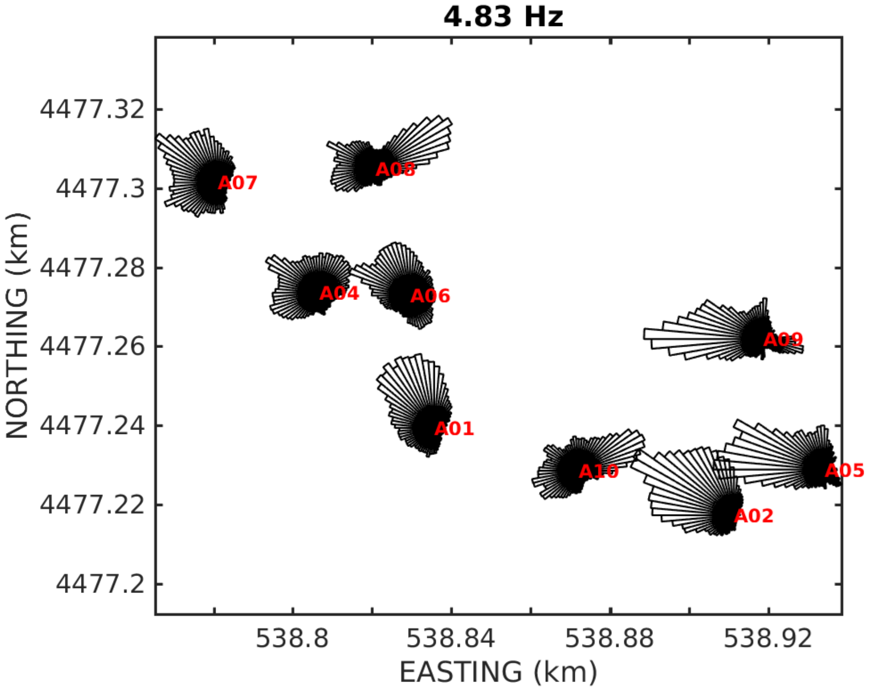
Seismometer array results
Polarization analysis

G. Saccorotti et al., 2023, Eur. Phys. J. Plus

At low frequencies, the polarization directions are rather uniform; they are oriented toward NW (marine microseismic source). At higher frequencies, the variability of polarization directions throughout the array deployment indicates a strong influence of topography.





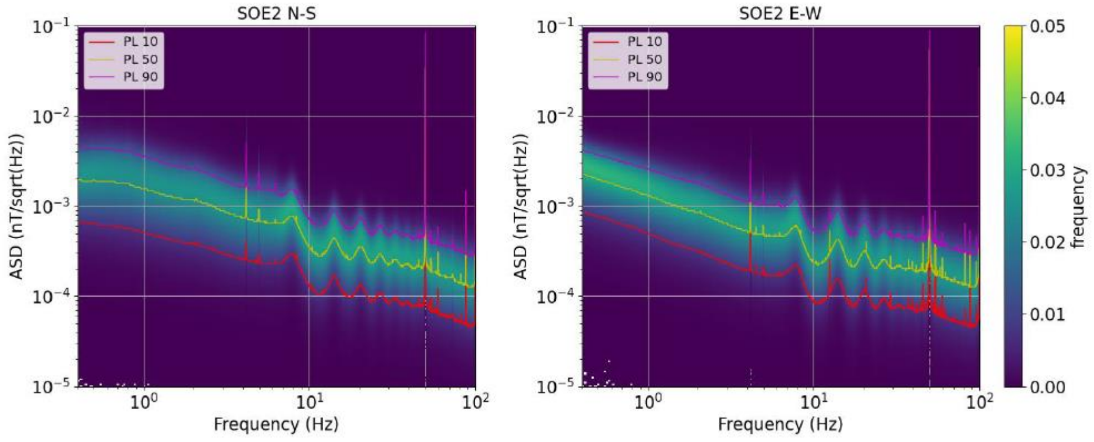


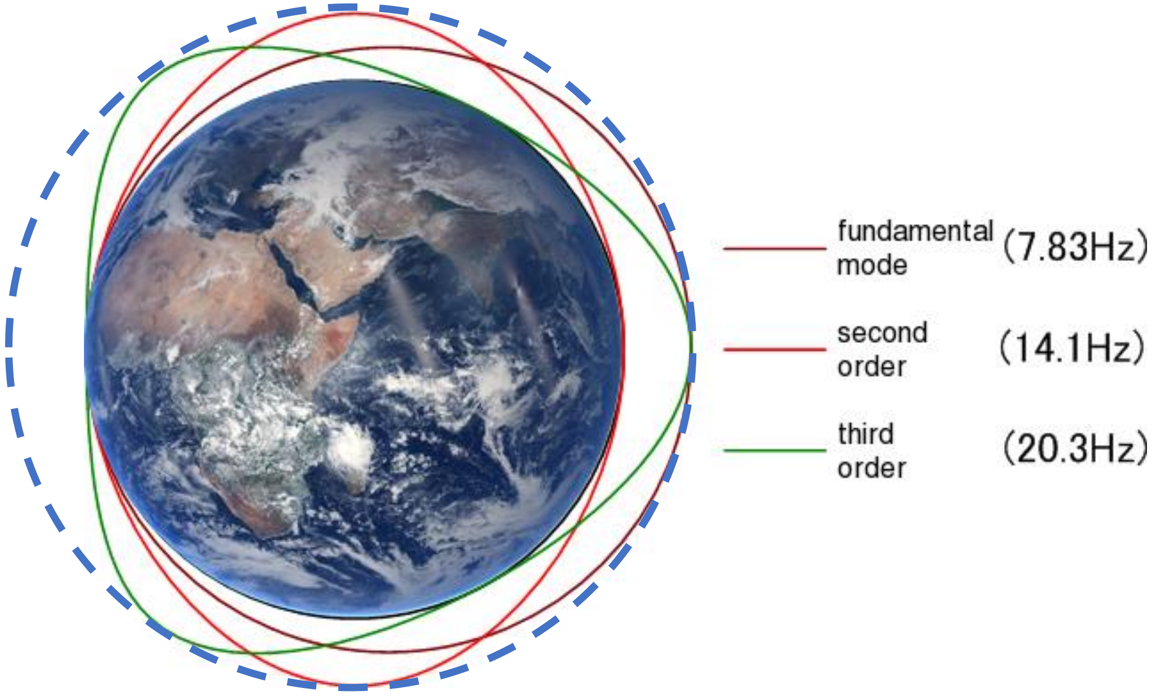
The Sos Enattos site

Main results

Magnetic Noise measurements

- In the band of interest of ET the main direct disturbances come from ULF (10^{-3}-3Hz), ELF (3-$3 \cdot 10^3$Hz) up to VLF (3-30 kHz) frequency bands.
- Main natural magnetic noise is in ULF and ELF, produced by resonance phenomena in the magnotosphere and/or in ionosphere cavities
- Most important mechanism in ET-LF:
  - **Geomagnetic pulsations Pc1** (0.2-5Hz);
  - **Schumann resonances** (5-100Hz)
- Artificial LF sources in ELF (e.g. 50-60Hz powerlines)

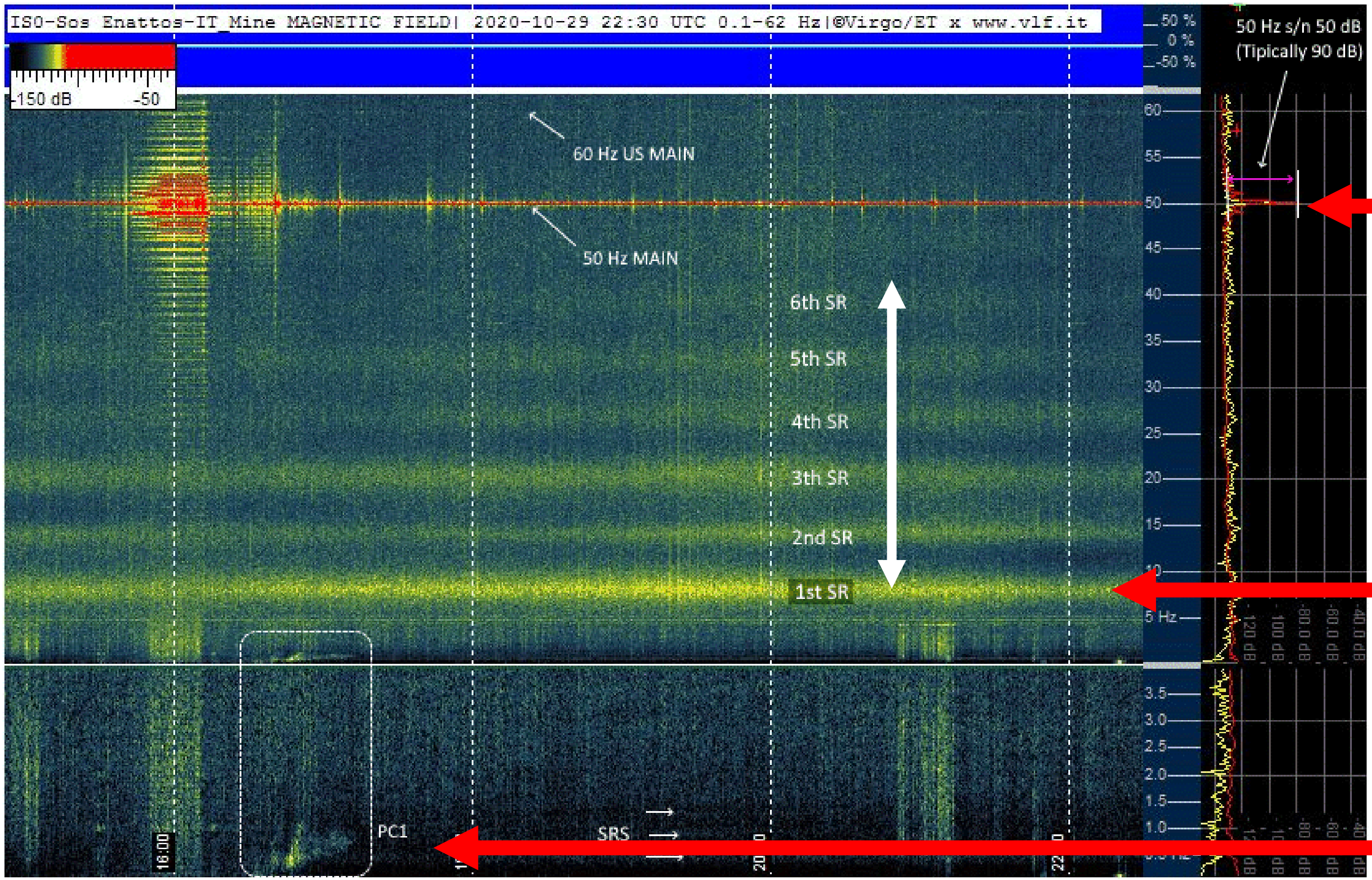




The Sos Enattos site

Main results

Magnetic Noise measurements



Power line (50 Hz)

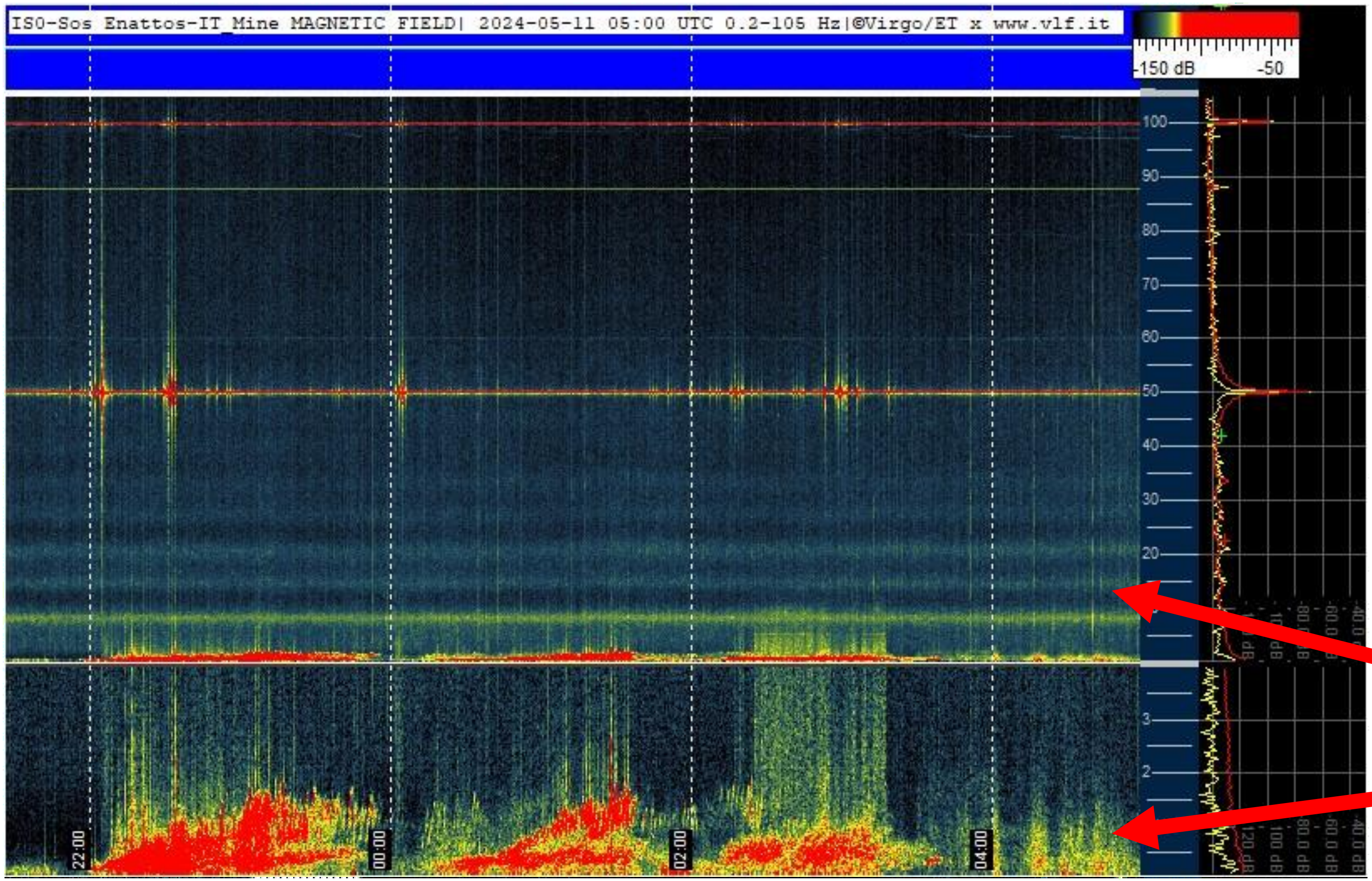
Schumann resonances

Geomagnetic pulsation

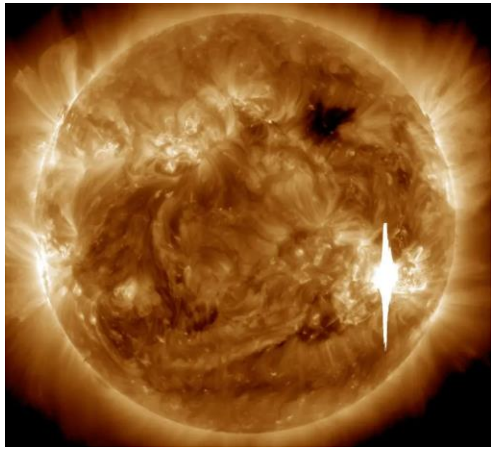
The Sos Enattos site

Main results

Magnetic Noise measurements



X5.8 solar flare measured at the Sos Enattos ET candidate site on May 11 2024



Schumann resonances

Geomagnetic pulsations

L. Naticchioni, Site Characterization – ET Italia 19/3/2025

The Sos Enattos site

Electromagnetic noise measurements

Magnetometers installed in the Sos Enattos area:

- 1 magnetometer (N-S dir.), surface level at Sos Enattos (SOE0)
- 2 magnetometers (N-S and E-W dir.) at -111 m underground at Sos Enattos (SOE2)
- 3 magnetometers (N-S, E-W, vertical) at surface level at Bitti (P2)
- Ready to be installed:
  - 3 magnetometers ready for installation at P3
- Future plans:
  - 6 magnetometers for new corners
  - 3 magnetometers for P1

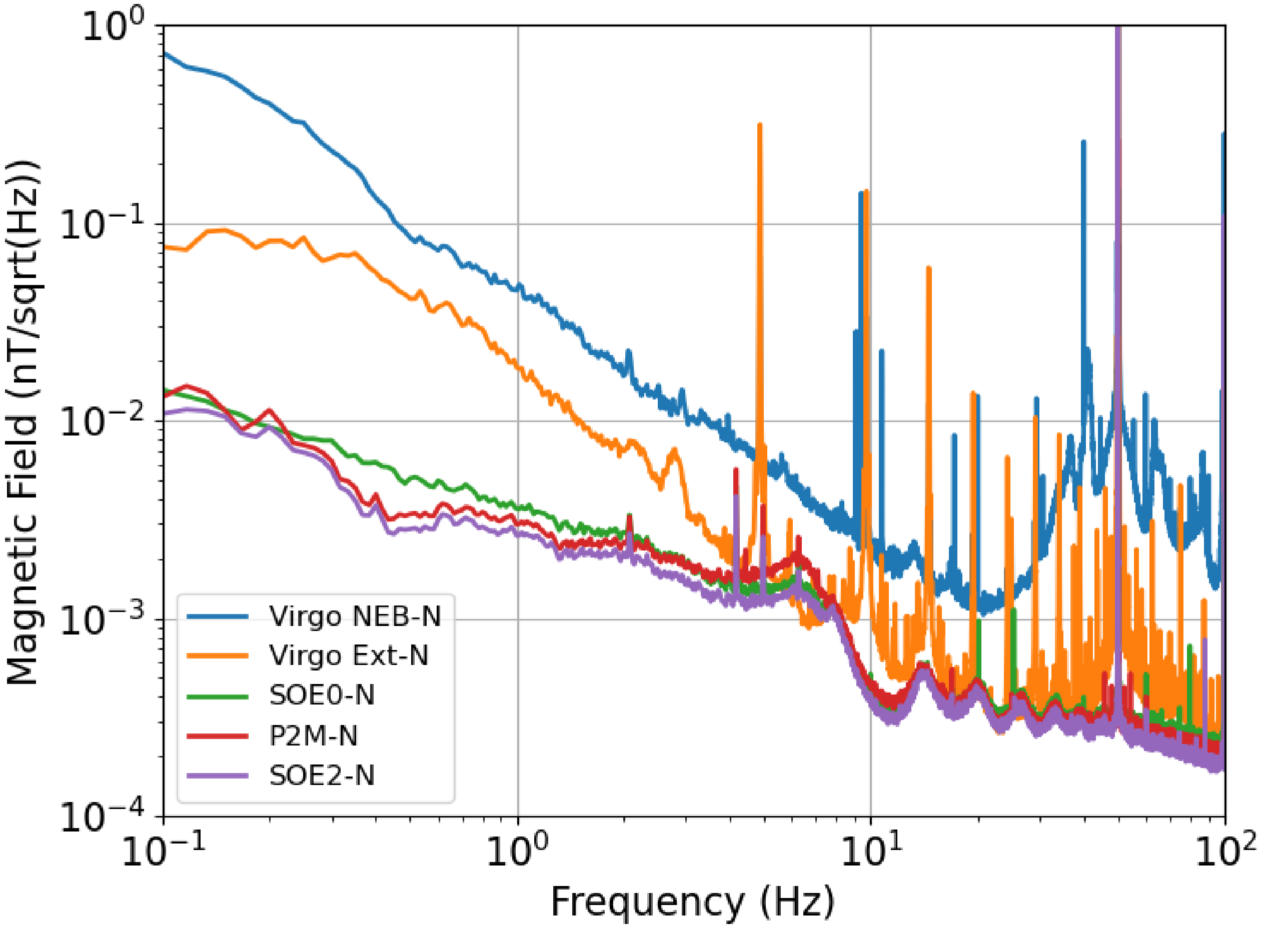
credit: R. De Rosa

The Sos Enattos site

Electromagnetic noise measurements

credit: R. De Rosa

- The EM noise is strongly dependent on the location, mainly for the impact of the anthropogenic contribution;
- An example of magnetic noise spectrum for the same time, at different locations (Virgo, Sos Enattos, P2)

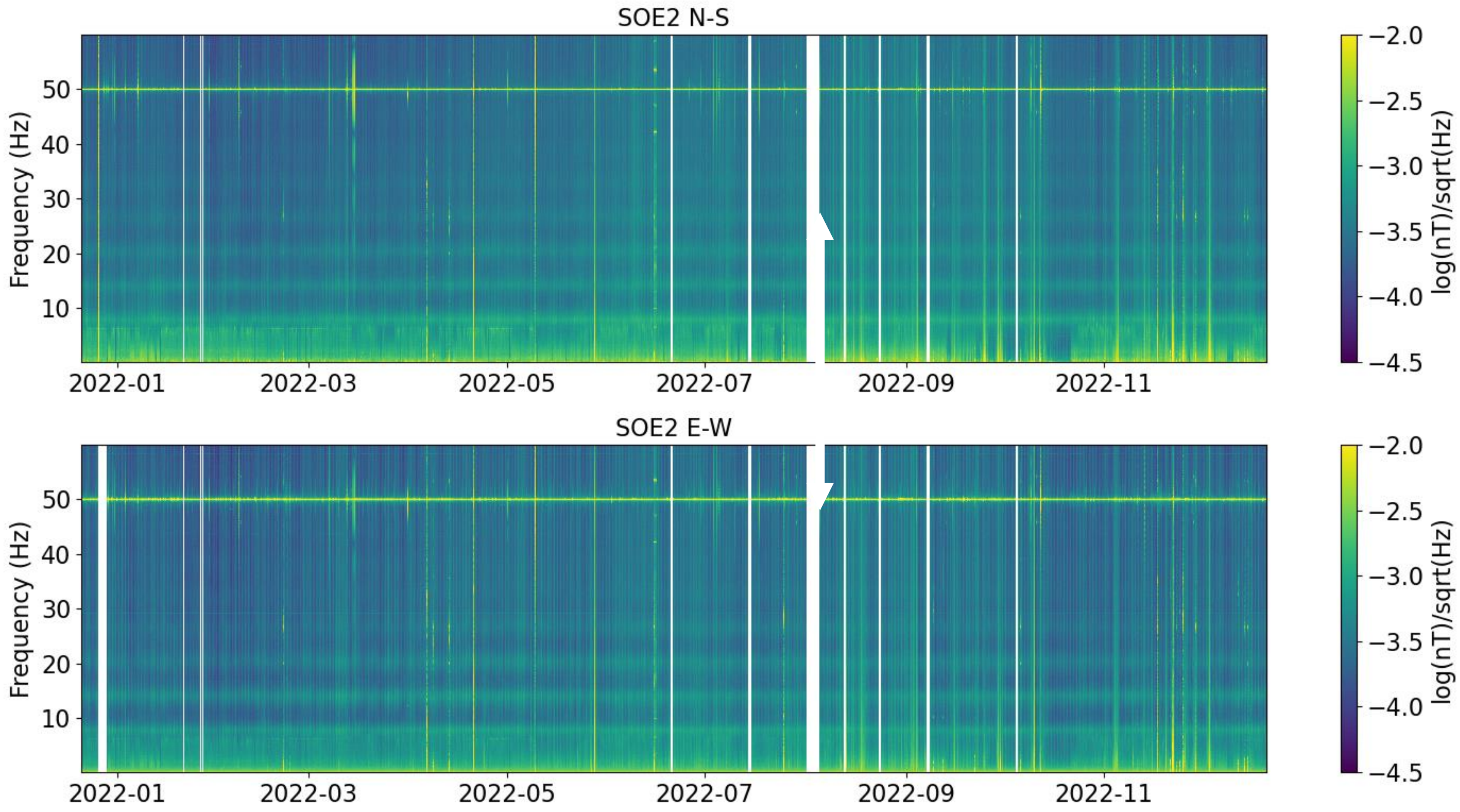


The Sos Enattos site

Electromagnetic noise measurements

credit: R. De Rosa

The long-term monitoring in a such quiet site, allows to clearly detect regular structure or periodic variability (mainly Schumann Resonances);



Probes installed at SOE2:
Sos Enattos level 2 (-111 m)

Data starts at
2021-12-21_00:00:00

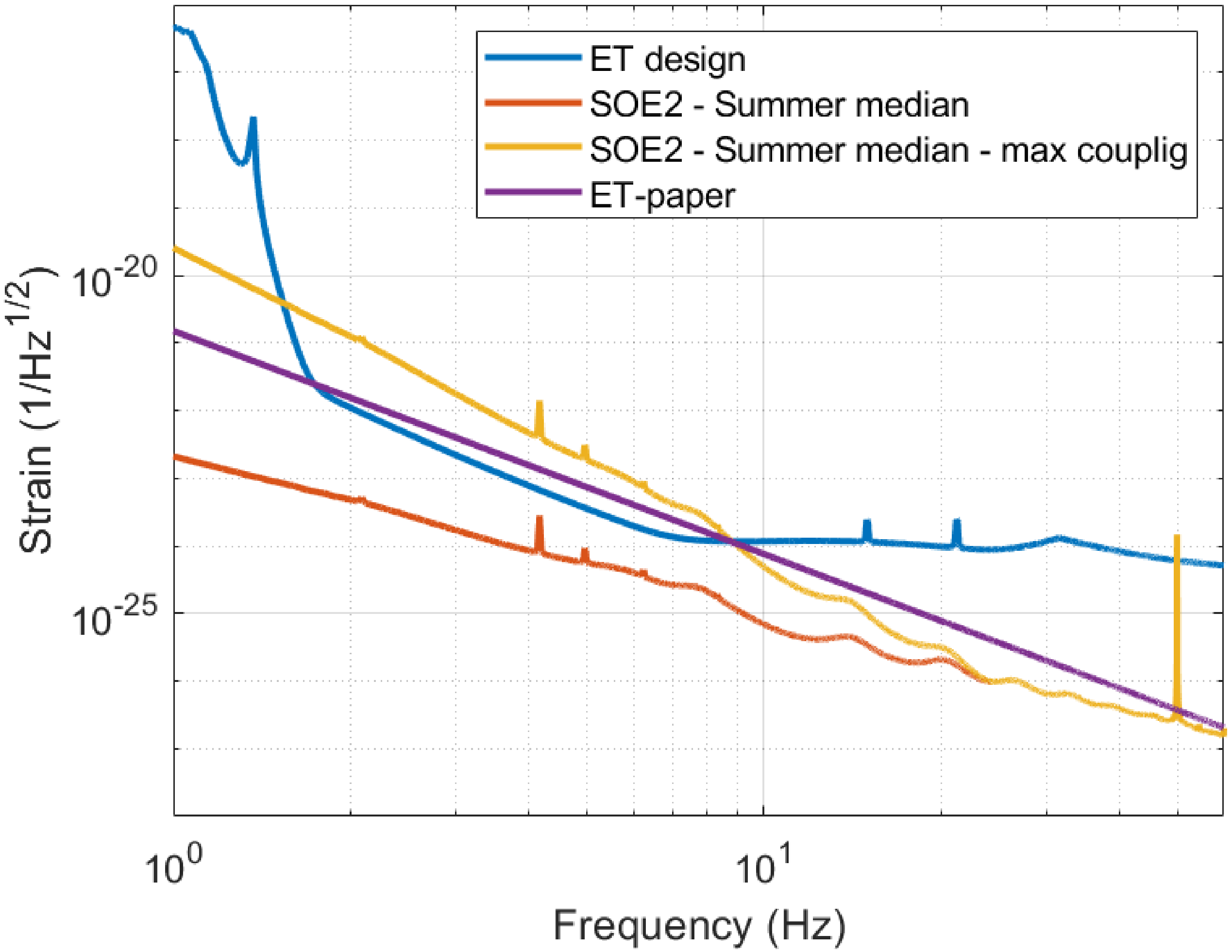
Duration: one year

The Sos Enattos site

Electromagnetic noise measurements

credit: R. De Rosa

- From the on-site measurements it is possible to estimate a lower limit for the EM noise projection on the ET sensitivity.
- The estimation was done using the Virgo data for the coupling function;
- More data (from Virgo) are required to obtain a clear estimation at low frequencies;

