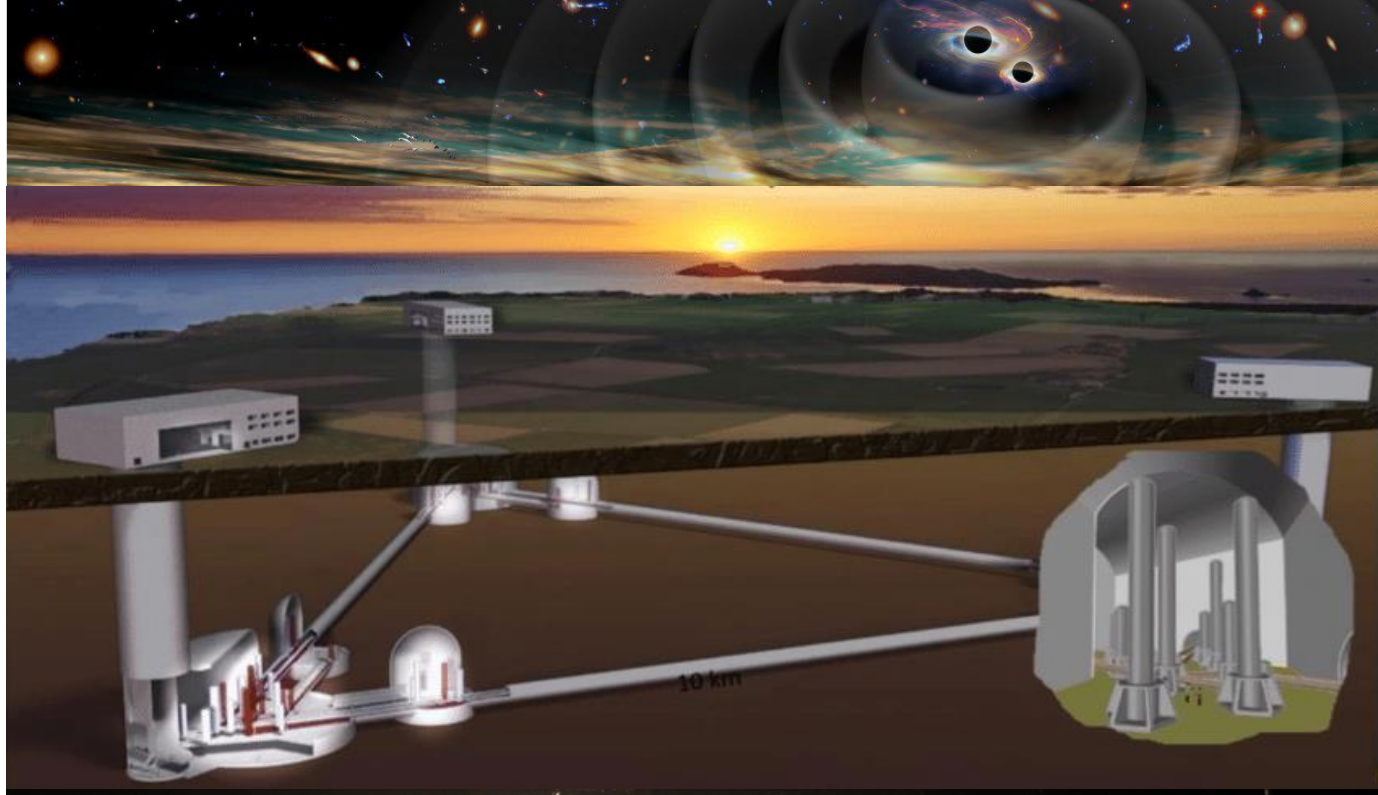
ET EINSTEIN TELESCOPE

Updates from the ET Sardegna seismic characterisation

Luca Naticchioni (INFN Roma)



INFN Istituto Nazionale di Fisica Nucleare

Istituto Nazionale di Geofisica e Vulcanologia

uniss Università degli Studi di Sassari

Sapienza Università di Roma

Università di Pisa

Università degli Studi di Napoli Federico II

GSSI Gran Sasso Science Institute — School of Advanced Studies — Scuola Universitaria Superiore

Characterisation of the Sardinia site

Measurement stations at the Sos Enattos corner:

- **SarGrav surface Lab** + **Control Room**;
- **SOE0** (surface);
- **SOE1**, **SOE2**, **SOE3** (84m, 111m, 160m underground).

Instrumented stations

Sensors currently installed:

- 5(6) broadband triaxial seismometers (*Nanometrics Trillium 360, 240* & *120 Horizon, Guralp CMG-3TD 360*);
- 2 magnetometers (*MF6-06*);
- 5(+3) short-period triaxial seismometers (*Nanometrics Trillium 20PH,* first seed of a transportable array);
- High Precision Tiltmeter (part of the *Archimedes* experiment @ SarGrav)
- Weather station (@ SarGrav Lab).

Work in progress: new sensors (seismometers, magnetometers, microphones) will be added to the network in the next months

Sos Enattos measurement stations (since Aug. 2020)

SOE1

STAZIONE SOE 1

SOE2 / SENA

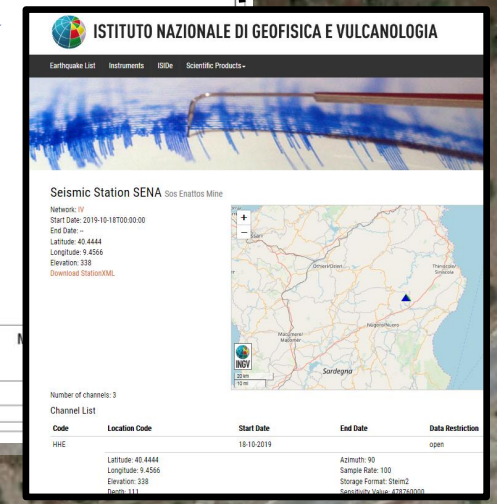
SarGrav surface lab

STAZIONE SOE 2

SarGrav Lab excavation zone

SOE0 (surf.)

SOE3

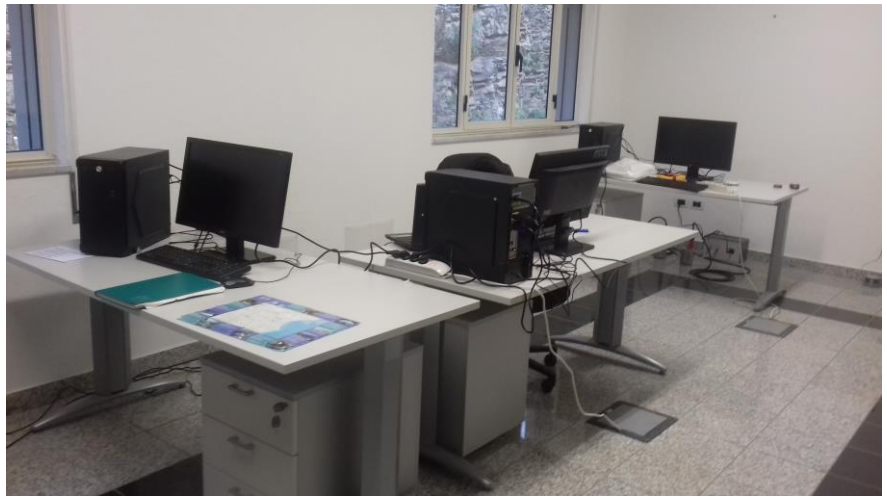


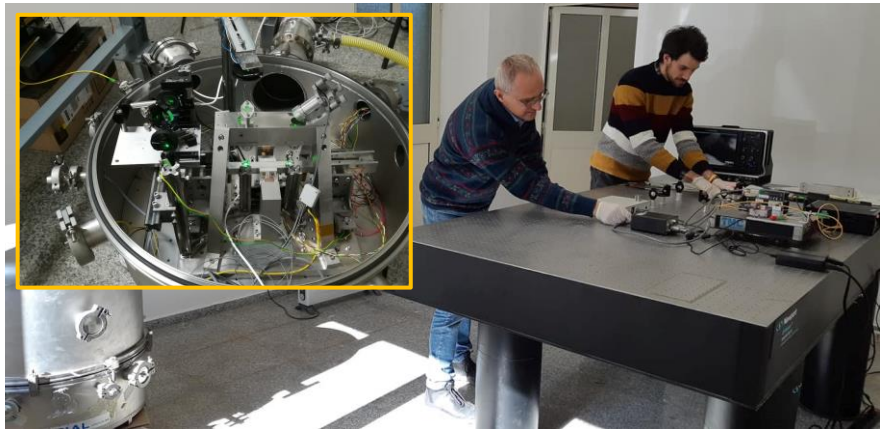
SOE2 public data:
http://cnt.rm.ingv.it/en/instruments/station/SENA

Characterisation of Sos Enattos

SARGRAV surface lab & control room

MFS06 Magnetometer buried at surface close to the SarGrav control room





DAQs, Network connections, weather stations, *Archimedes* tiltmeter, T20 seismometers

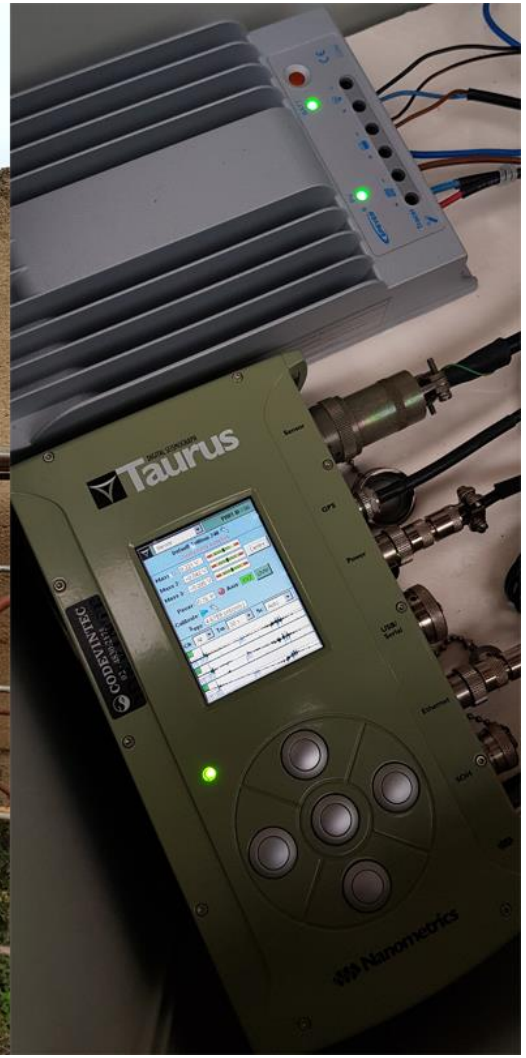
Characterisation of Sos Enattos

SARGRAV surface lab & control room

New (large) experimental area – surface lab

Characterisation of Sos Enattos

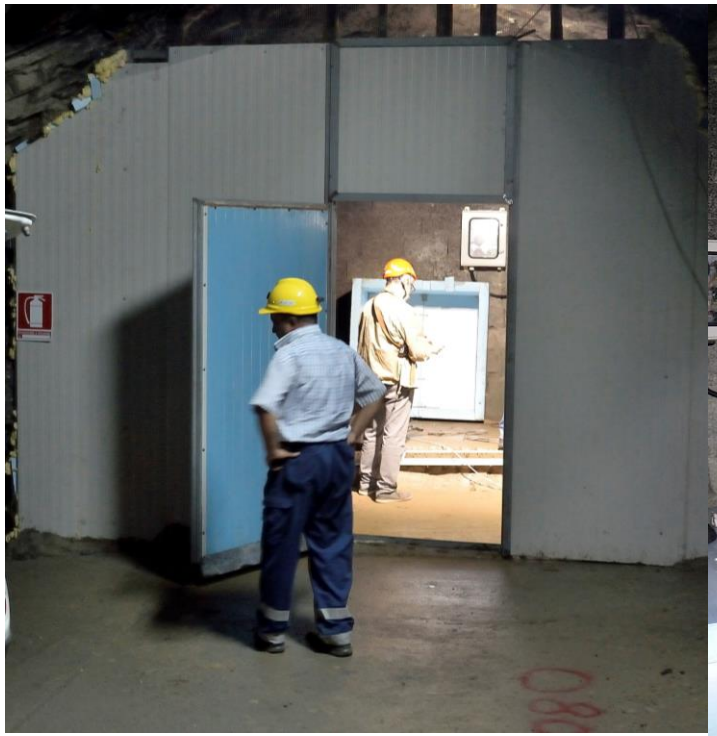
SOE0 station (*since December 2019*)



TRILLIUM 240s +
Taurus DAQ

Characterisation of Sos Enattos

SOE1 station (84m underground, *Mar. 2019 – June 2020*)



TRILLIUM 240s + Taurus DAQ

Characterisation of Sos Enattos

SOE1 station (84m underground, *since June 2020*)



TRILLIUM 120 Horizon + Centaur6 DAQ + Guralp 360 (since July 2021)

DAQ input range reduced to 4Vpp (WRT 40Vpp standard settings);

→ Effective reduction of DAQ self noise in the few Hz band;

→ Measured noise floor hits the Earth Person's Low Noise Model.

Characterisation of Sos Enattos

SOE2 station (111m underground, *since March 2019*)

Double wall + insulation box + *pasta-pot* insulation

1x TRILLIUM 240s (until June 2021)
2x TRILLIUM 360s (from July 2021)
Centaur6 DAQ

Characterisation of Sos Enattos

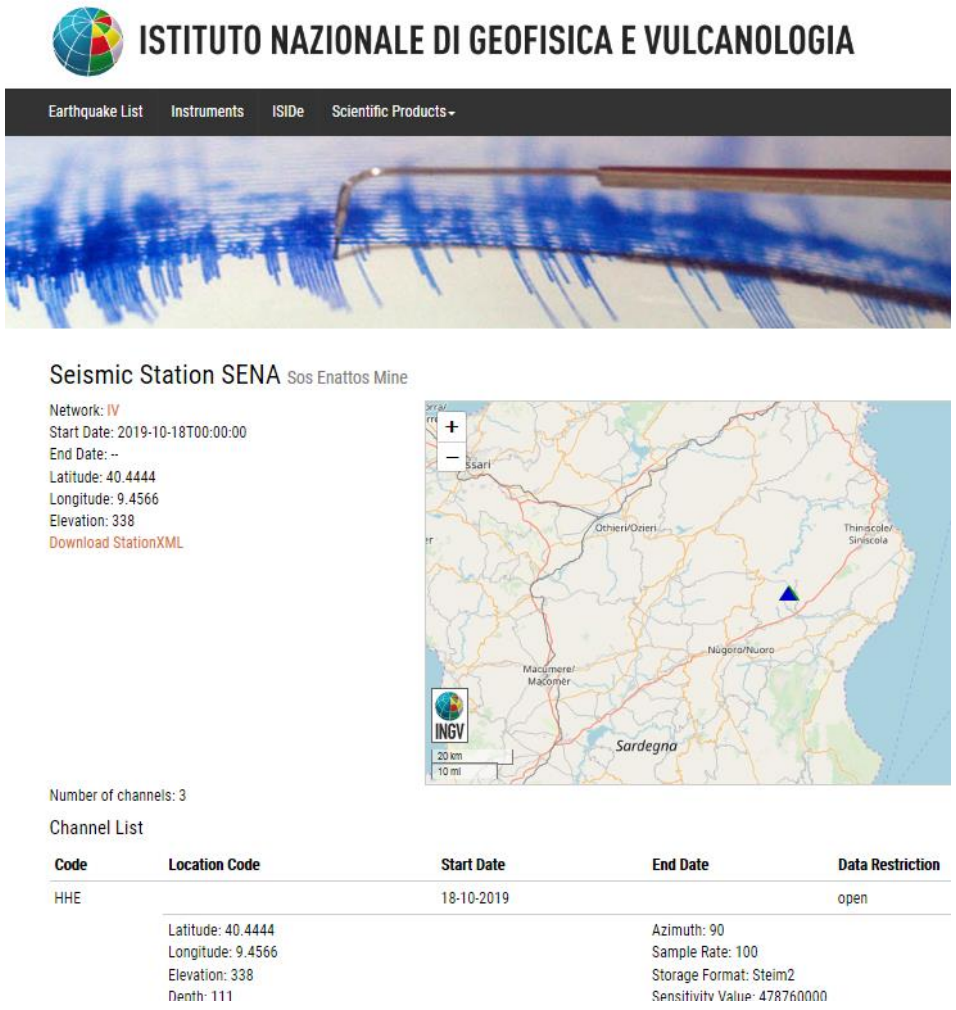
SOE2 station (111m underground, *since March 2019*)

Double wall + insulation box + *pasta-pot* insulation

Magnetometer MFS-06

Characterisation of Sos Enattos

SOE2 station (111m underground, *since March 2019*)



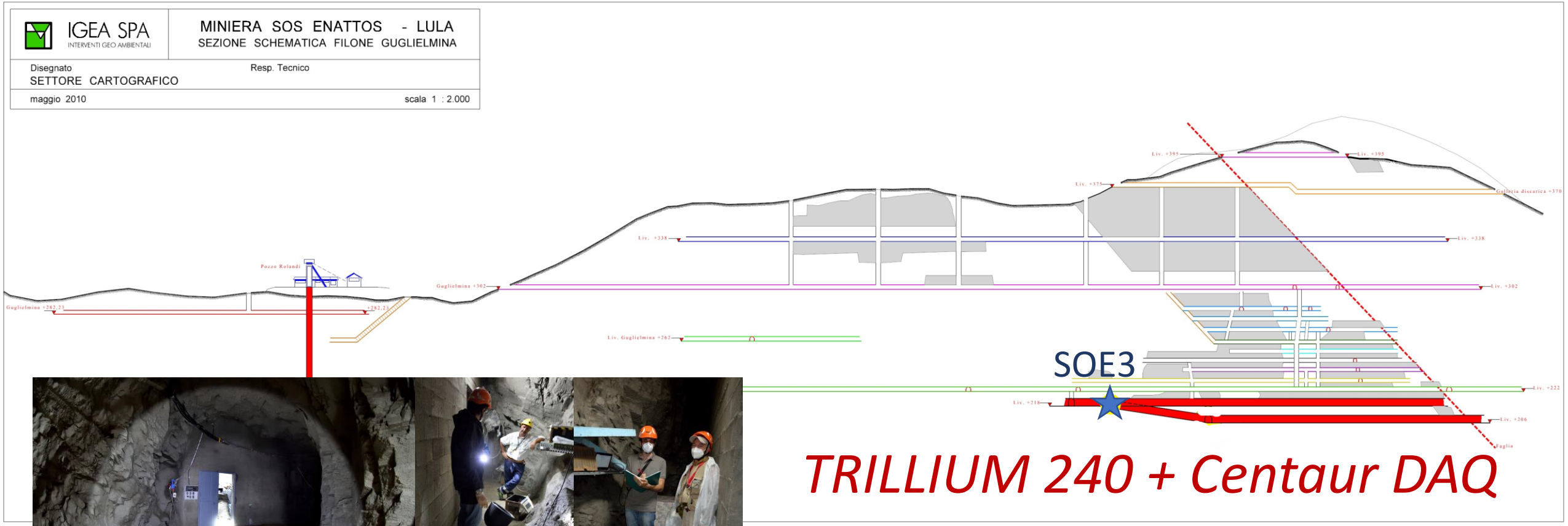
SOE2 station is integrated into the Italian national seismometer network of INGV (SENA station)

http://cnt.rm.ingv.it/en/instruments/station/SENA

Public data access
T240 Until June 2021, T360 from July 2021 (with reduced input range 4Vpp)

Characterisation of Sos Enattos

SOE3 station (160m underground, *since Aug. 2020*)



TRILLIUM 240 + Centaur DAQ

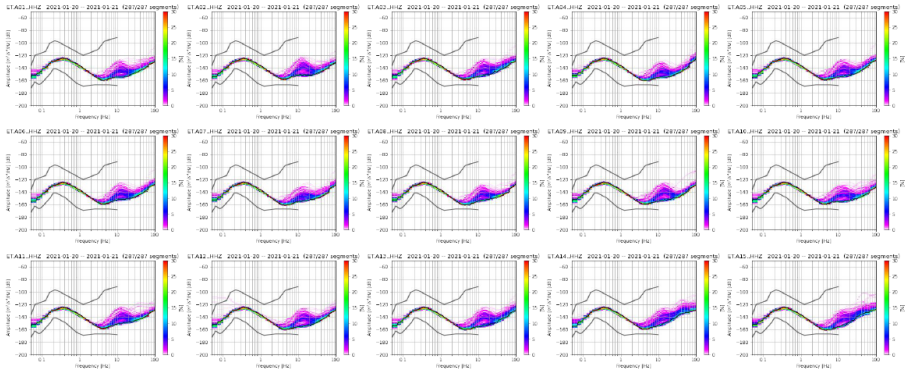
DAQ input range reduced to 4Vpp as in SOE1

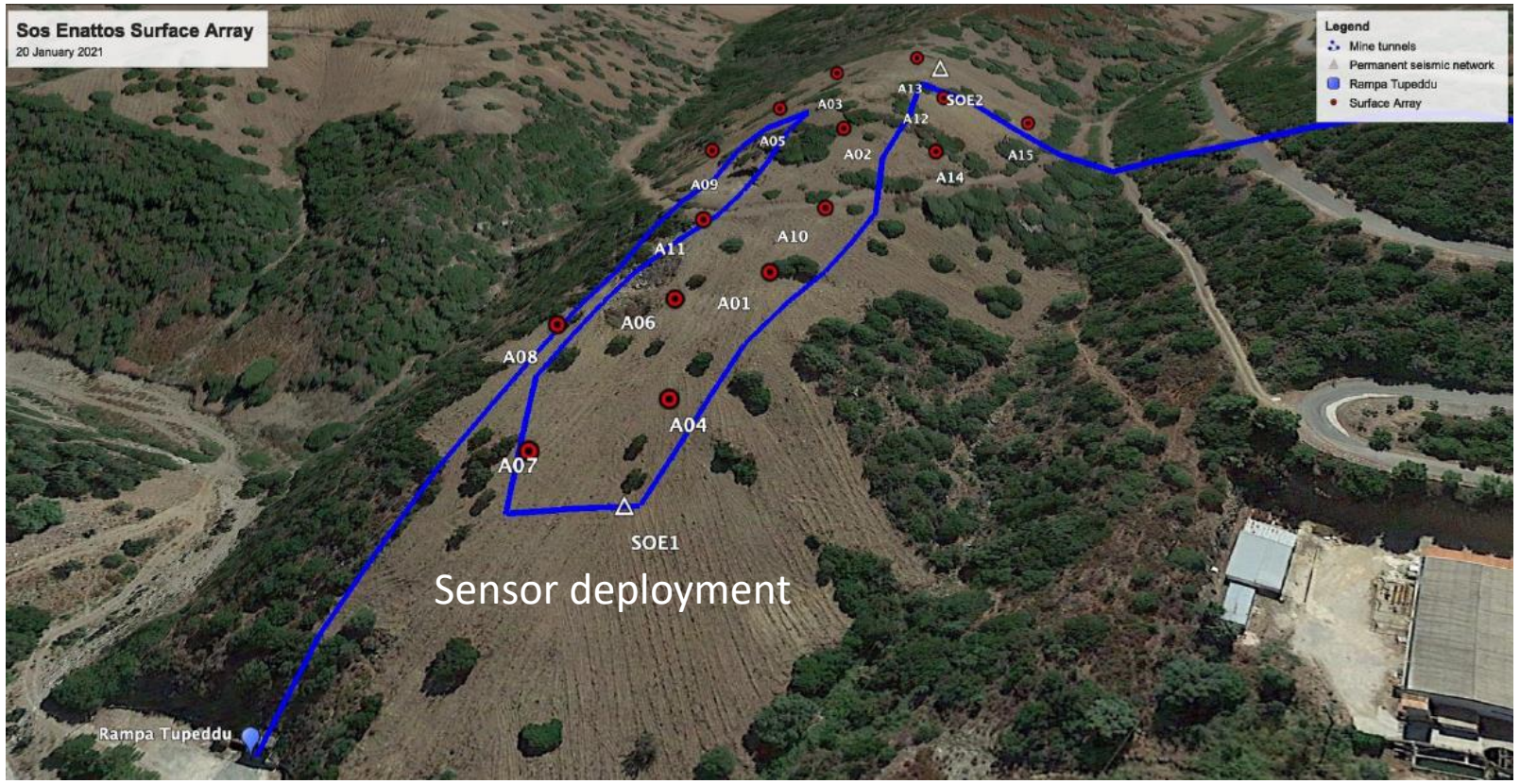
Characterisation of Sos Enattos

Surface Seismometers Array *Local noise sources and Noise modelization*

A surface array made of tens of seismometers (12 Trillium120 + 3 Trillium20 provided by INGV & INFN) have been installed at Sos Enattos in January-February 2021