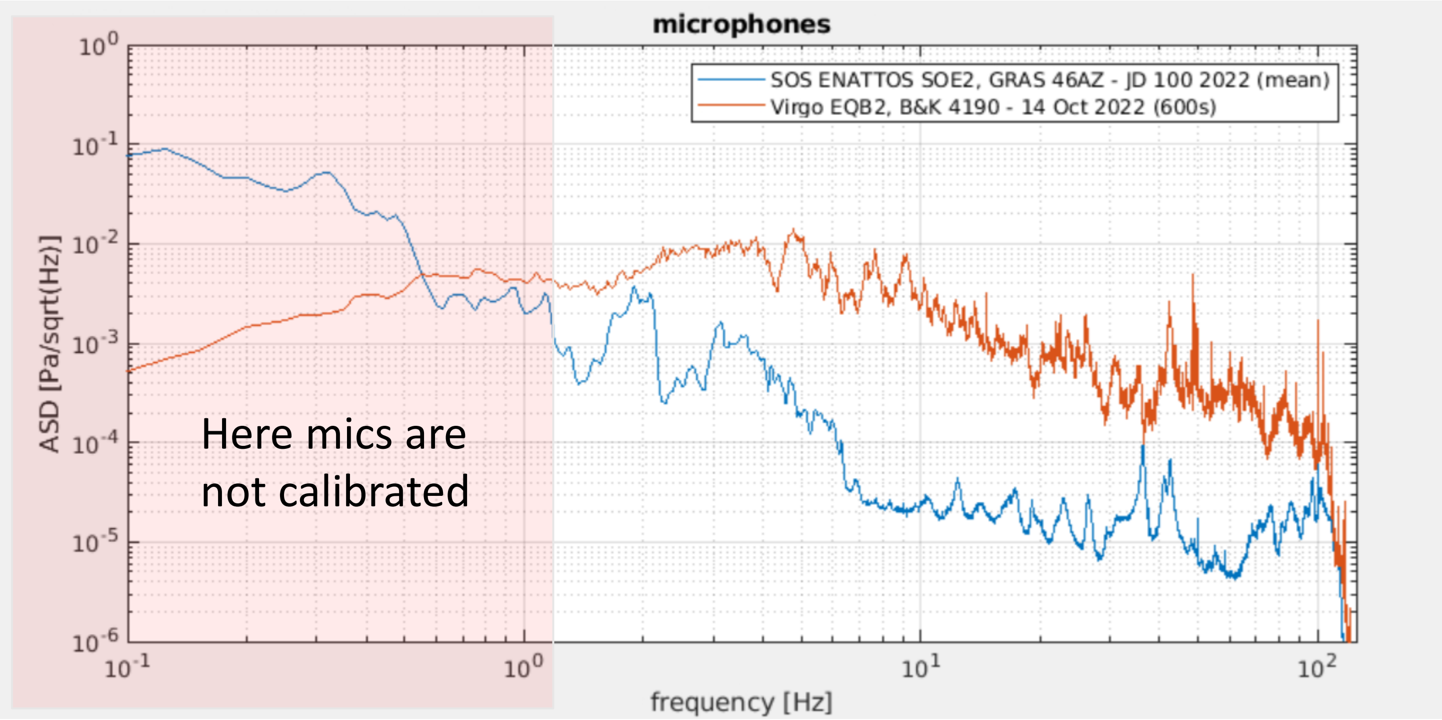


The Sos Enattos site

Underground acoustic measurements

credit: R. De Rosa

- The Acoustic noise characterization is mainly performed inside the Sos Enattos former mine.
- Microphones (GRAS 46 AZ) are installed in surface (SOE0) and at each underground level (SOE1, SOE2, SOE3).
- Data available from December 2021 (SOE2) and from December 2022 (SOE0, SOE1, SOE3)
- Other microphones installed (for comparison) by Poland group
- Infrasound microphones at P2,P3: installation planned (GSSI), also for acoustic NN modeling.



Comparison between SOE2 and the quietest Virgo location

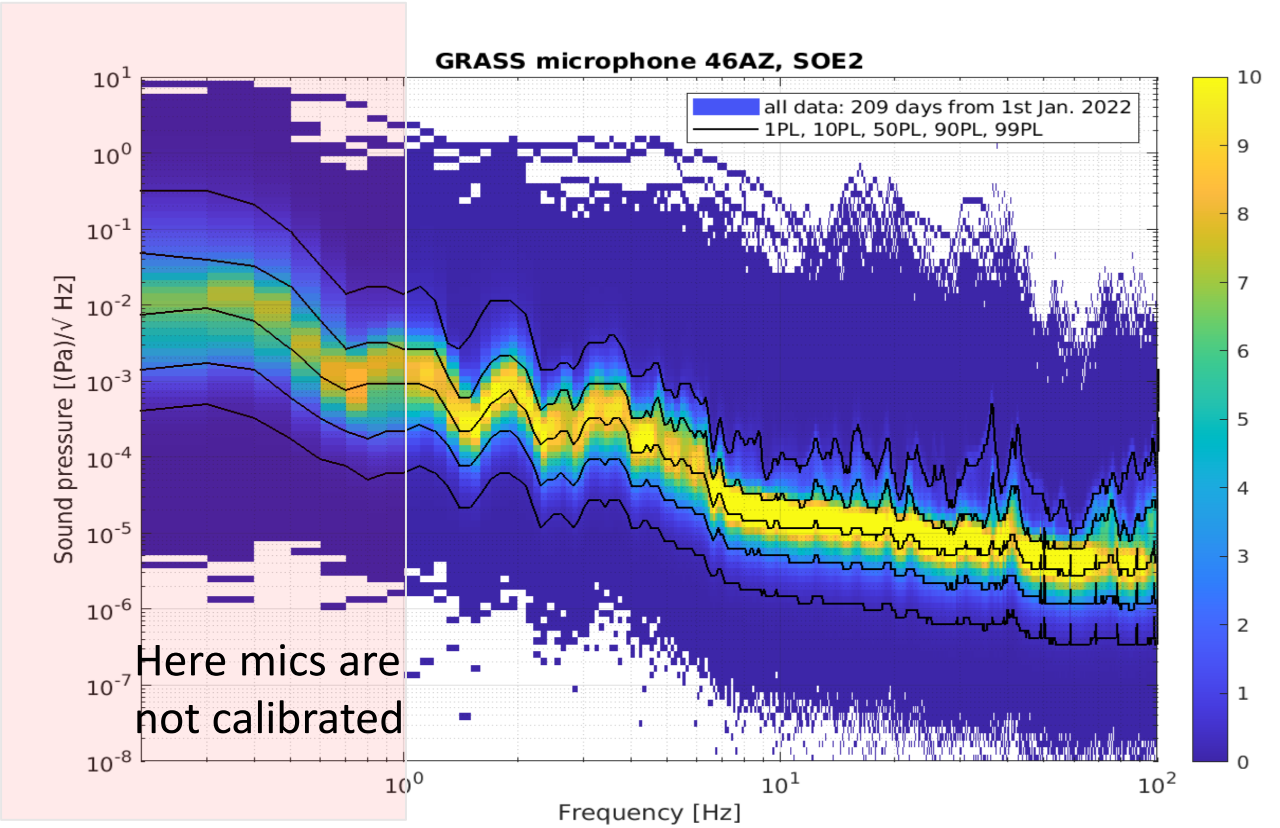
More than two order of magnitude at 10 Hz
…but practically no noisy (electronics, pumps, air conditioning) equipment presently installed at Sos Enattos

The Sos Enattos site

Underground acoustic measurements

credit: R. De Rosa

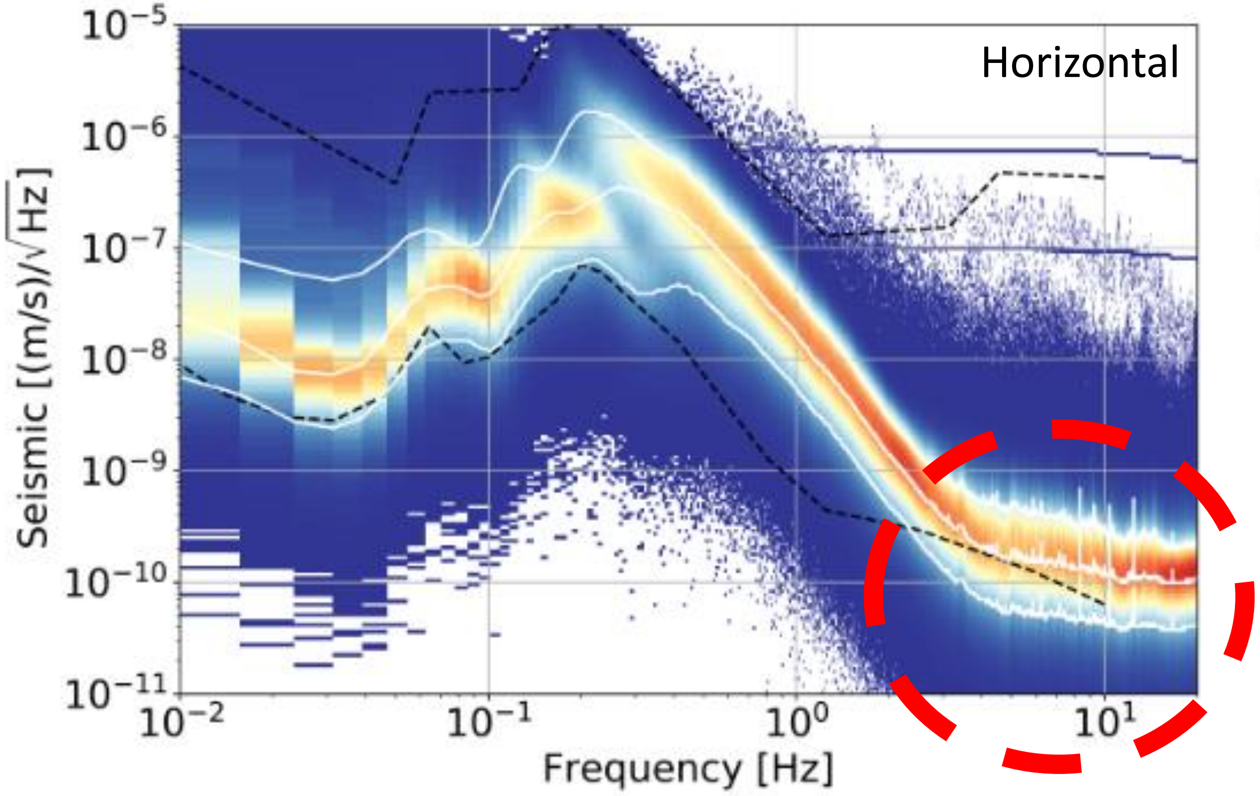
A 209 days long histogram shows the most important and persistent structures inside the cavern;