Preliminary test





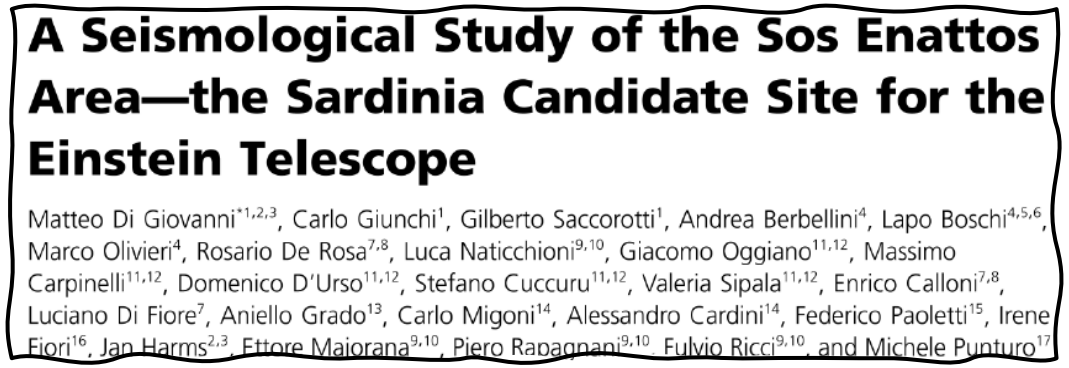
Characterisation of Sos Enattos

The **results** of the first 2-years of seismic characterisation at the Sos Enattos corner have been published in:

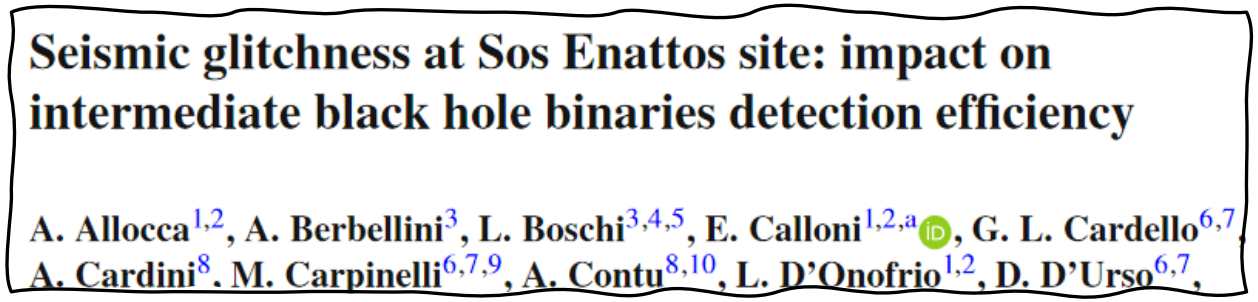
- L. Naticchioni et al., ***Characterization of the Sos Enattos site for the Einstein Telescope,*** **JPCS** 1468, 2020

- 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


A Seismological Study of the Sos Enattos Area—the Sardinia Candidate Site for the Einstein Telescope

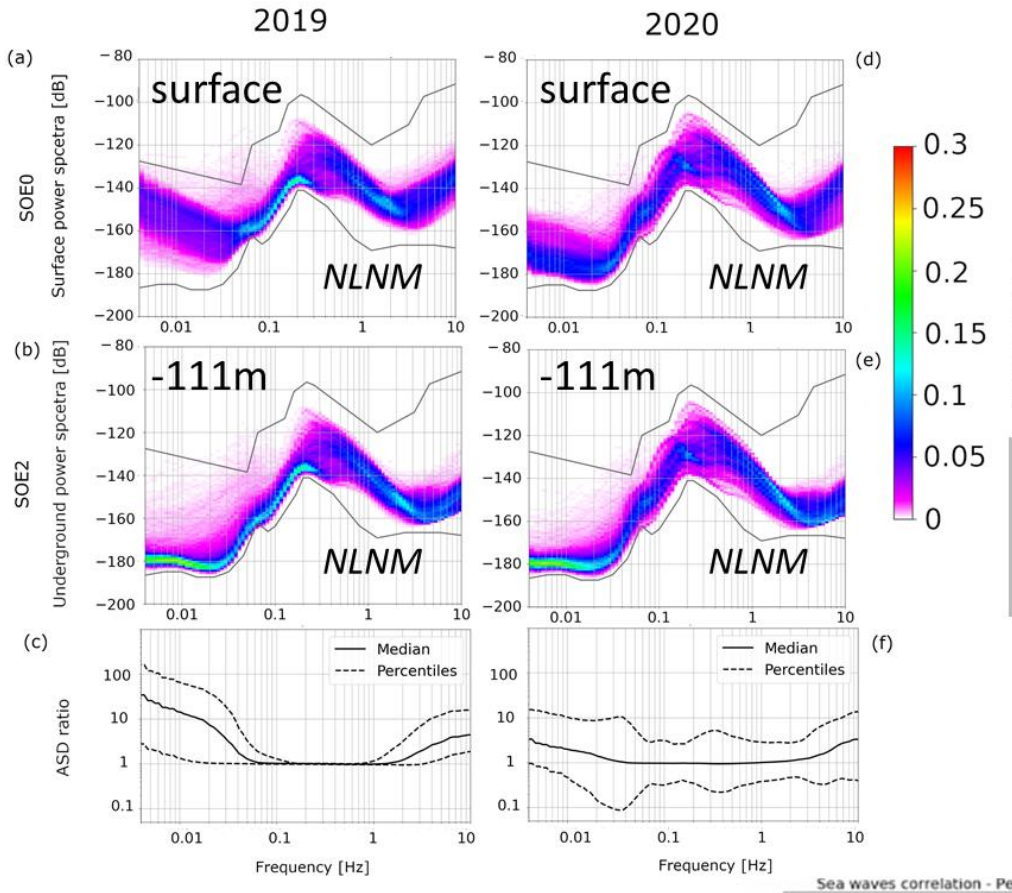
Matteo Di Giovanni[*1,2,3], Carlo Giunchi[1], Gilberto Saccorotti[1], Andrea Berbellini[4], Lapo Boschi[4,5,6], Marco Olivieri[4], Rosario De Rosa[7,8], Luca Naticchioni[9,10], Giacomo Oggiano[11,12], Massimo Carpinelli[11,12], Domenico D'Urso[11,12], Stefano Cuccuru[11,12], Valeria Sipala[11,12], Enrico Calloni[7,8], Luciano Di Fiore[7], Aniello Grado[13], Carlo Migoni[14], Alessandro Cardini[14], Federico Paoletti[15], Irene Fiori[16], Jan Harms[2,3], Ettore Majorana[9,10], Piero Rapagnani[9,10], Fulvio Ricci[9,10], and Michele Punturo[17]

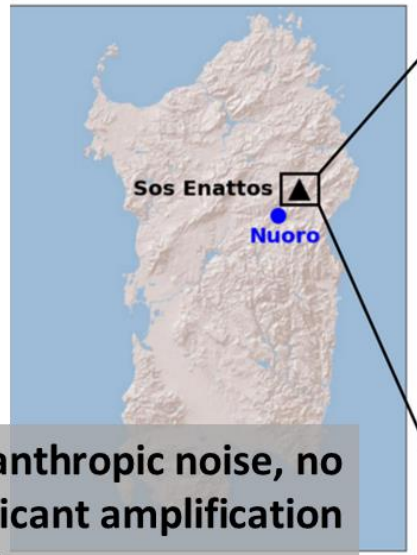

Seismic glitchness at Sos Enattos site: impact on intermediate black hole binaries detection efficiency

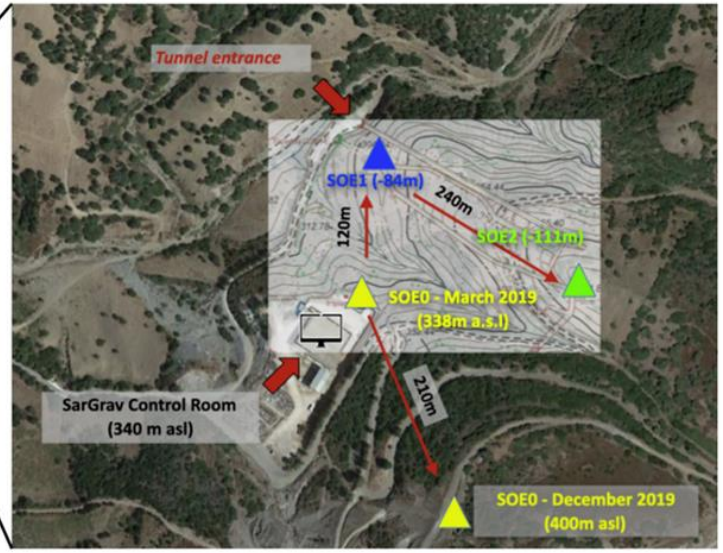
A. Allocca[1,2], A. Berbellini[3], L. Boschi[3,4,5], E. Calloni[1,2,a], G. L. Cardello[6,7], A. Cardini[8], M. Carpinelli[6,7,9], A. Contu[8,10], L. D'Onofrio[1,2], D. D'Urso[6,7],

… another publication about the features of the seismic noise at the site is in preparation

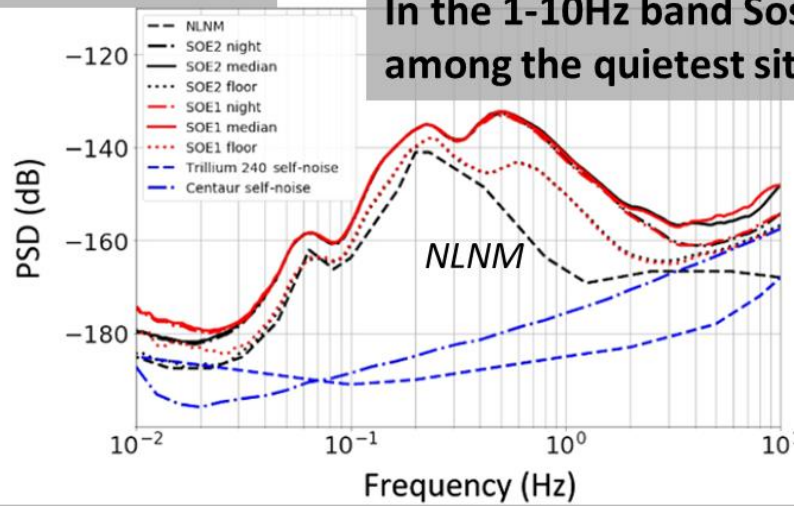
First results at Sos Enattos



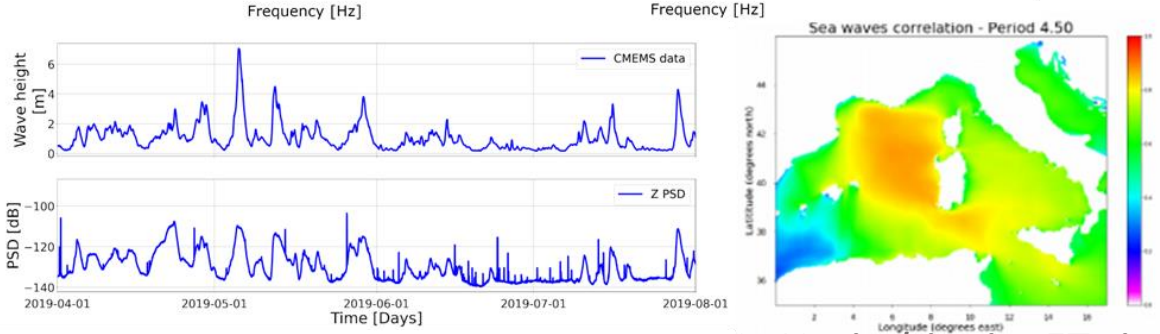




Low anthropic noise, no significant amplification effects



In the 1-10Hz band Sos Enattos is among the quietest sites in the world



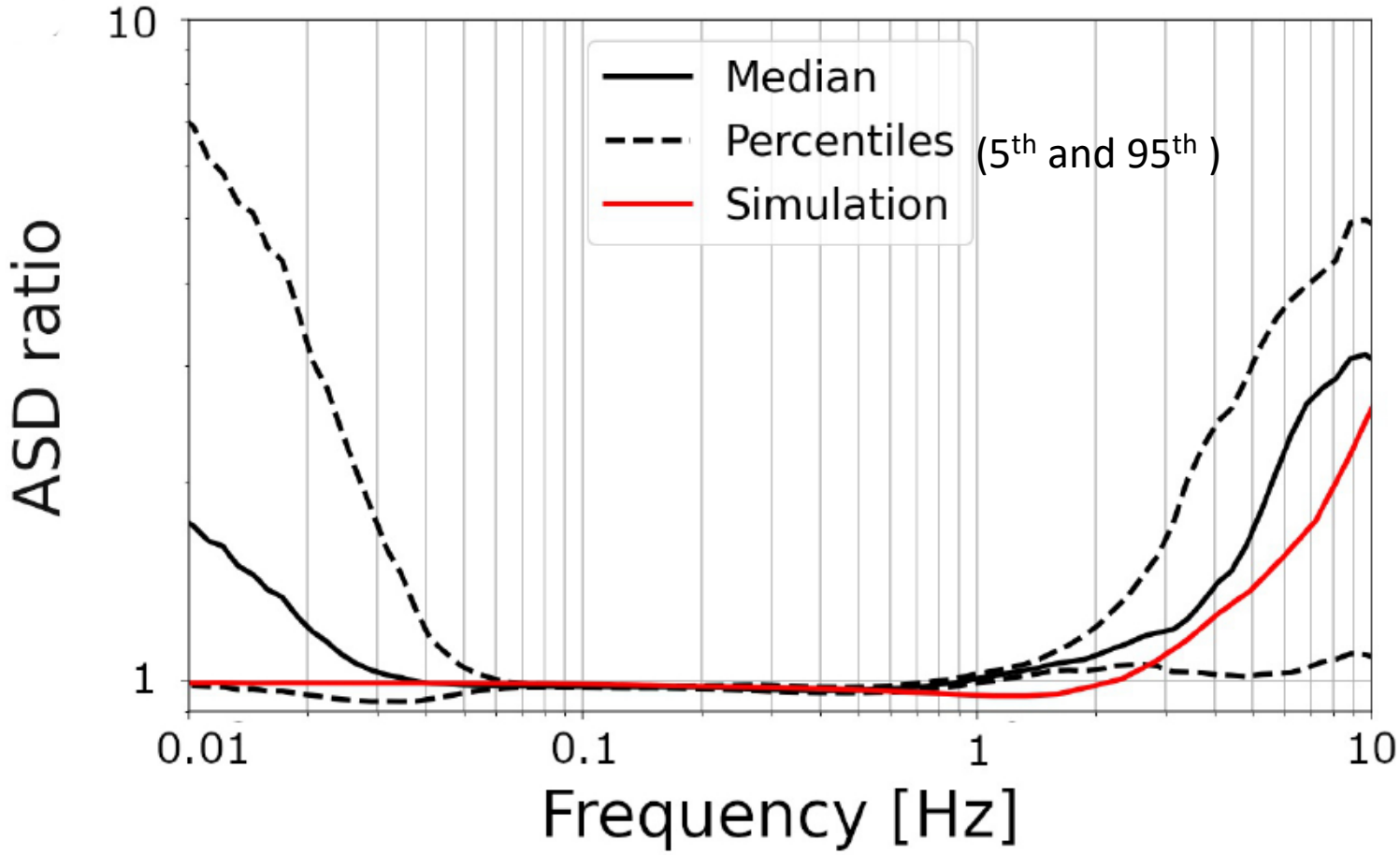
Microseisms correlation with NW 4.5s Med Sea waves

Seismological Research Letters (2021) 92 (1): 352–364

First results at Sos Enattos

Amplitude decay with depth significant only for f>2Hz, consistent with Rayleigh-wave propagation in local rocks

SOE0 (surface) / SOE2 (-111m vault)

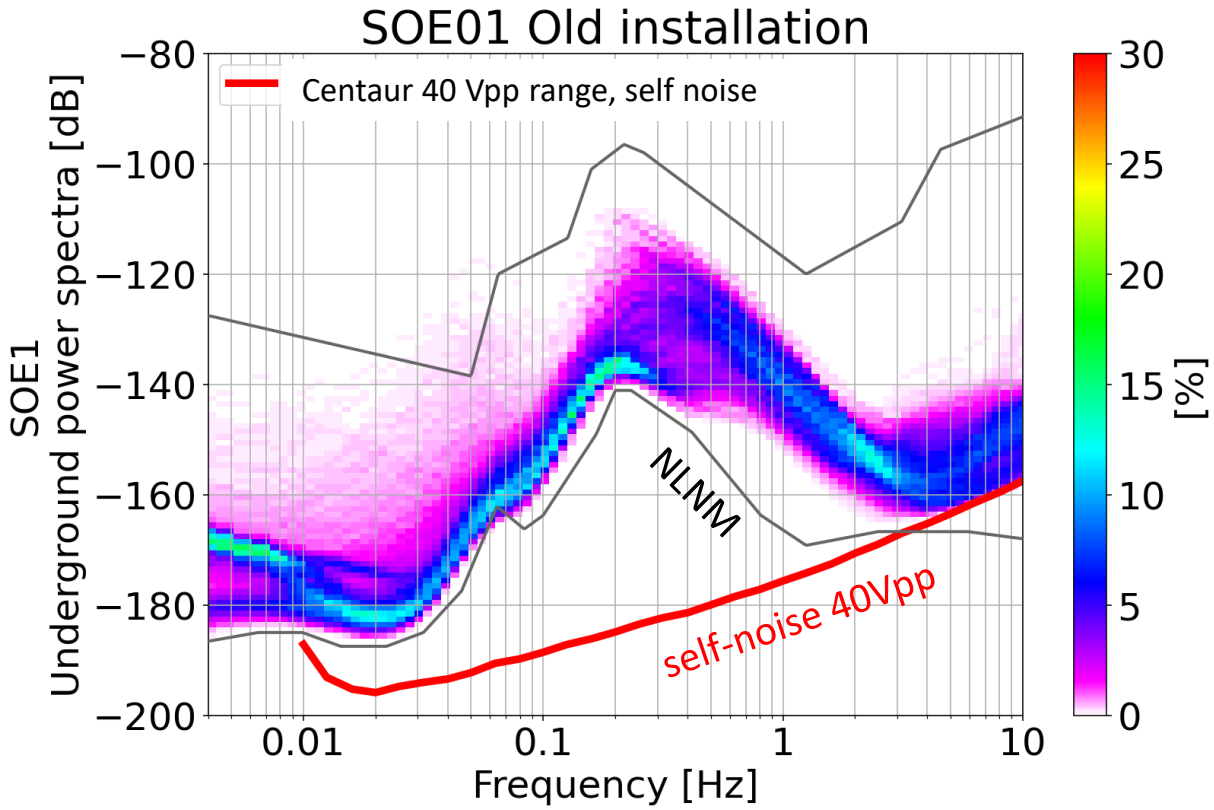


Synthetic seismograms

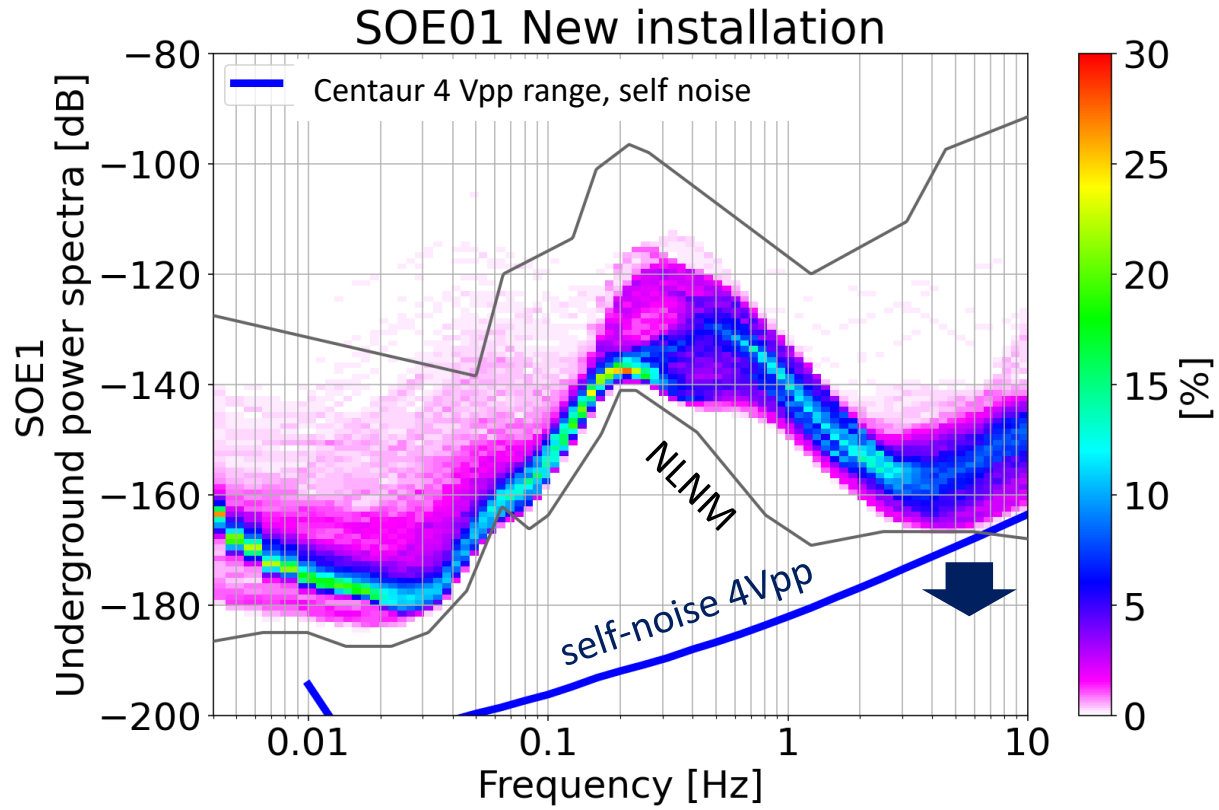
Seismological Research Letters (2021) 92 (1): 352–364

First results at Sos Enattos

Reduced input range → reduced DAQ self noise → environmental seismic noise floor below the standard seismometer settings in few Hz band, **close to NLNM** (here SOE1, 84m depth)