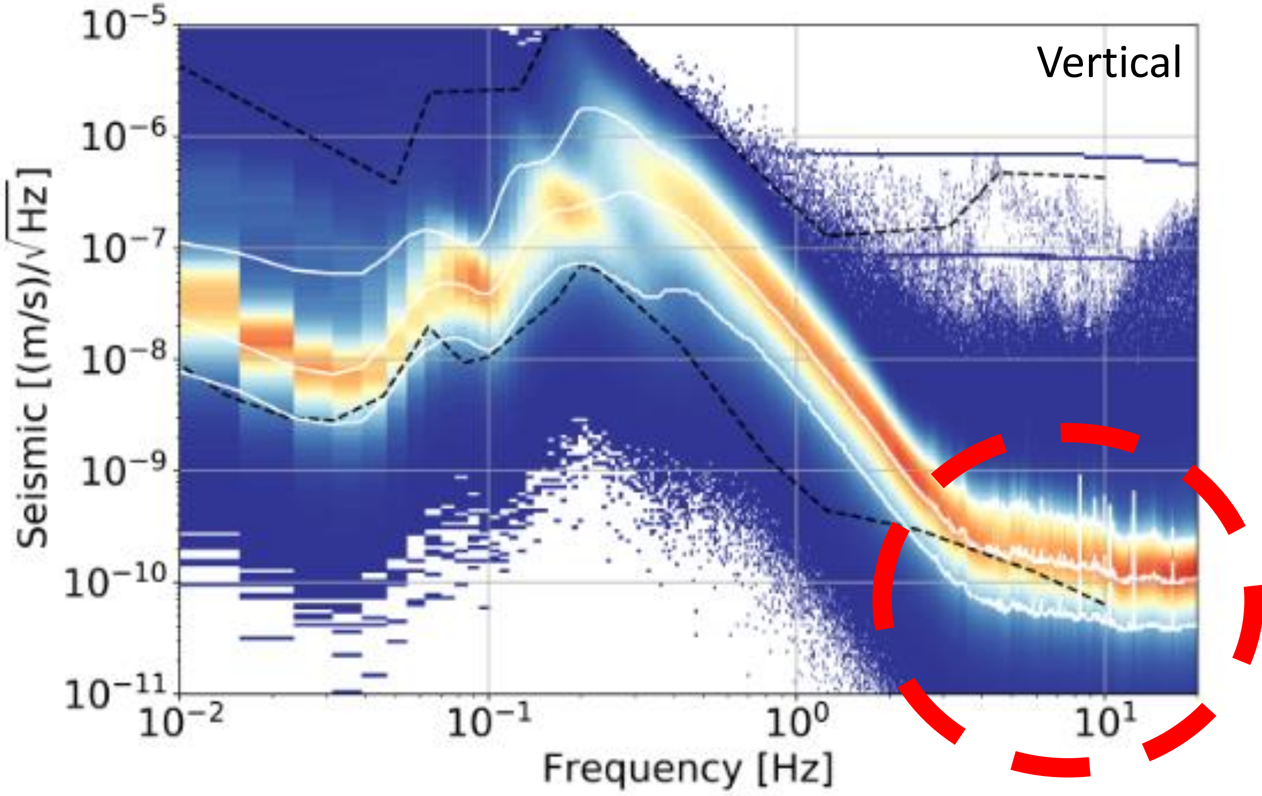


Characterization of the (original) Δ corners

A quick glance at the measurements

PPSD - P2 borehole seismometer



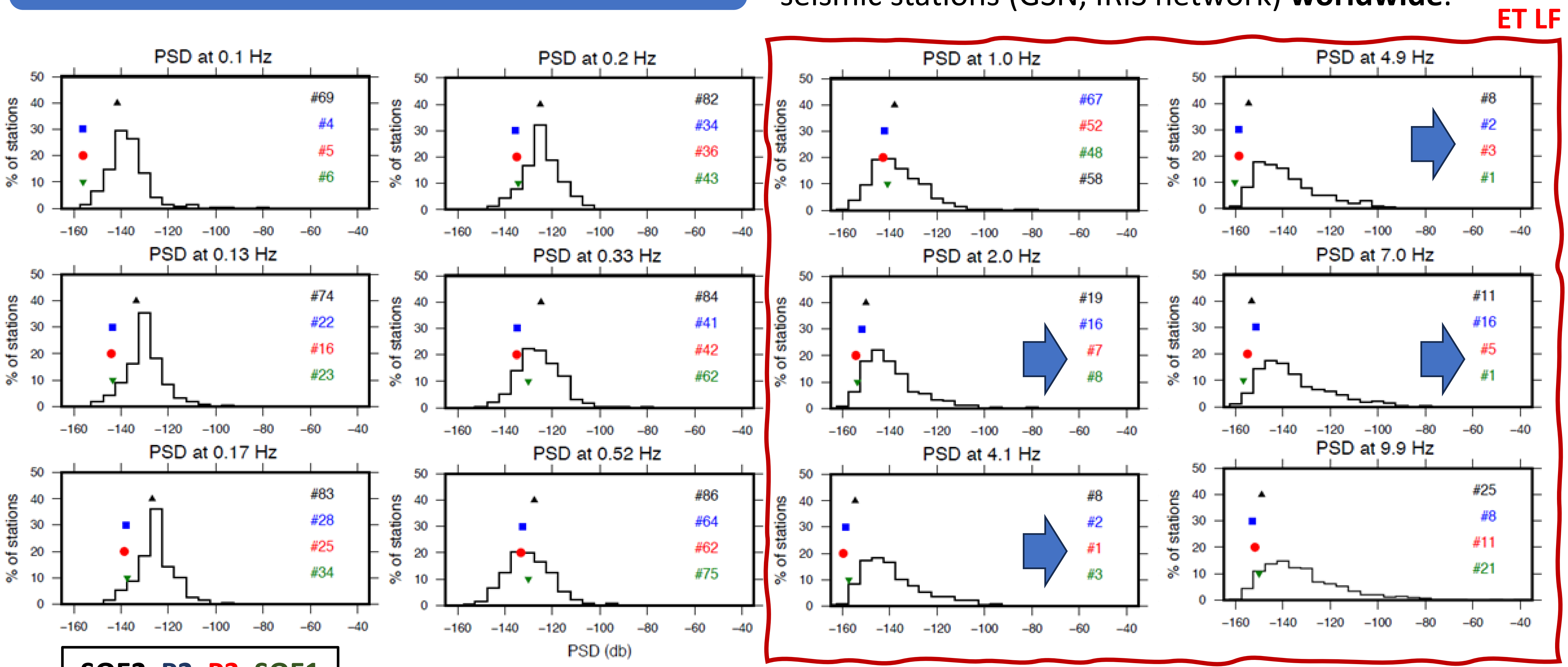


Very low noise background in the 2-10 Hz band, sometimes even **below** the Peterson's **New Low Noise Model**!

Characterization of the (original) Δ corners

A quick glance at the measurements

Ranking of Sardinia site compared to the quietest seismic stations (GSN, IRIS network) **worldwide**.



SOE2 P2 P3 SOE1

L. Naticchioni, Site Characterization – ET Italia 19/3/2025

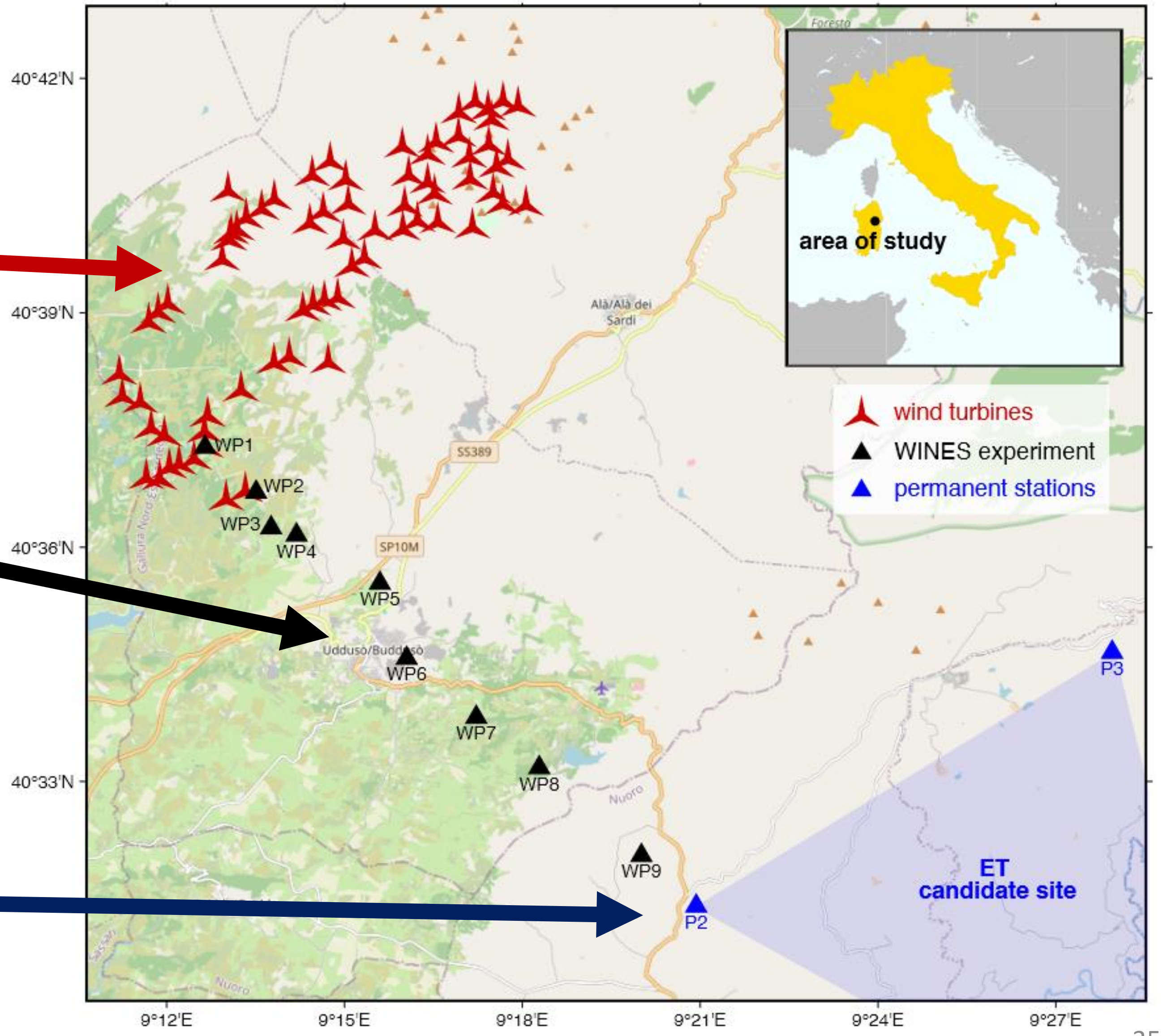
Windpark noise

Wind farm temporary array

Buddusò wind park

Temporary seismometer array

Permanent borehole station

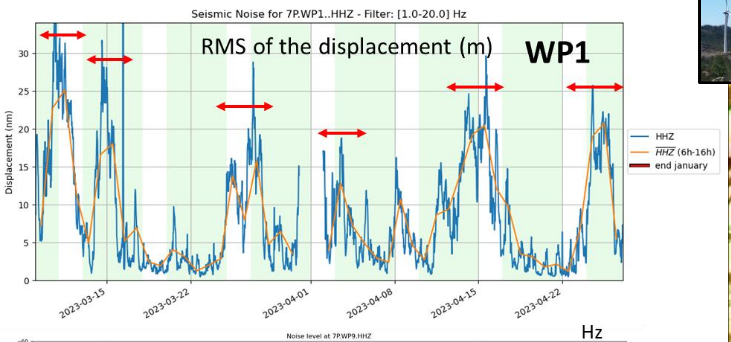


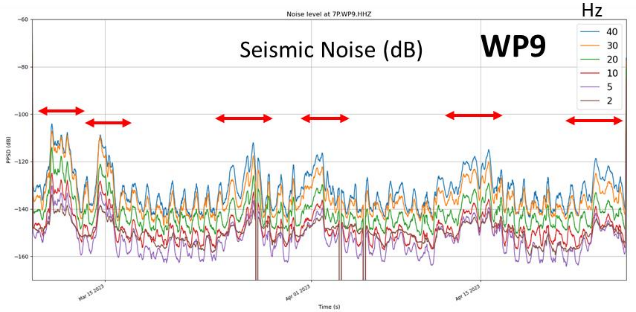
L. Naticchioni, Site Characterization – ET Italia 19/3/2025

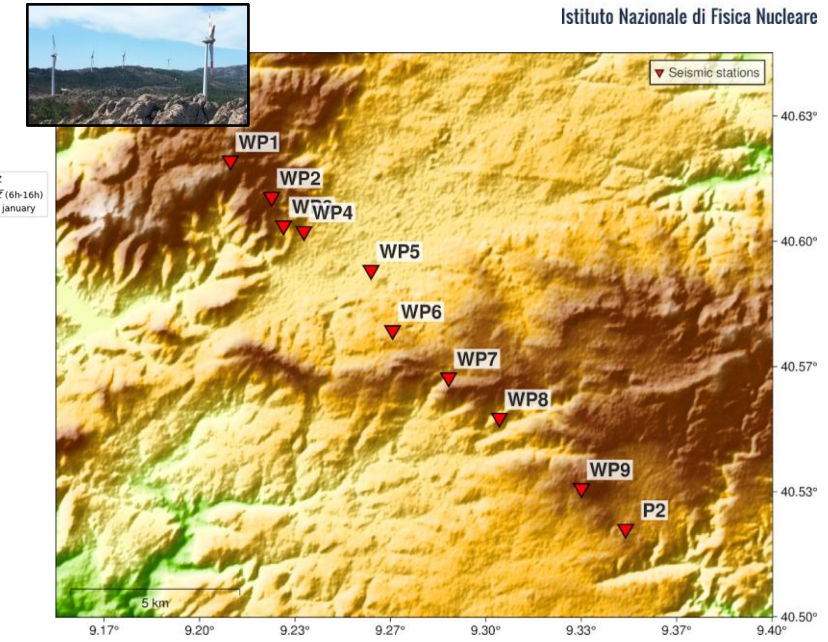
Windpark noise

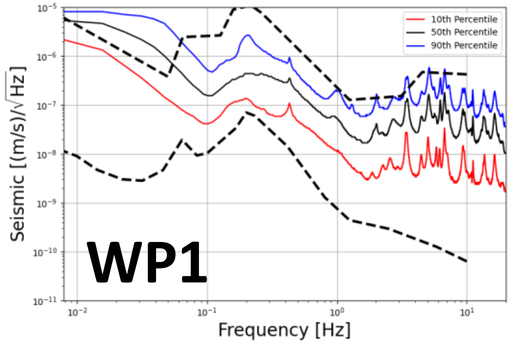
Wind farm temporary array

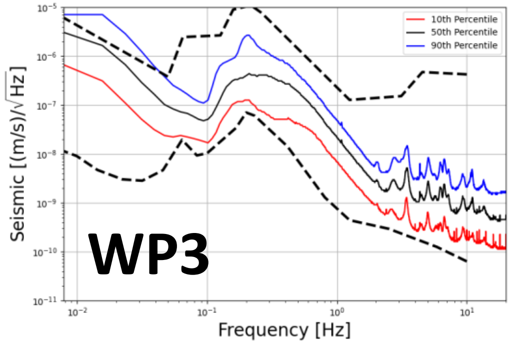
- Main peak at ~3Hz + harmonics close to the wind farm (WP1);
- Only main peak + first few harmonics close to P2, visible wrt to the low background (NLNM);
- Wind-correlated increase of noise rms;
- **Final goal: derive the attenuation function for a better definition of exclusion zones.**