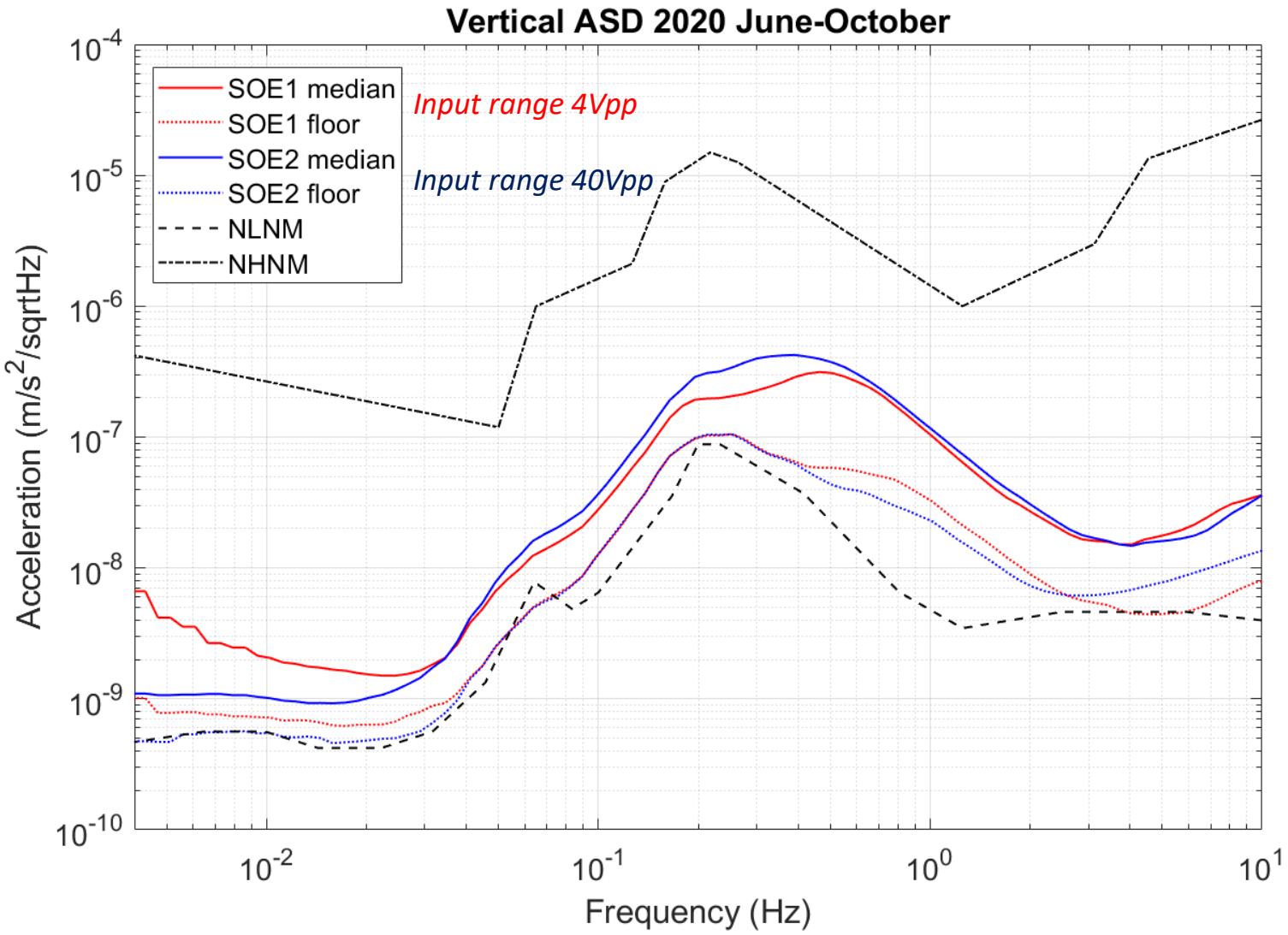


May to June 2020

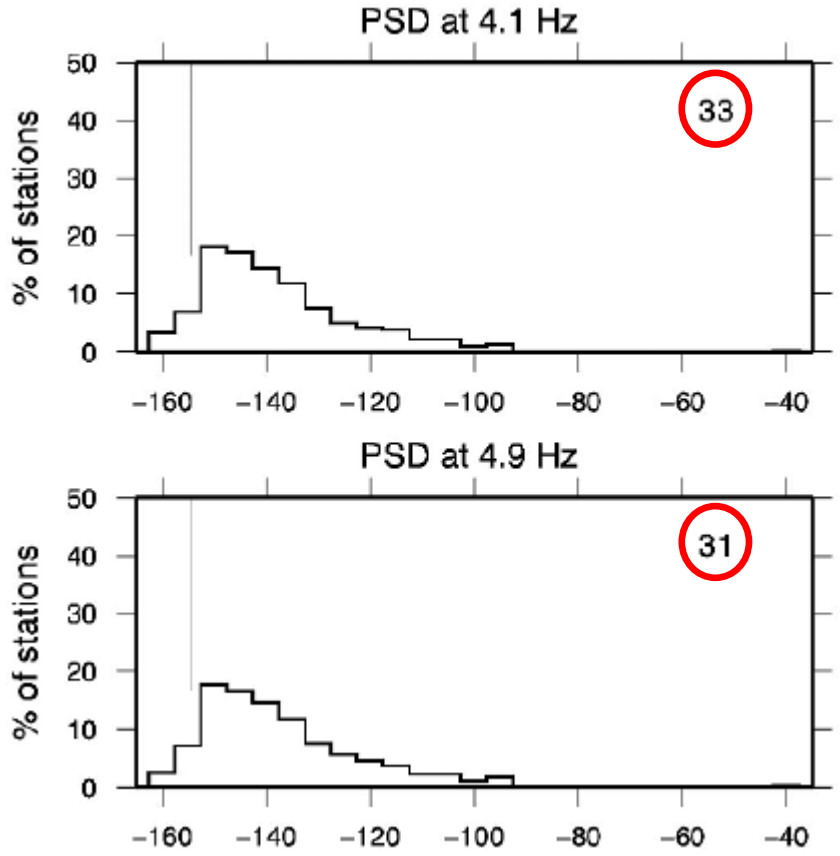


June to August 2020

First results at Sos Enattos



SOE2 ranking among 445 stations of IRIS network



Seismological Research Letters (2021) 92 (1): 352–364

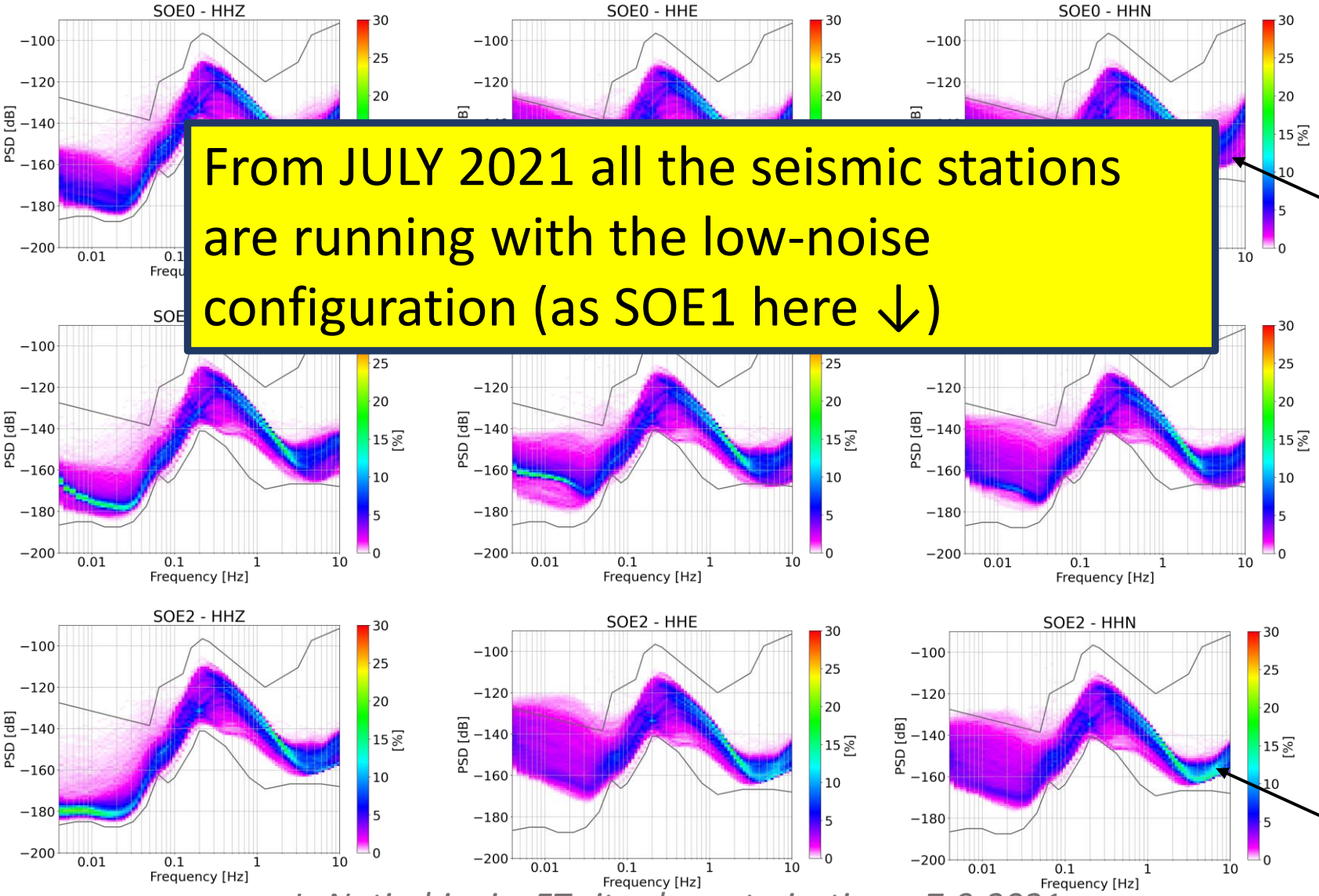
First results at Sos Enattos

Vertical | Horizontal

SOE0
Surface

SOE1
-84m

SOE2
-111m



From JULY 2021 all the seismic stations are running with the low-noise configuration (as SOE1 here ↓)

2021 data
January-April

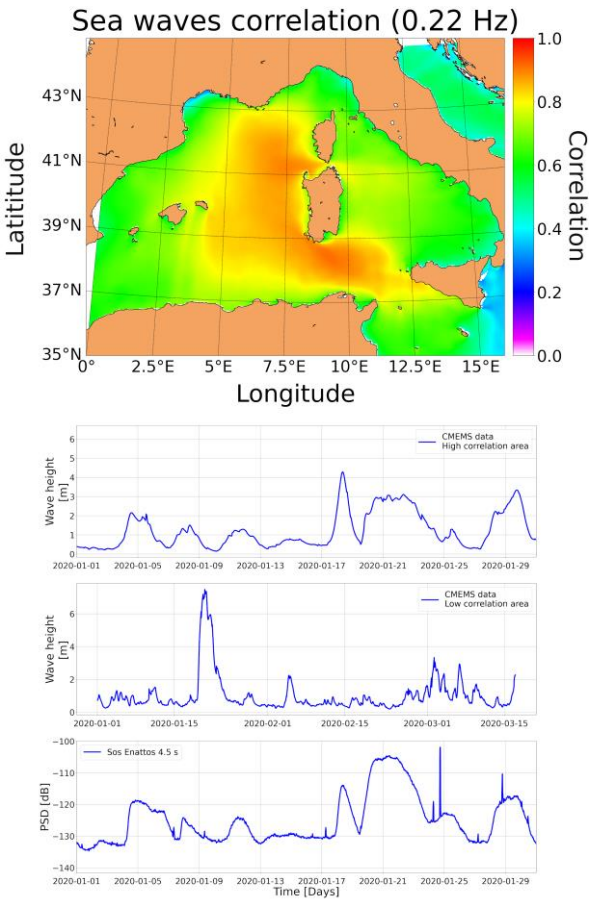
DAQ self-noise limit

DAQ self-noise limit

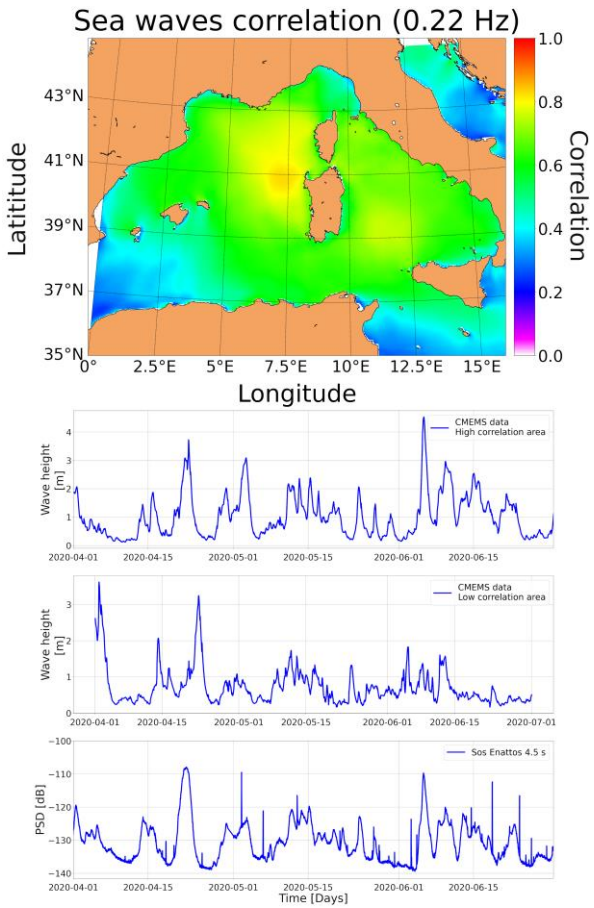
First results at Sos Enattos

Seasonal Microseismic variations in 2020

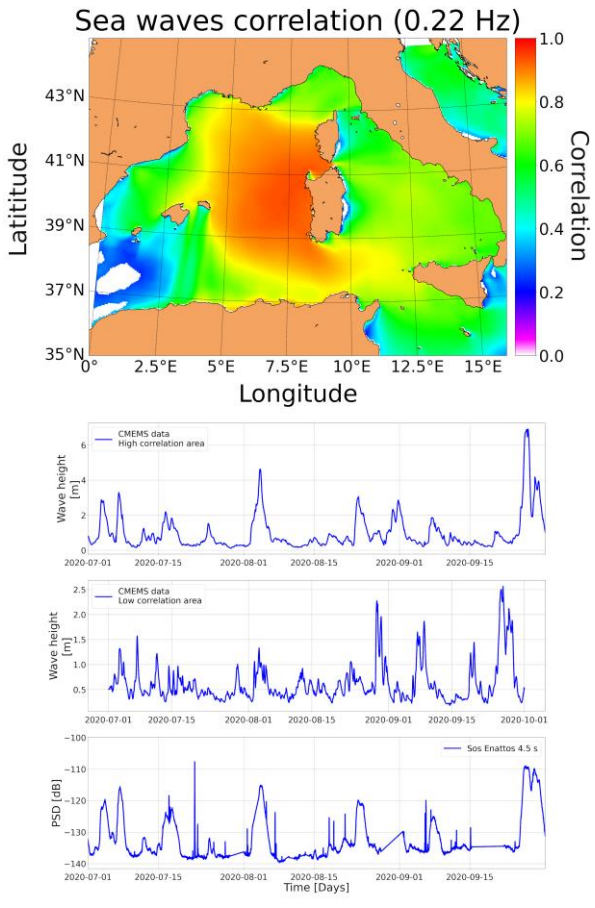
I trimester



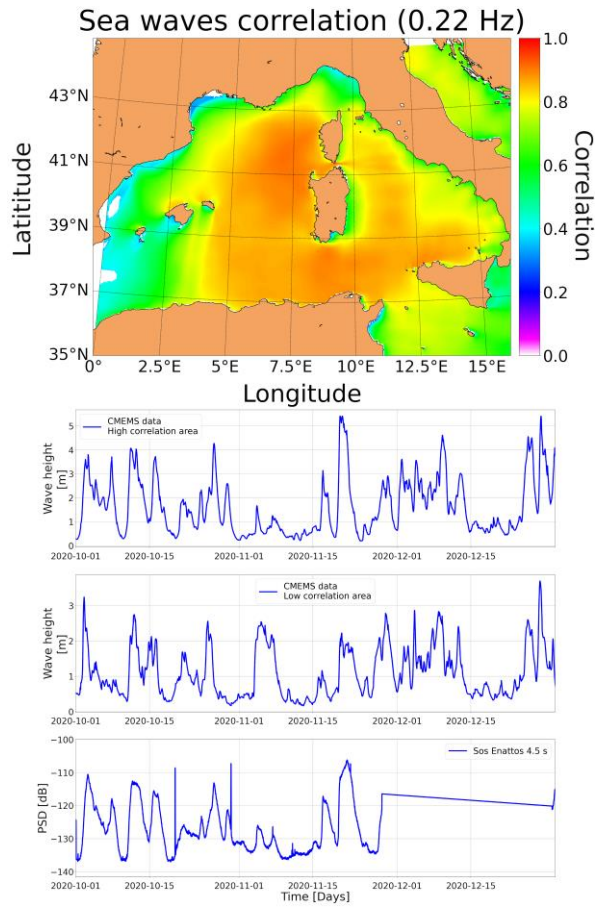
II trimester



III trimester

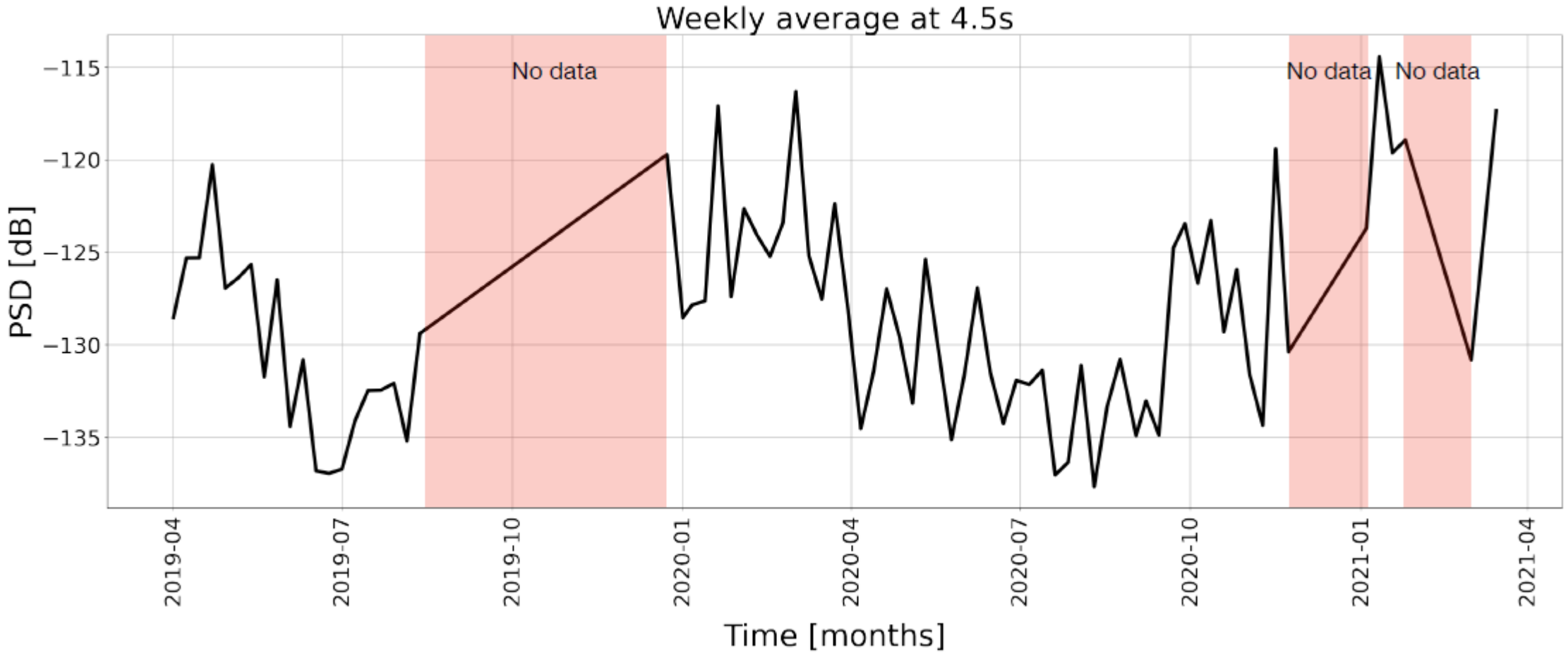


IV trimester



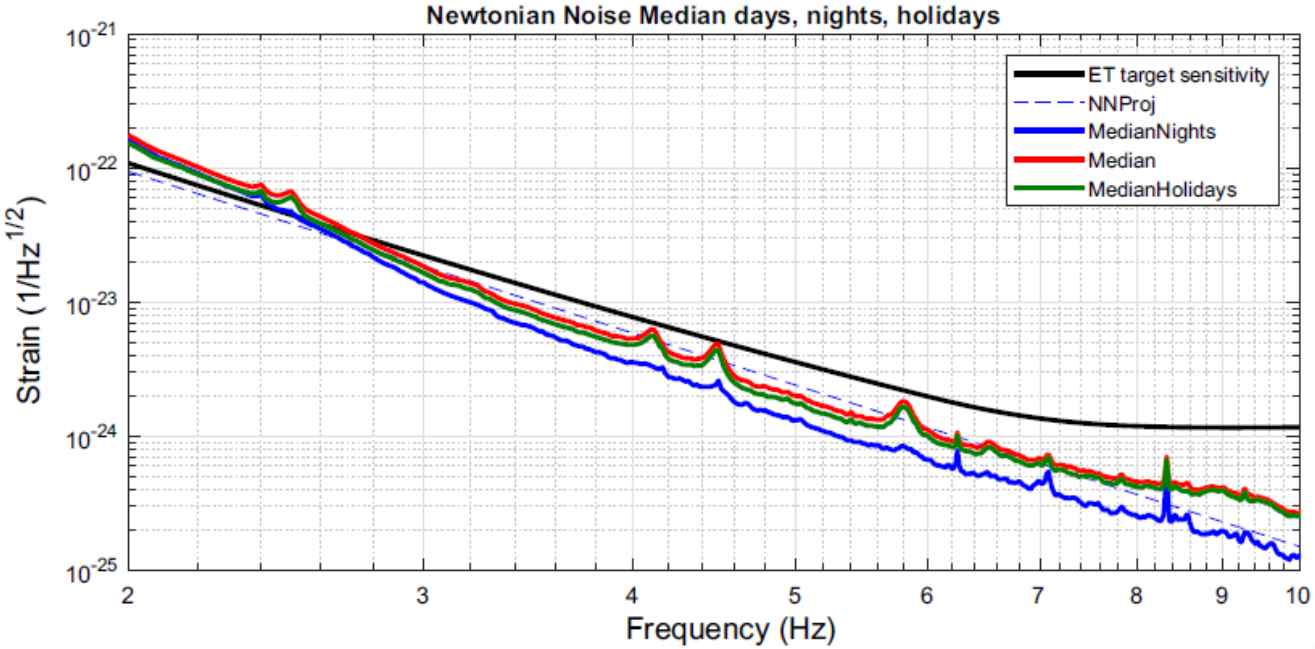
First results at Sos Enattos

Seasonal Microseismic noise trend in 2019-2021



First results at Sos Enattos

Newtonian Noise & seismic glitches (based on 2020 data at SOE1, -84m)



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

Defining the Newtonian Noise ASD as:

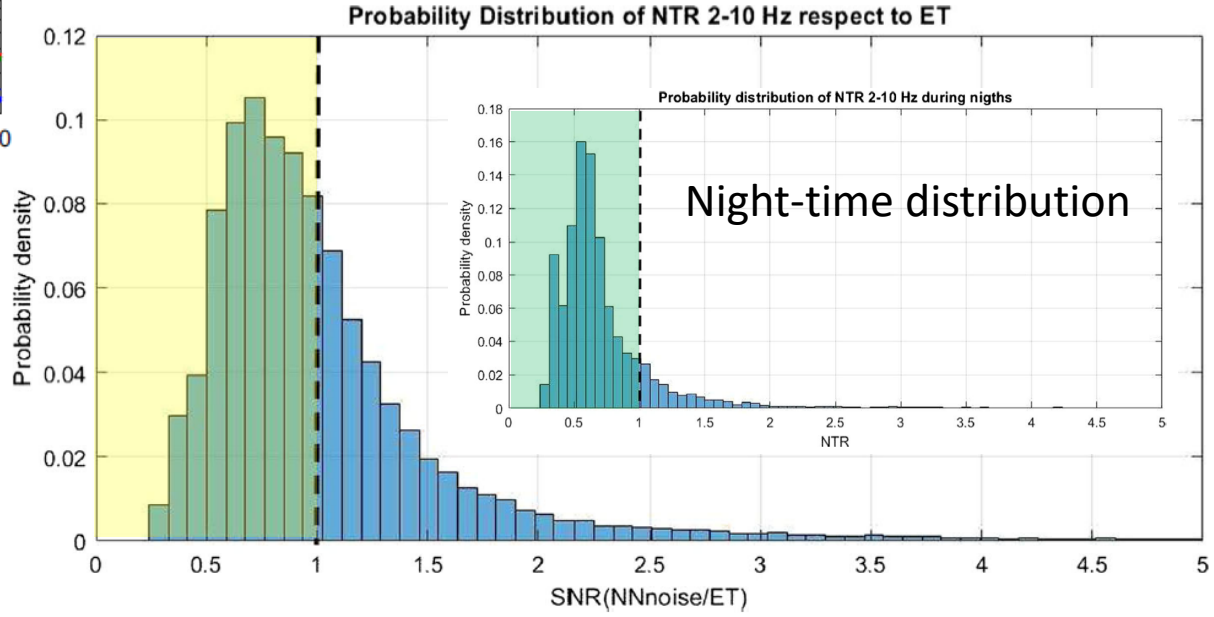
$$\tilde{h}_{NN}(f) = \frac{4\pi}{3} G\rho_0 \frac{2\sqrt{2}}{L} \frac{1}{(2\pi f)^2} \tilde{x}(f)$$