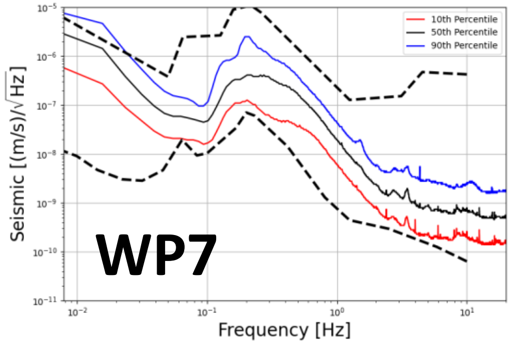


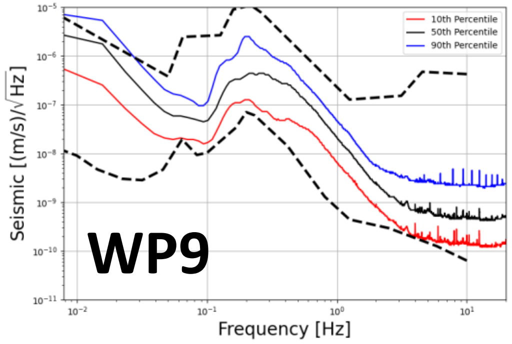






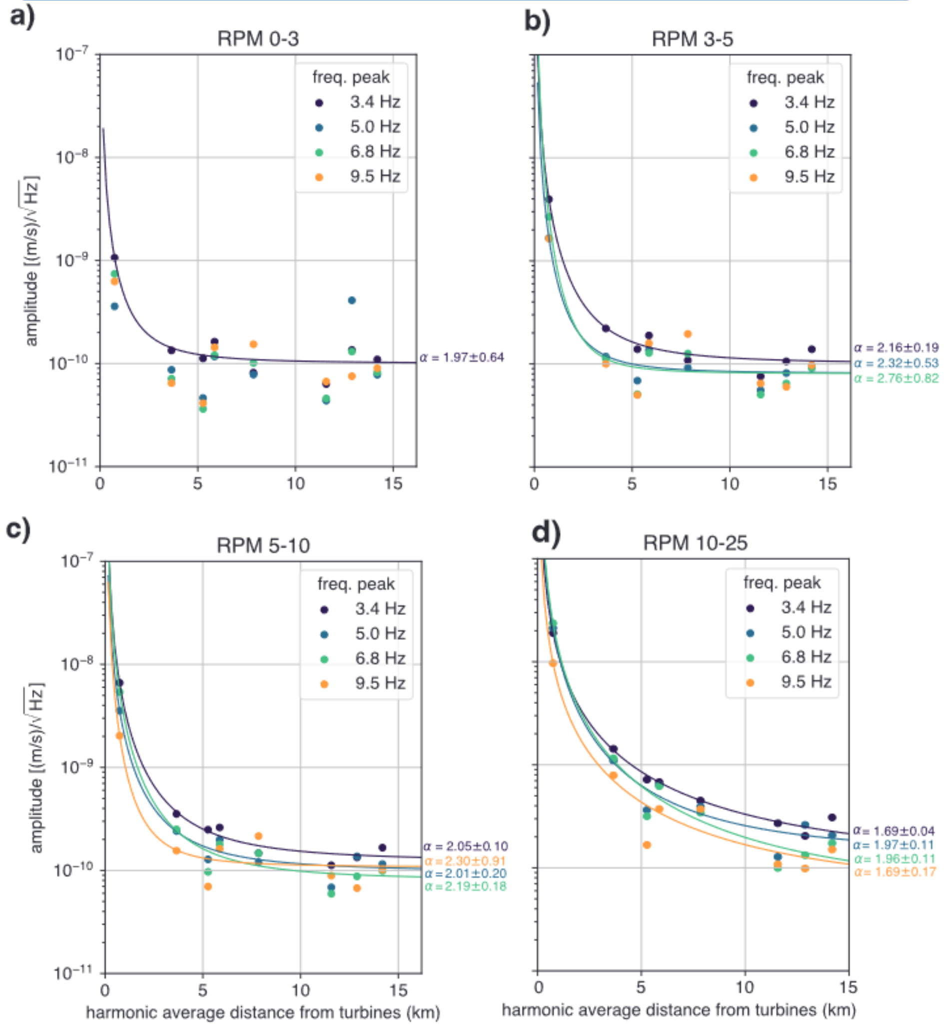


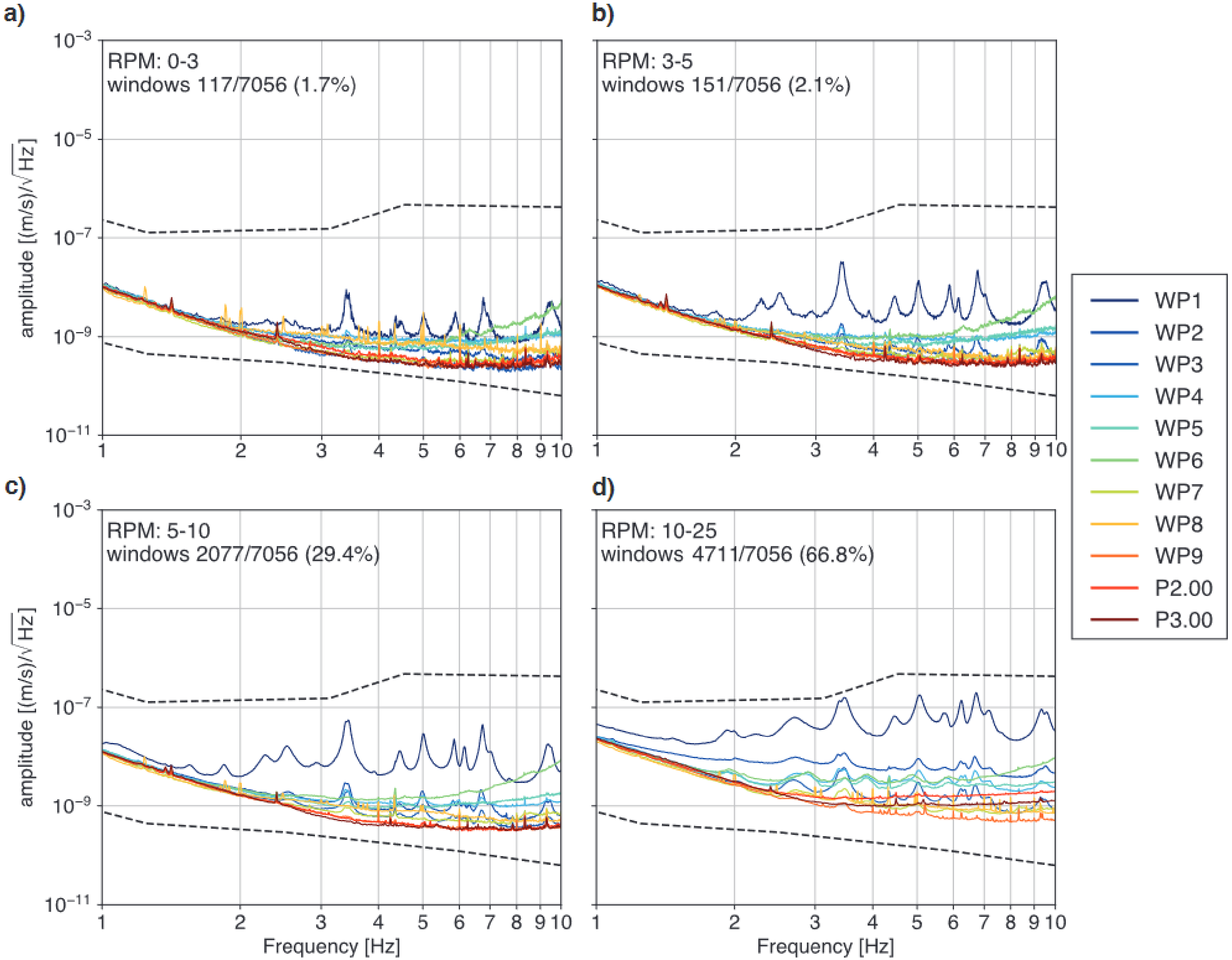




Windpark noise

Wind farm temporary array



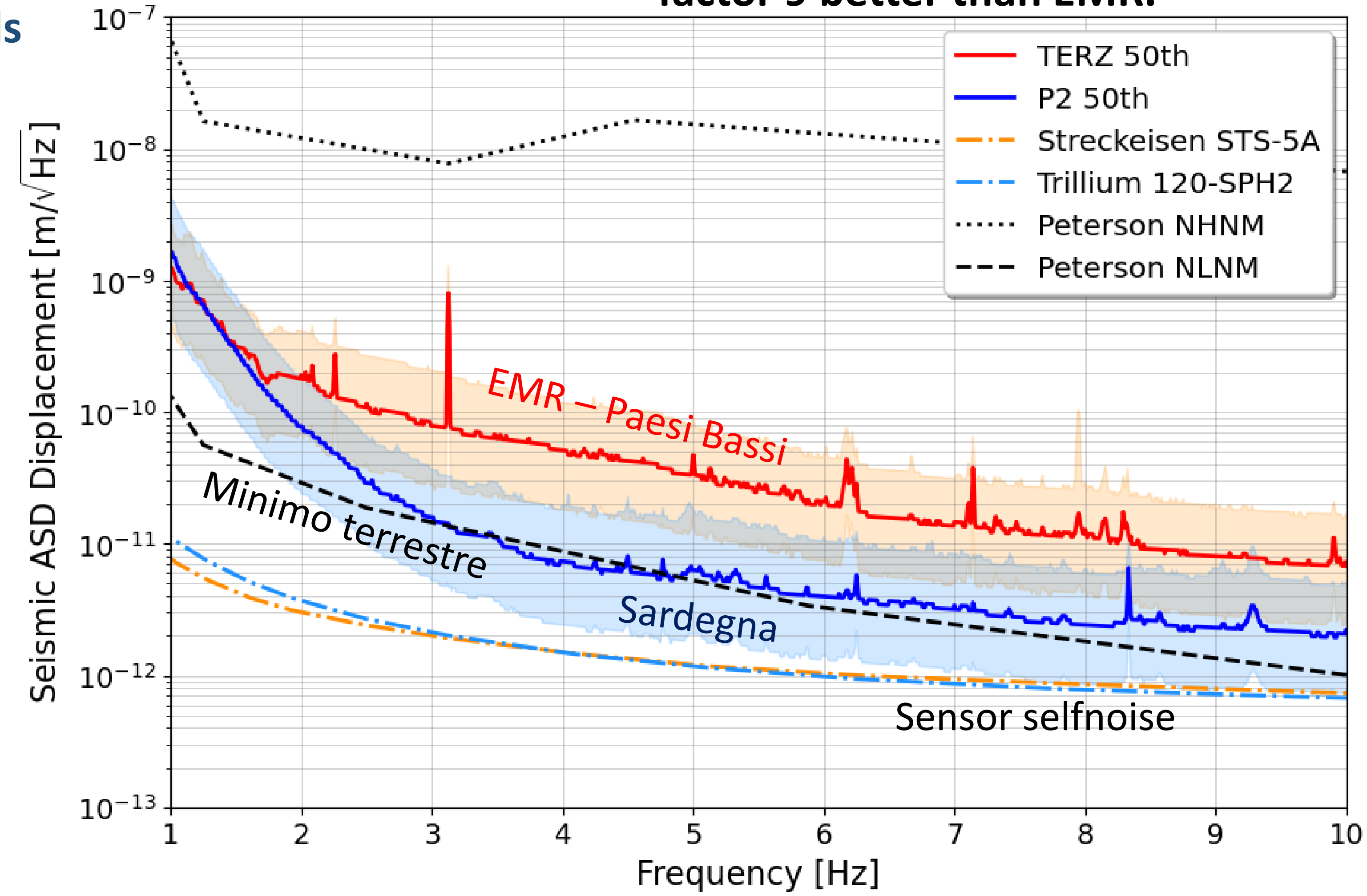


Site comparison with other candidates

Borehole measurements comparison

In the crucial few Hz band of ET (2-10 Hz), Sos Enattos area is among the quietest sites in the world and up to a factor 9 better than EMR.

Horizontal Channels



Measured in the two boreholes at -250m

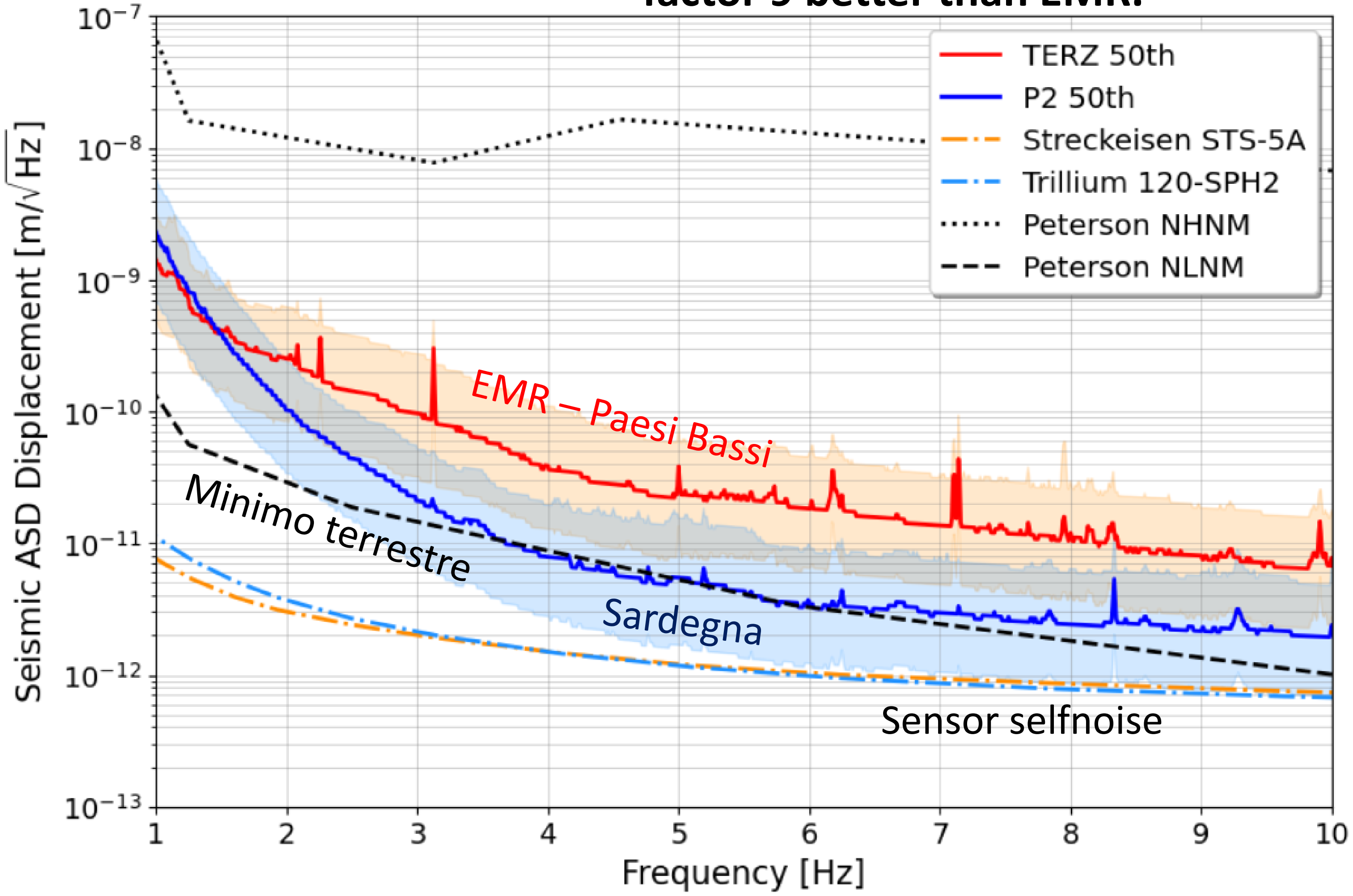
L. Naticchioni, Site Characterization – ET Italia 19/3/2025

Site comparison with other candidates

Borehole measurements comparison

In the crucial few Hz band of ET (2-10 Hz), Sos Enattos area is among the quietest sites in the world and up to a factor 9 better than EMR.

Vertical Channels



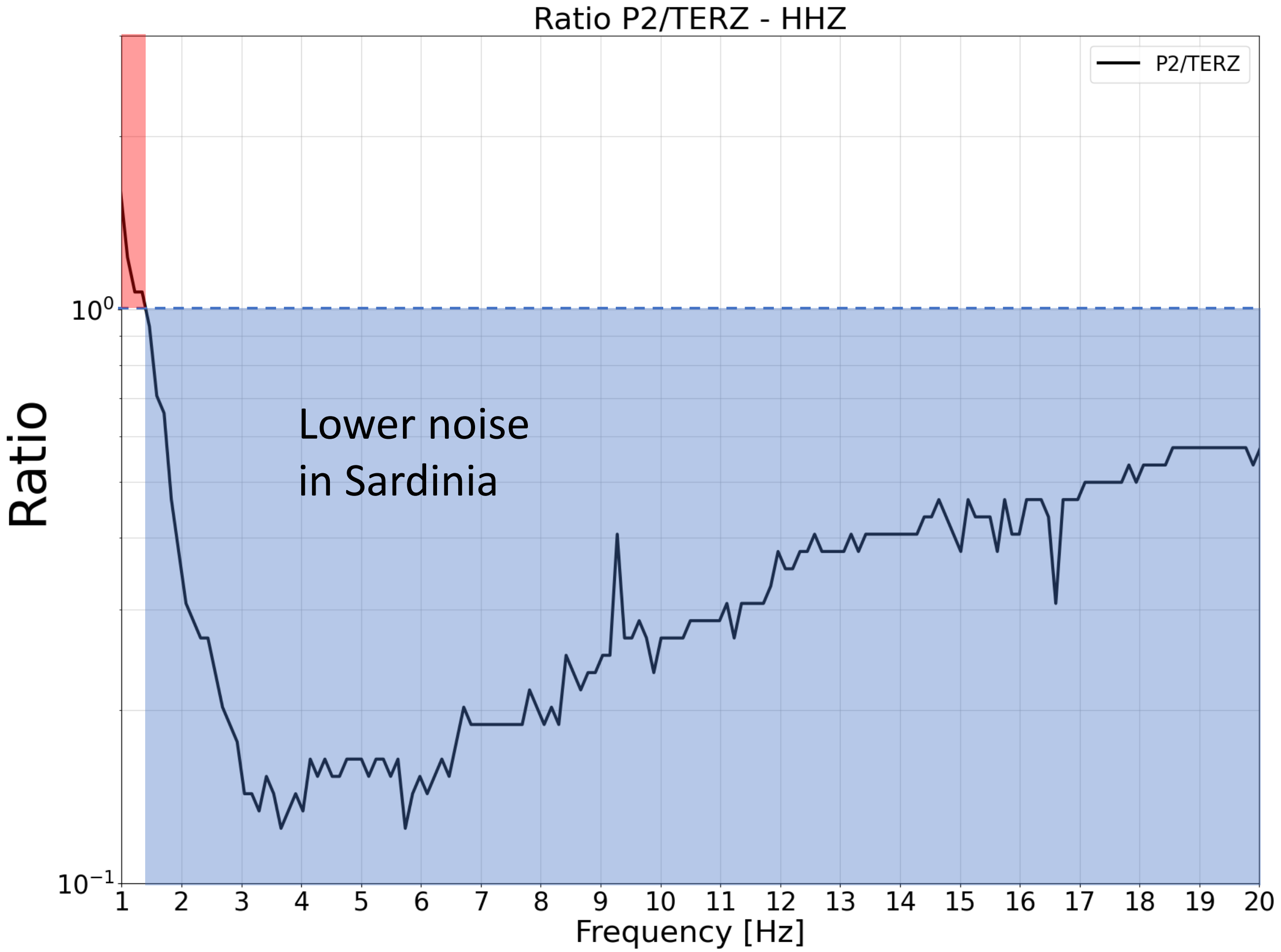
Measured in the two boreholes at -250m

L. Naticchioni, Site Characterization – ET Italia 19/3/2025

Site comparison with other candidates

Borehole measurements comparison

In the crucial few Hz band of ET (2-10 Hz), Sos Enattos area is among the quietest sites in the world and up to a factor 9 better than EMR.



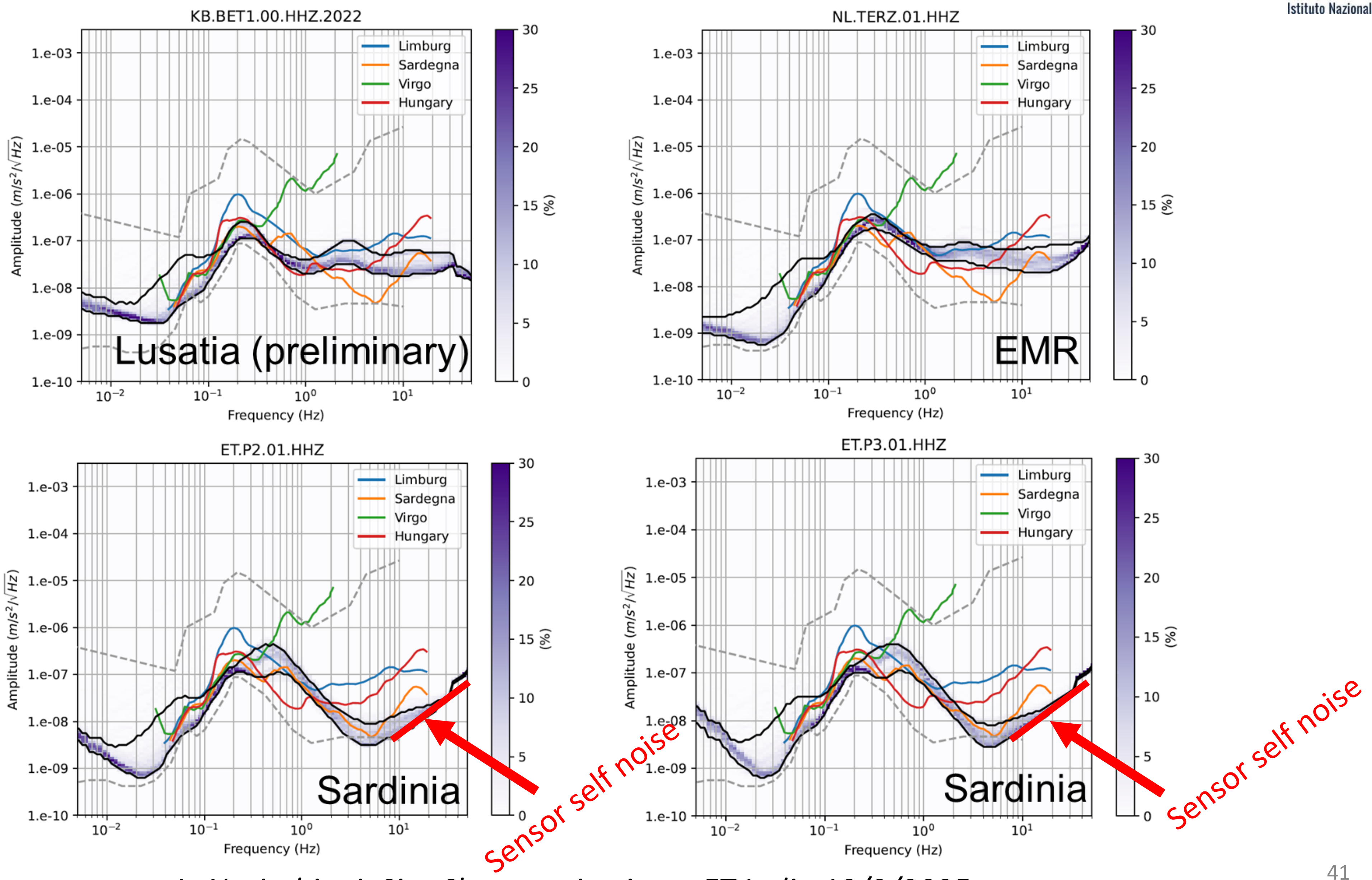
Measured in the two boreholes at -250m

L. Naticchioni, Site Characterization – ET Italia 19/3/2025

Site comparison with other candidates

Borehole comparison

A. Rietbrock et al., ET-SPB Workshop 2023



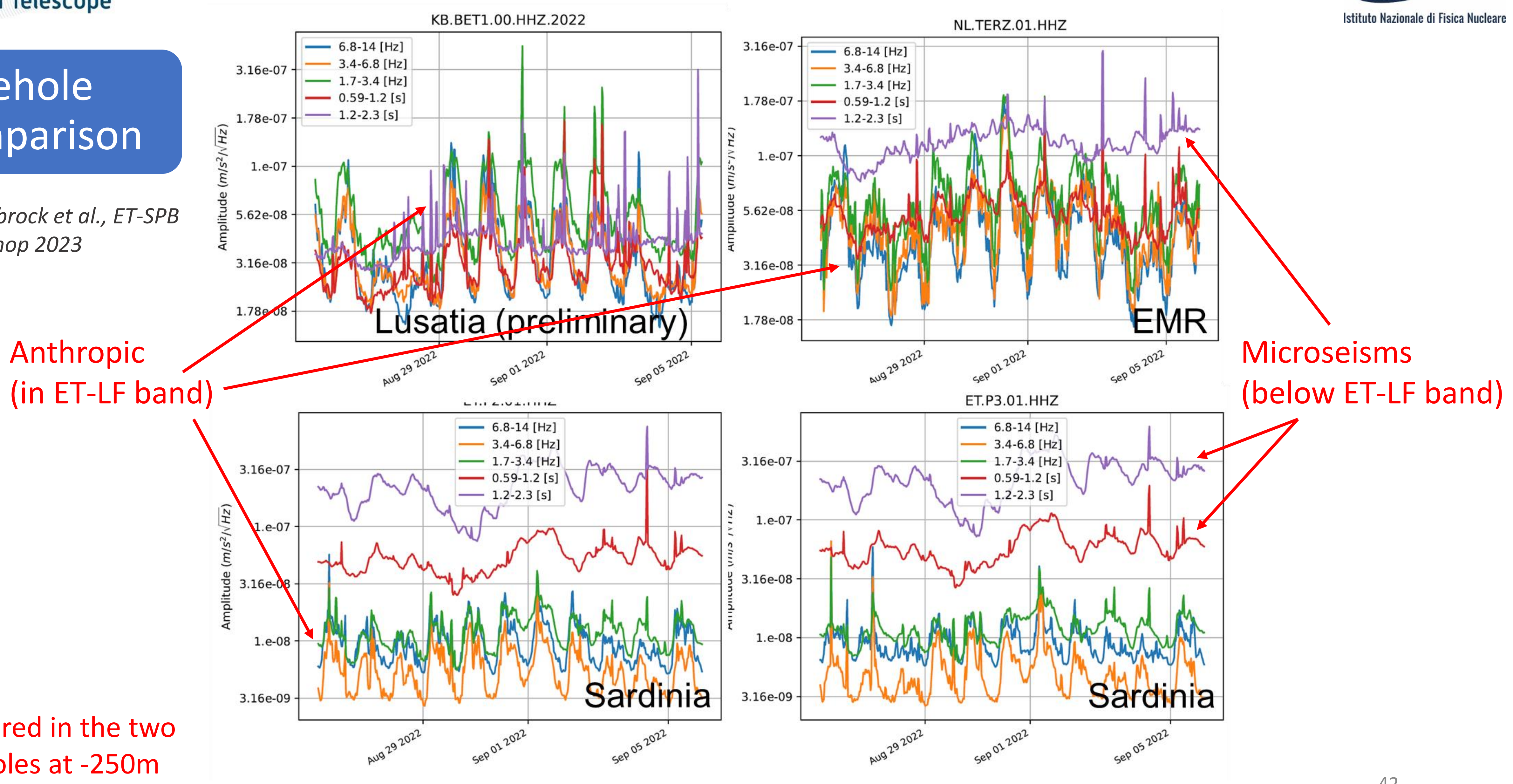
Measured in the boreholes at -250m

L. Naticchioni, Site Characterization – ET Italia 19/3/2025

Site comparison with other candidates

Borehole comparison

A. Rietbrock et al., ET-SPB Workshop 2023



Measured in the two boreholes at -250m

L. Naticchioni, Site Characterization – ET Italia 19/3/2025

Site comparison with other candidates

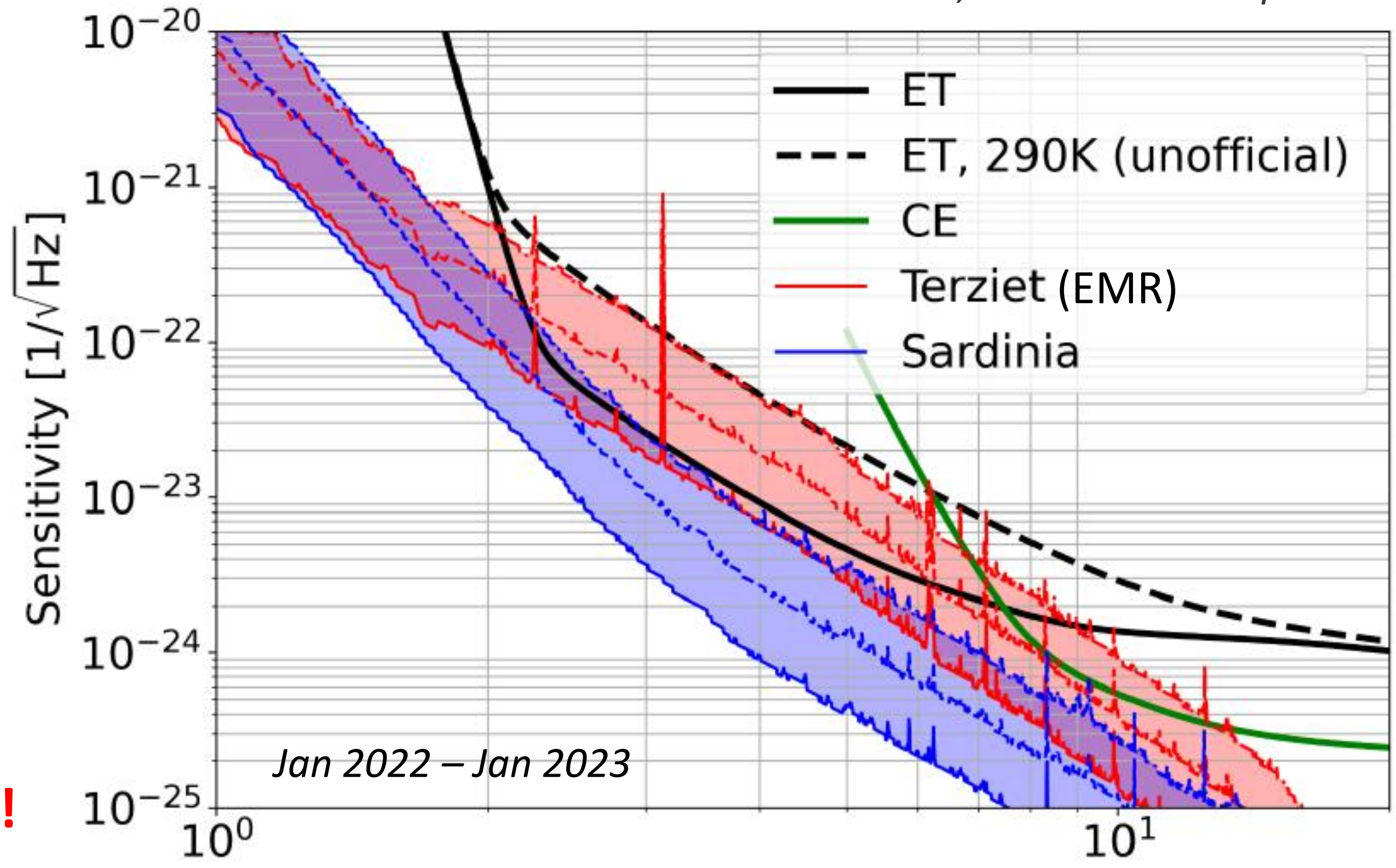
Seismic Newtonian Noise projections

J.Harms, ET-SPB workshop 2023

Defining the Newtonian Noise ASD as:

$$\tilde{h}_{NN}(f) = \frac{4\pi}{3} G\rho_0 \frac{2\sqrt{2}}{L} \frac{1}{(2\pi f)^2} \tilde{x}(f)$$

seismic noise displacement ASD



Impatto del Newtonian Noise sulla sensibilità di ET-LF:
→ presentazione di Davide Rozza!

Conclusioni

- Estesa **campagna di caratterizzazione geofisica** e di **misure di rumore ambientale** nell'area di Sos Enattos, a partire dalle prime pionieristiche misure del 2010-2012. Dal 2019 installata una rete di misura stabile a Sos Enattos per la misura di **rumore sismico**, **magnetico**, **acustico**.
- Rete di sensori nell'area del sito candidato con possibili vertici dell'infrasttura già strumentati a cui si aggiungeranno le nuove stazioni di misura in corrispondenza dei vertici della configurazione "L" di ET.
- Particolare attenzione al **rumore di bassa frequenza** (in particolare tra 2 e 10 Hz), che potrebbe limitare le capacità scientifiche di ET: in questa banda **l'area della Barbagia in Sardegna è tra le più quiete al mondo**.
- Le potenziali sorgenti "locali" di rumore (ad es. pale eoliche) sono oggetto di studio e hanno determinato la definizione di un'**area di rispetto** attorno all'infrastruttura di ET.
- Impatto del rumore ambientale di bassa frequenza sulla potenziale sensibilità di ET: Talk di Davide Rozza a seguire.
- **Grazie alla stabilità geologica, alla qualità delle rocce e al basso livello di rumore ambientale e antropico, la Sardegna è il miglior sito candidato ad ospitare ET, quale che sia la sua configurazione finale (Δ o L).**

Conclusioni

Backup slides

Characterization of the (original) Δ corners

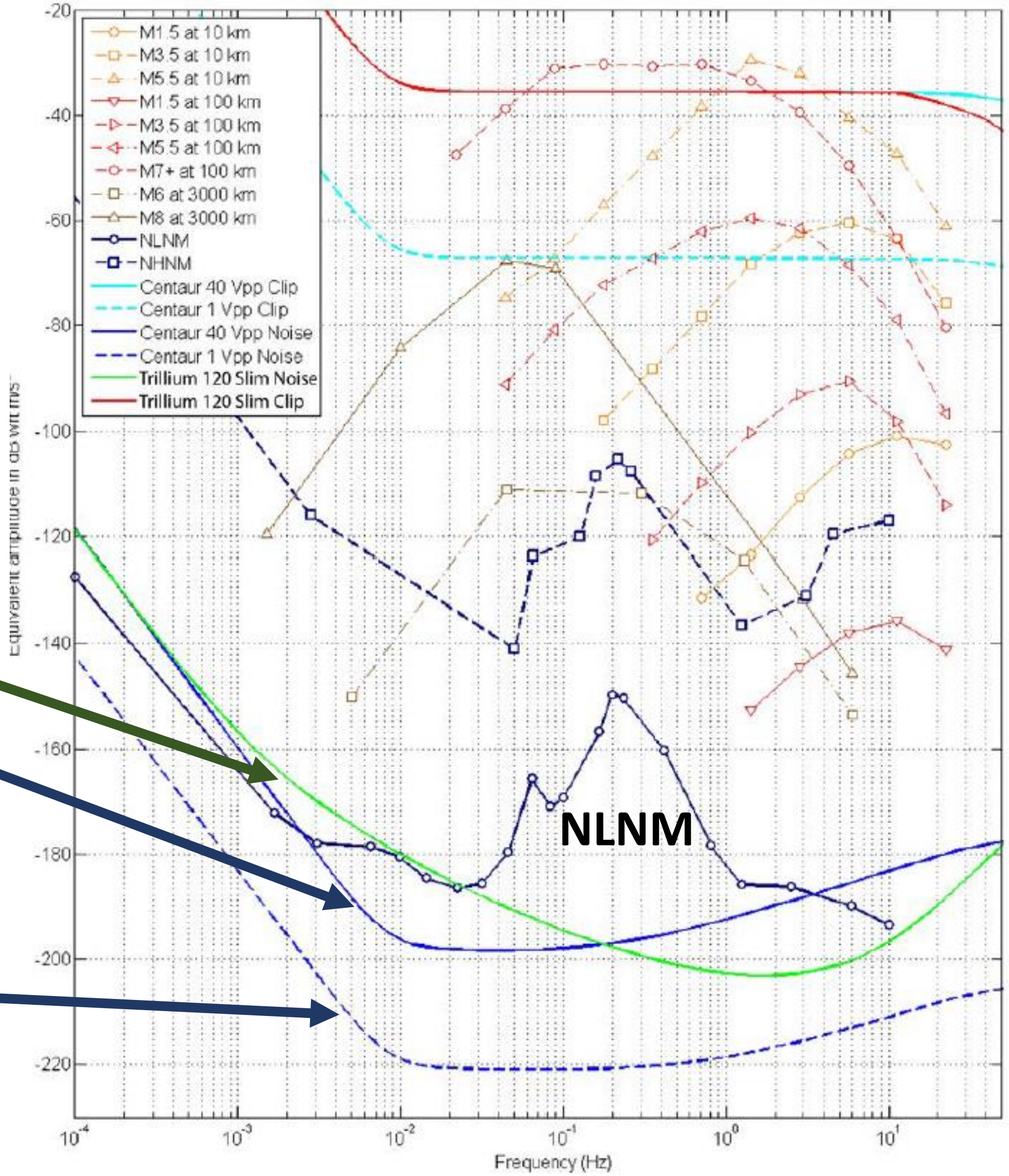
Trillium 120-SPH2

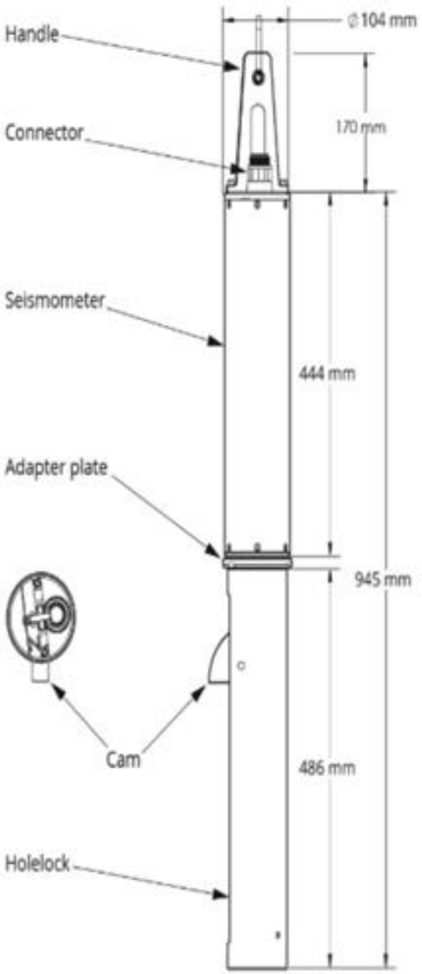
Broadband triaxial seismometer

Sensor self-noise

DAQ 40V self-noise

DAQ 1V (max gain) self-noise





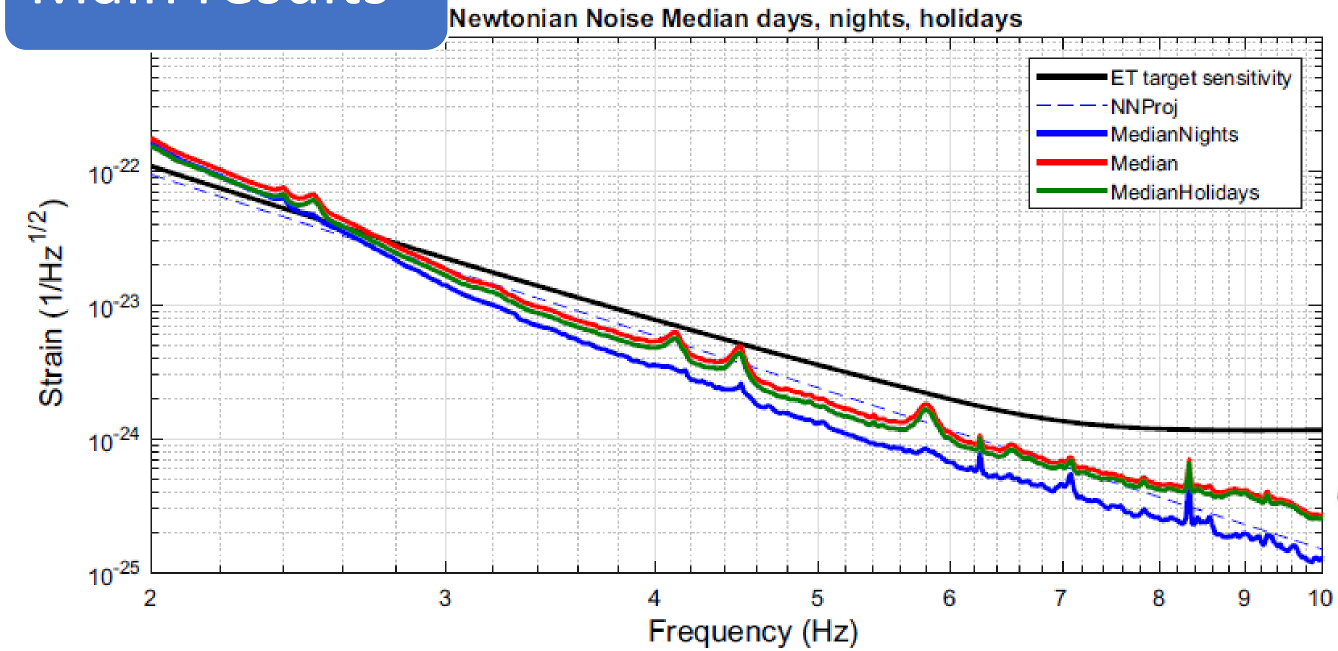
ET ITALY Einstein Telescope

The Sos Enattos site

INFN Istituto Nazionale di Fisica Nucleare

Main results

Newtonian Noise & seismic glitches (based on 2020 data at SOE1)



Defining the Newtonian Noise ASD as:

$$\tilde{h}_{NN}(f) = \frac{4\pi}{3} G\rho_0 \frac{2\sqrt{2}}{L} \frac{1}{(2\pi f)^2} \tilde{x}(f)$$

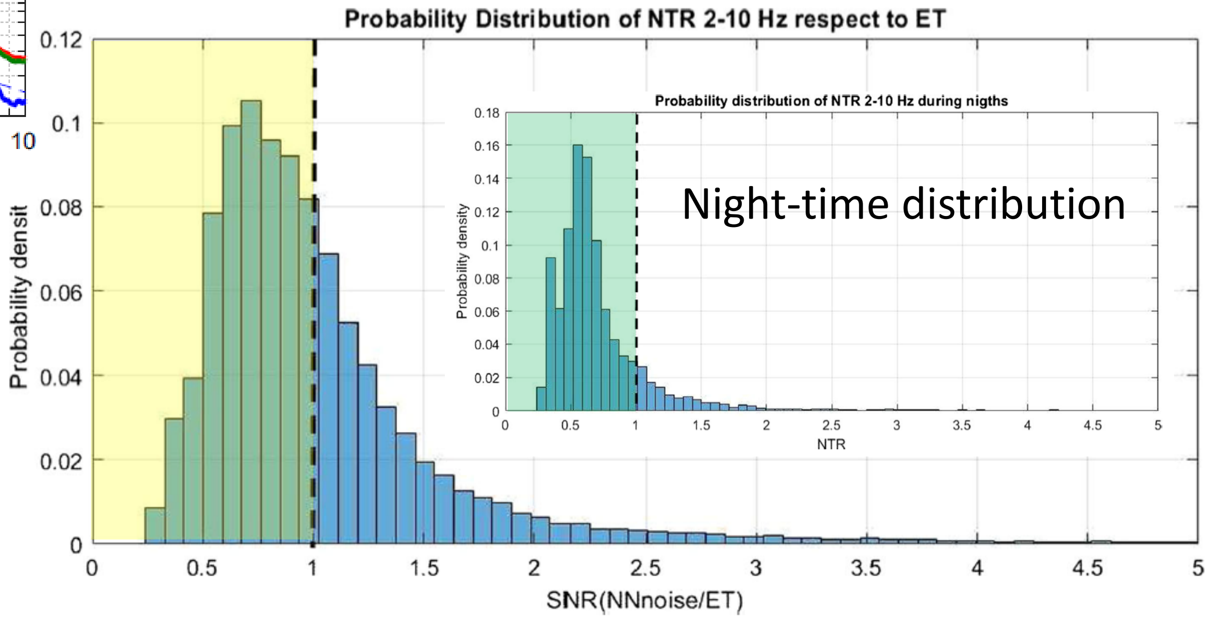
Eur. Phys. J. Plus (2021) 136:511

Defining the Noise-to-Target Ratio of the Newtonian Noise in 1 minute window (~IMBH duration in ET band)

$$\mathrm{NTR} = \sqrt{\frac{1}{\Delta f} \int df \, \frac{\tilde{N} * \tilde{N}}{S_h}}$$

PSD of NN

PSD of ET sensitivity



P(NRT<1)=0.6 , considering only the nights: $P(NRT<1)_n=0.86$

→Need for moderate NN subtraction only for a limited time

Glitchness comparison

Sardinia P2 borehole

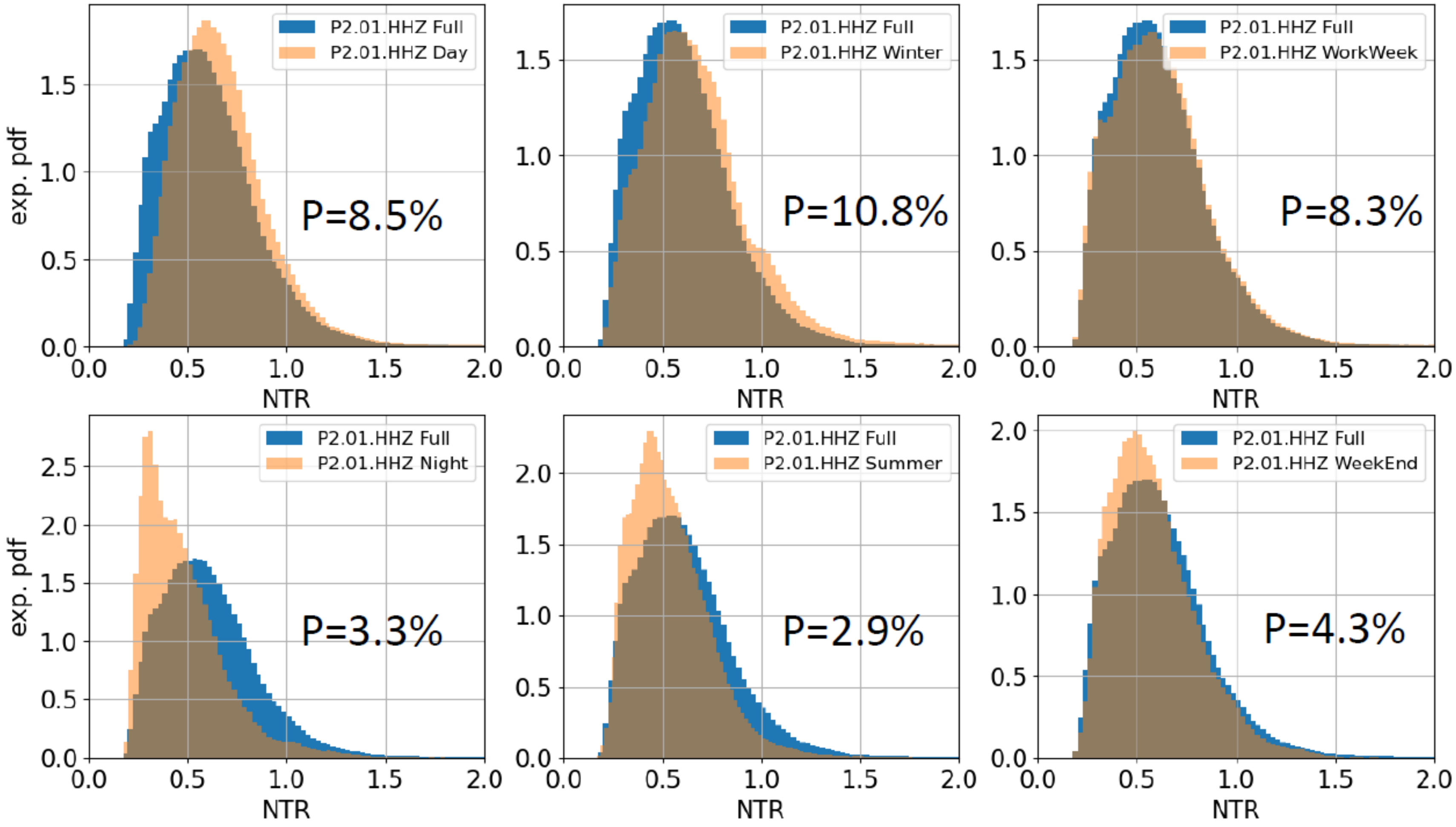
Seismic NN glitches in ET LF band

Defining the Noise-to-Target Ratio of the Newtonian Noise in 1 minute window (~IMBH duration in ET band):

PSD of NN

$$\mathrm{NTR} = \sqrt{\frac{1}{\Delta f} \int df \, \frac{\tilde{N} * \tilde{N}}{S_h}}$$

PSD of ET sensitivity



Over one year (2022) of data

P(NTR>1, 2-10Hz)=6.3%
at P2 (Sardinia)

→ NN does not limit the ET sensitivity for a large fraction of time, only moderate cancellation needed for a limited time

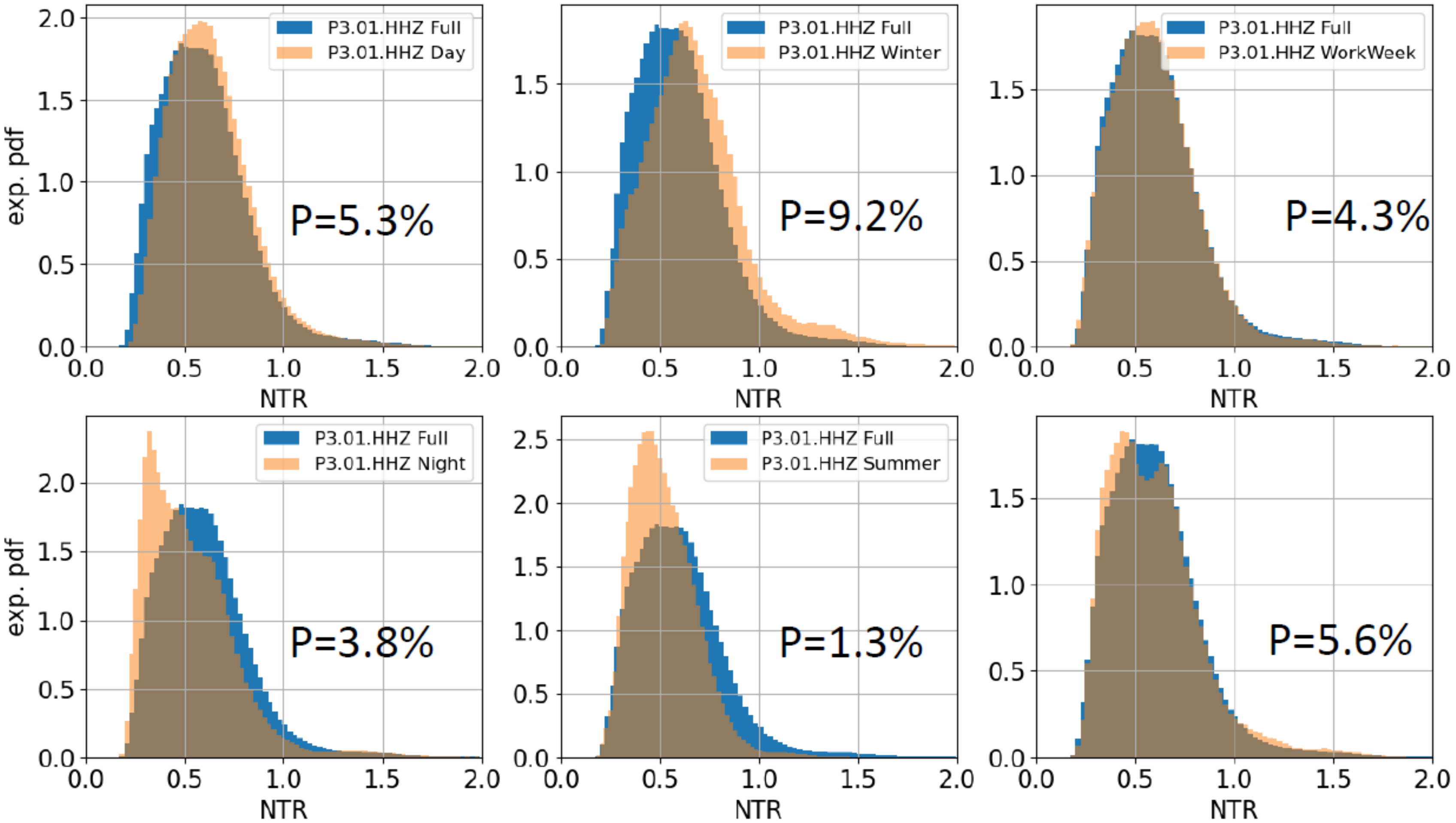
R. De Rosa et al., SPB workshop 2023

Glitchness comparison

Sardinia P3 borehole

Seismic NN glitches in ET LF band

Defining the Noise-to-Target Ratio of the Newtonian Noise in 1 minute window (~IMBH duration in ET band):



PSD of NN

$$\mathrm{NTR} = \sqrt{\frac{1}{\Delta f} \int df \frac{\tilde{N} * \tilde{N}}{S_h}}$$

PSD of ET sensitivity

Over one year (2022) of data

P(NTR>1, 2-10Hz)=4.7%
at P3 (Sardinia)

→ NN does not limit the ET sensitivity for a large fraction of time, only moderate cancellation needed for a limited time

R. De Rosa et al., SPB workshop 2023

Glitchness comparison

Terziet borehole (NL)

Istituto Nazionale di Fisica Nucleare

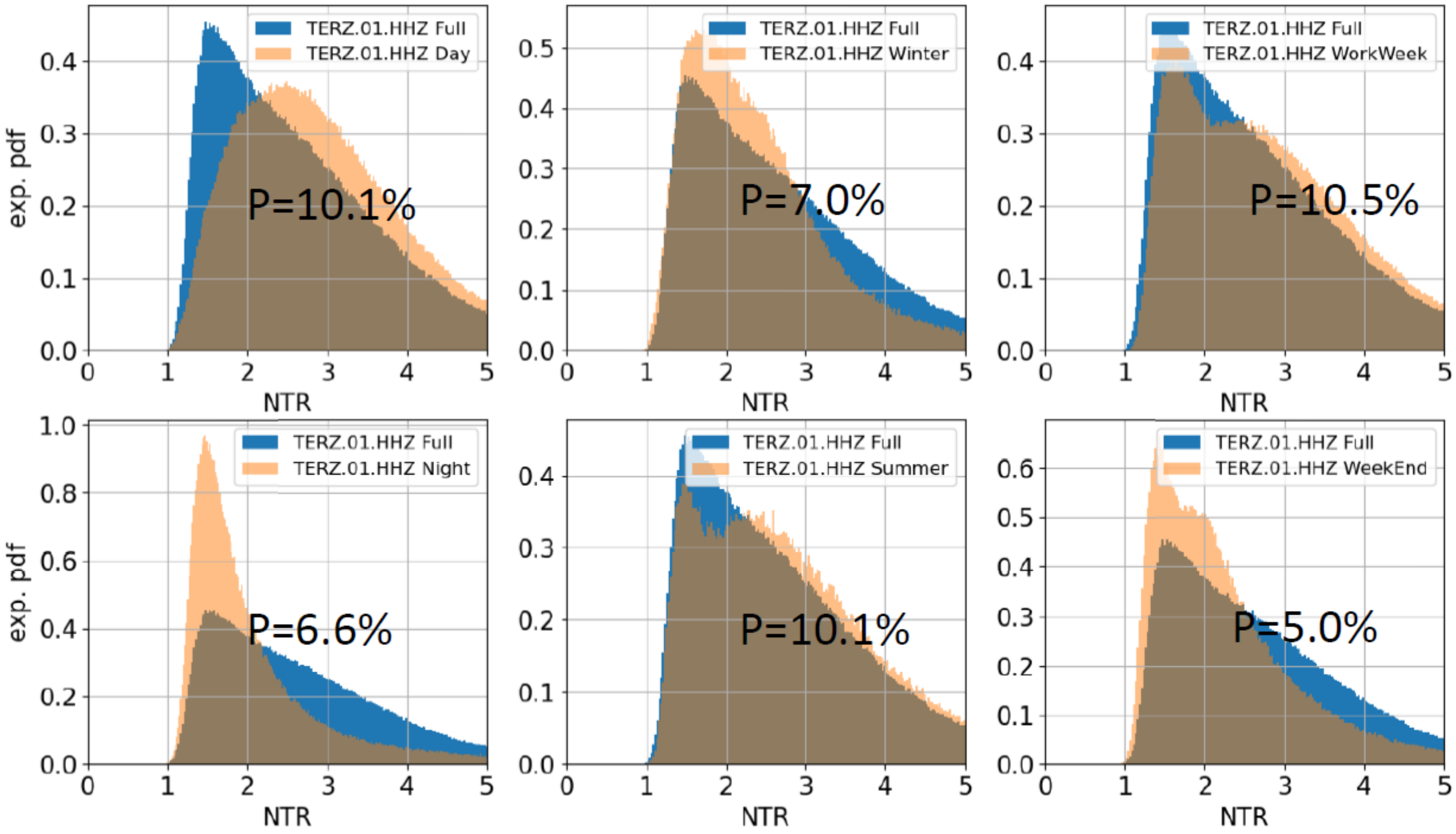
Seismic NN glitches in ET LF band

Defining the Noise-to-Target Ratio of the Newtonian Noise in 1 minute window (~IMBH duration in ET band):

PSD of NN

$$\mathrm{NTR} = \sqrt{\frac{1}{\Delta f}\int df\, \frac{\tilde{N} * \tilde{N}}{S_h}}$$

PSD of ET sensitivity



Over one year (2022) of data

P(NTR>1, 2-10Hz)=100%
P(NTR>5, 2-10Hz)=8.9%
at Terziet (EMR)

→ NN limit the ET sensitivity, NN cancellation needed up to factor 5…
NB: currently, for ET a factor 2 NNC is optimistic.

R. De Rosa et al., SPB workshop 2023