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



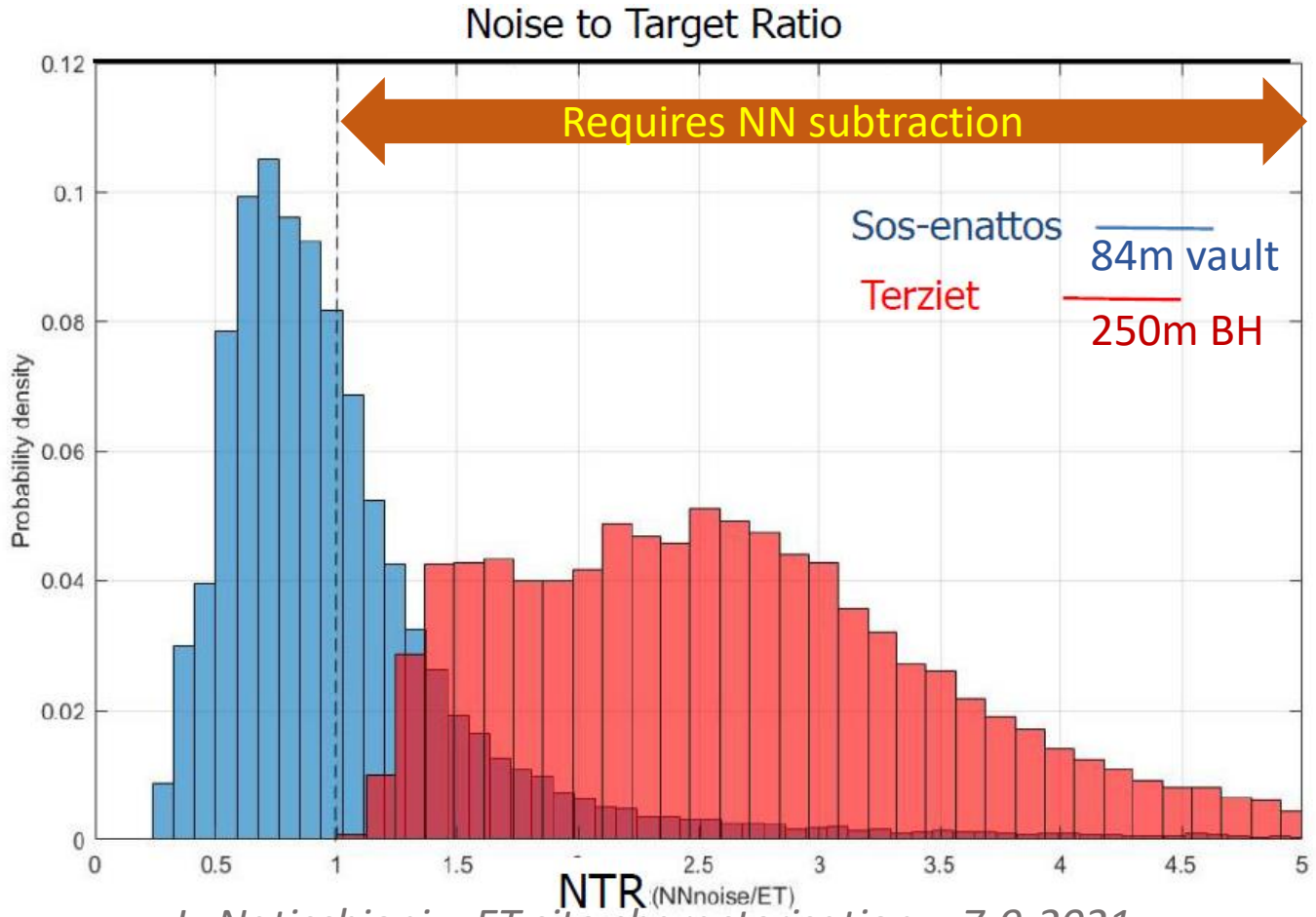
P(NRT<1)=0.6 , considering only the nights: $P(NRT<1)_n$=0.86

→Need for moderate NN subtraction only for a limited time

First results at Sos Enattos

Newtonian Noise & seismic glitches (based on 2020 data at SOE1, -84m)

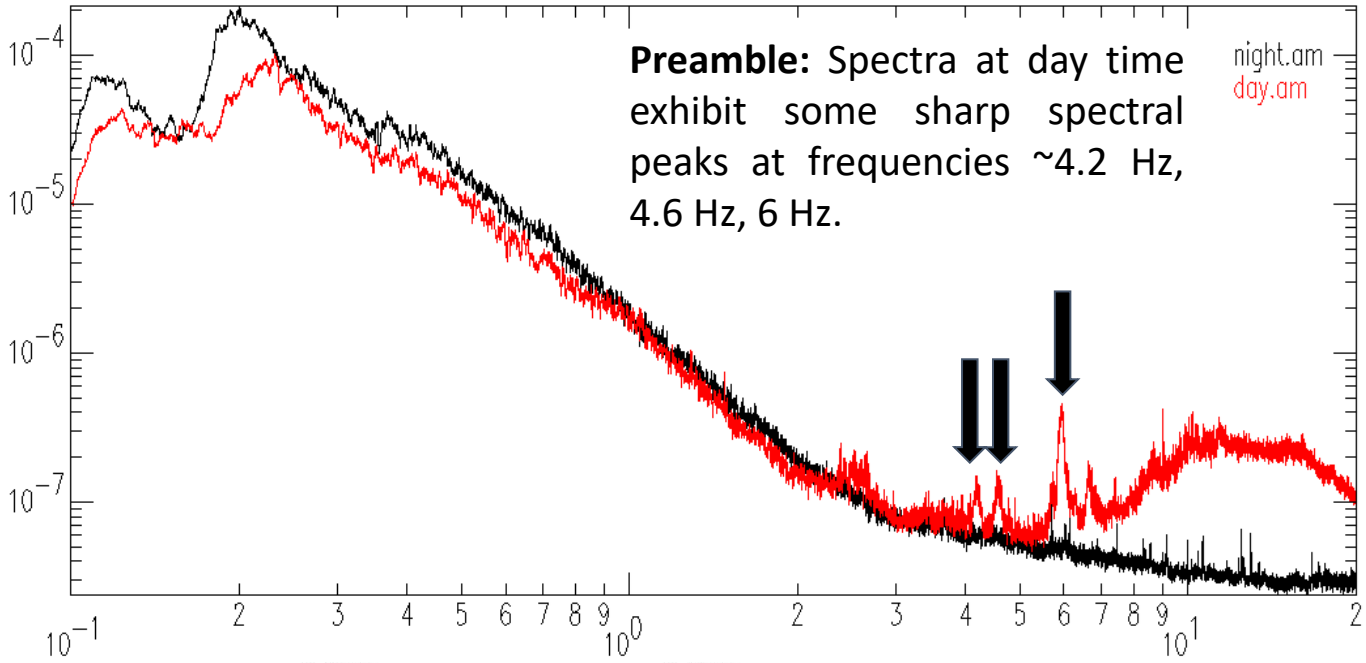
…doing the same exercise with Terziet site (-250m) public data:



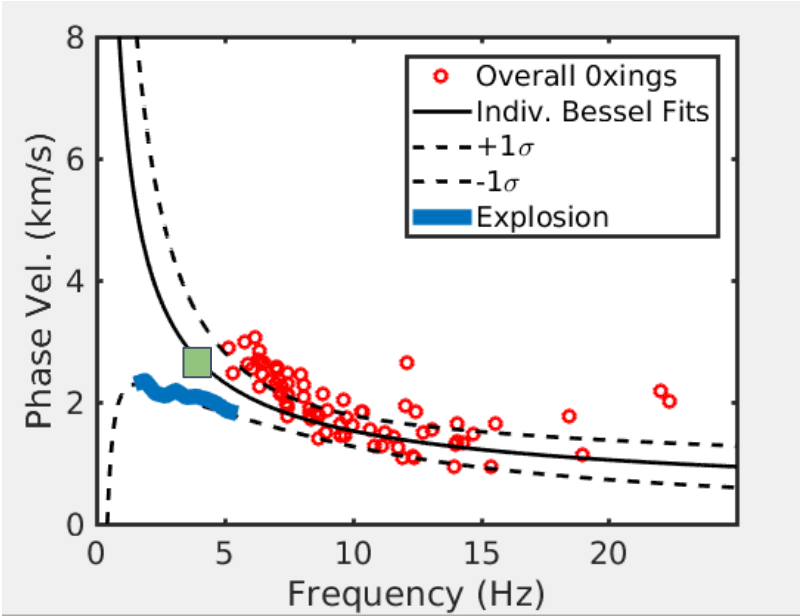
First results at Sos Enattos

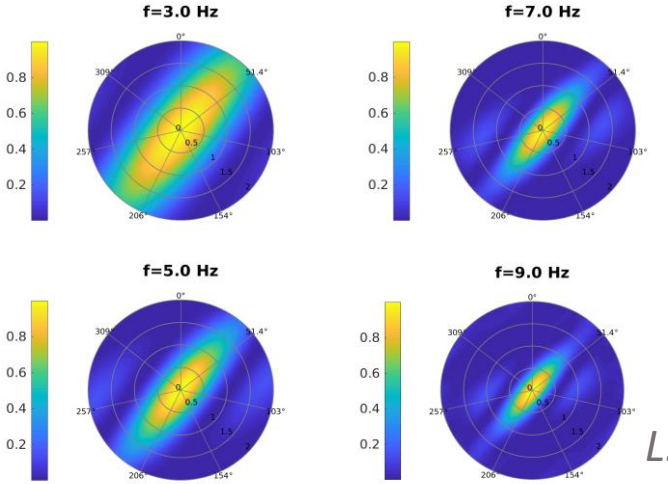
Seismometer array results

Array-stacked spectra:

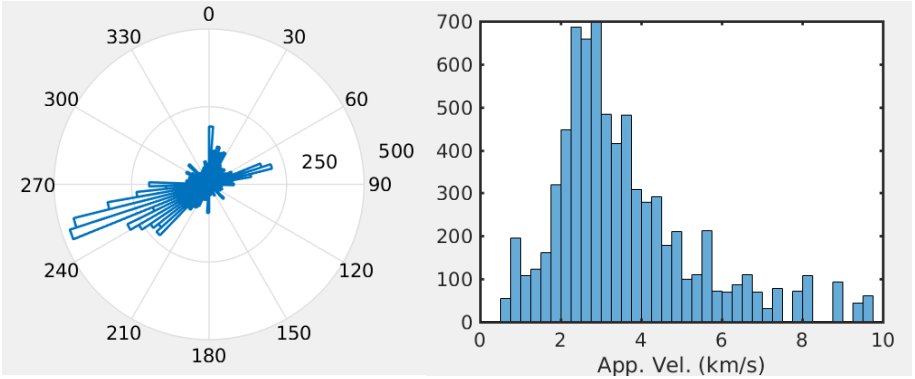


SPatial AutoCorrelation:





FK-Analysis

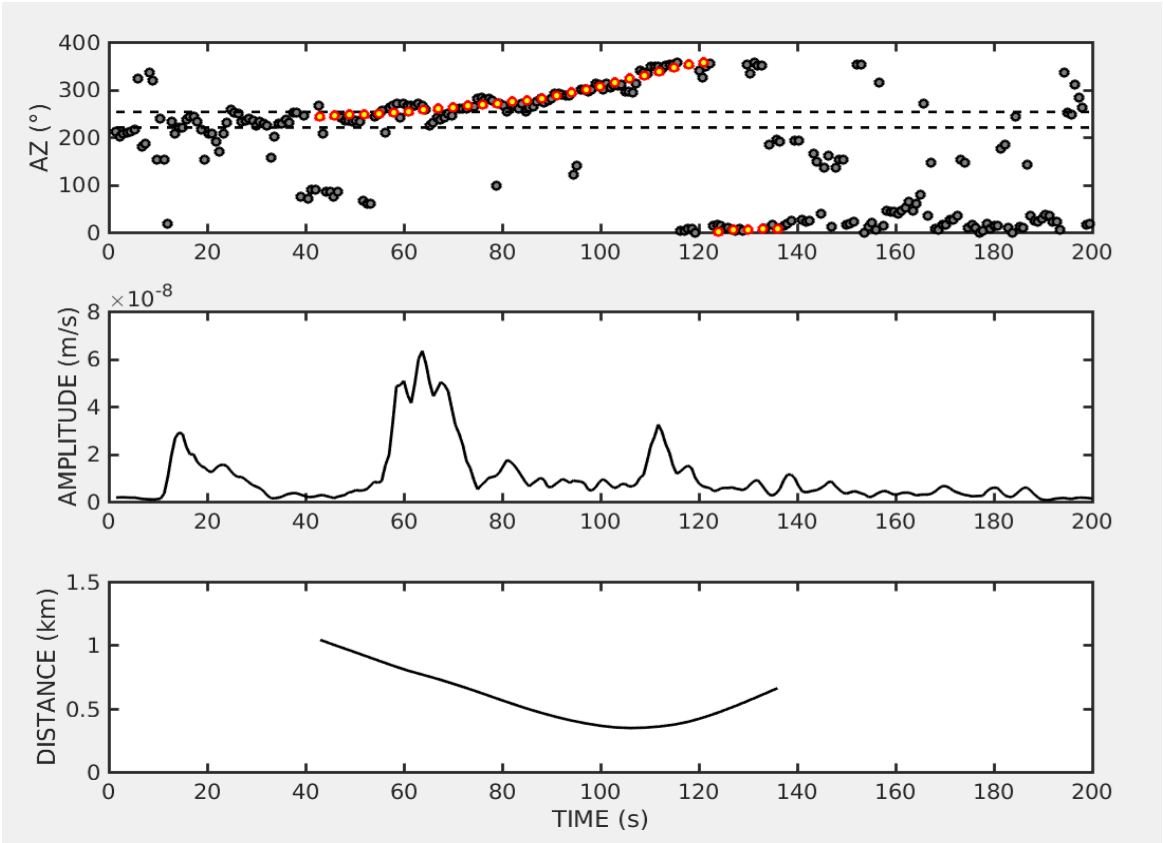


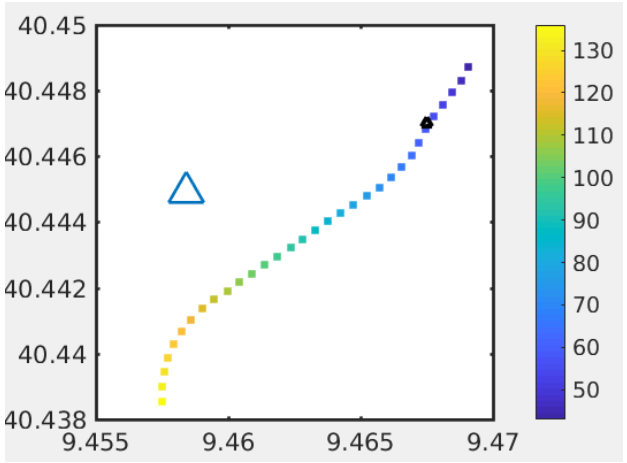
Not-isotropic wavefield
Peaks at f = 4-5 Hz
Propagation azimuths directed WSW (i.e., main sources located ENE of the array)
High velocities (~2.5 km/s)

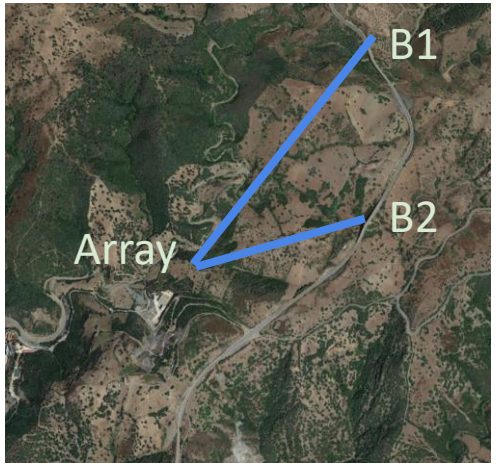
First results at Sos Enattos

Seismometer array results

Vehicle Tracking close to the site







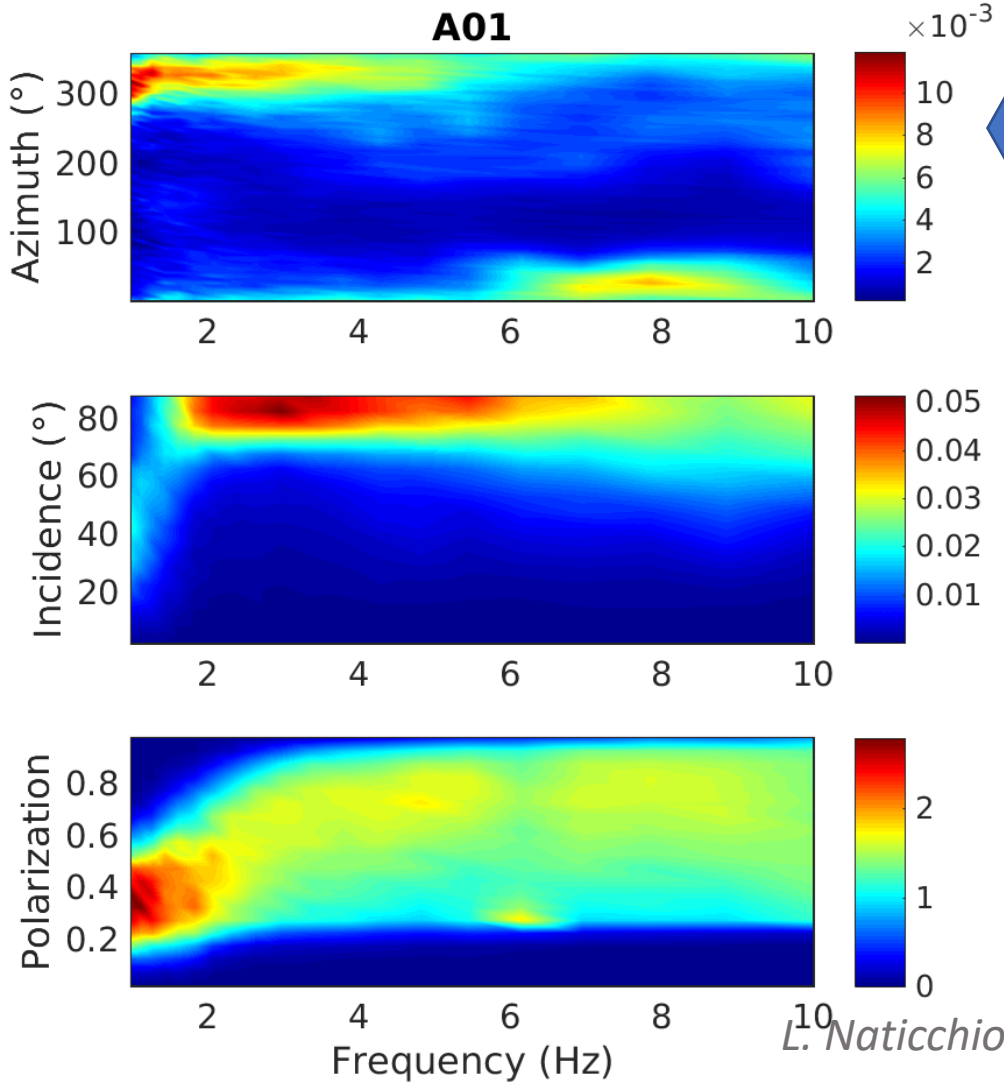
Time evolution of azimuth compatible with a vehicle traveling at 60 km/h southward along road SP73.

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

First results at Sos Enattos

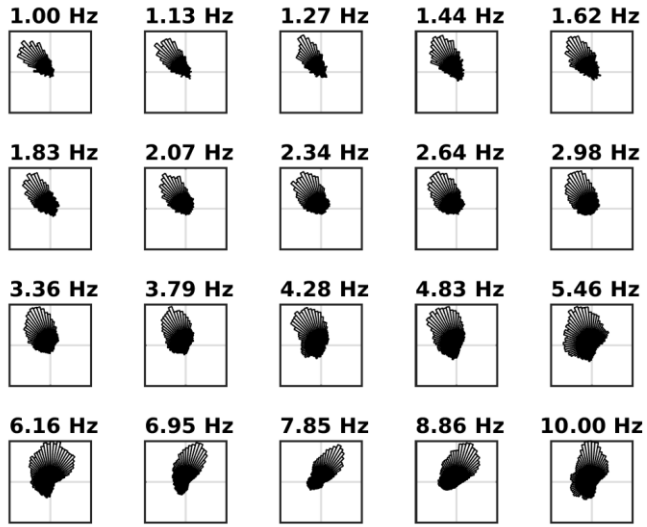
Seismometer array results

Polarization analysis



Probability density of particle motion Azimuth, Incidence Angle and Degree of Polarization as a function of frequency.

Polarization angle [0°- 180°]: the ellipsoid dips to East.
Polarization angle [180°- 360°]: the ellipsoid dips to West.

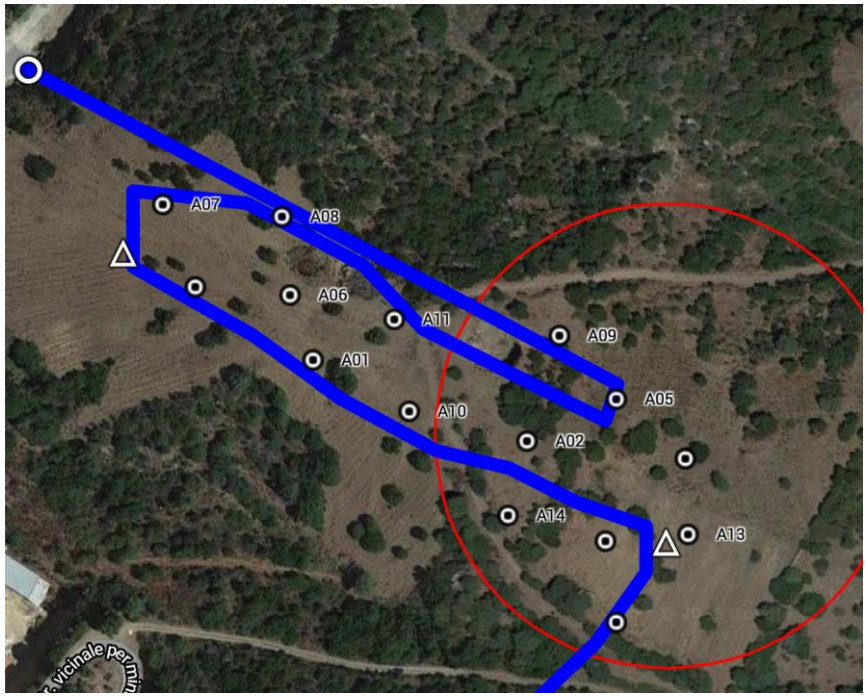


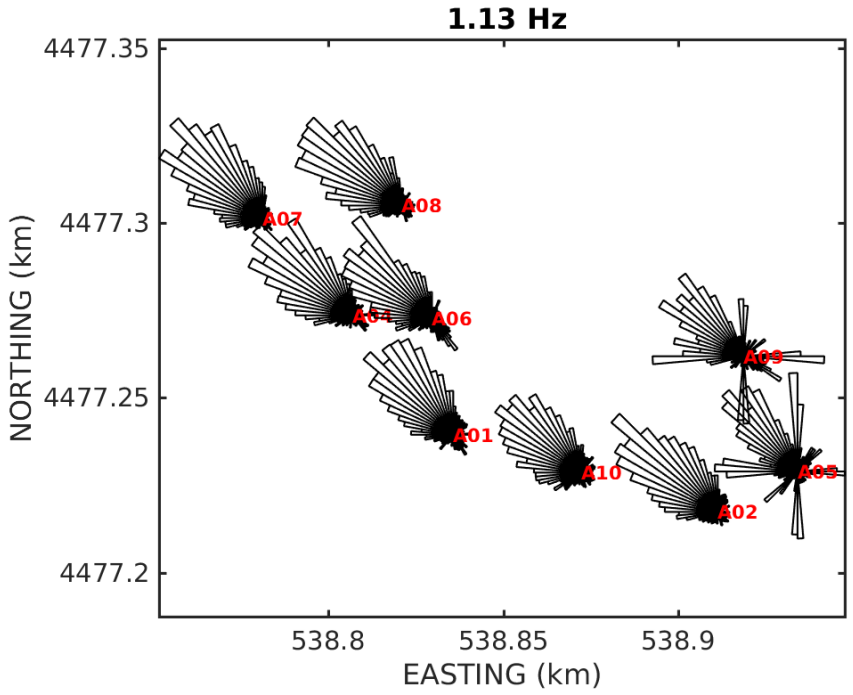
First results at Sos Enattos

Seismometer array results

Polarization analysis

At low frequencies, the polarization directions are rather uniform; they are oriented toward NW (see marine microseismic source).



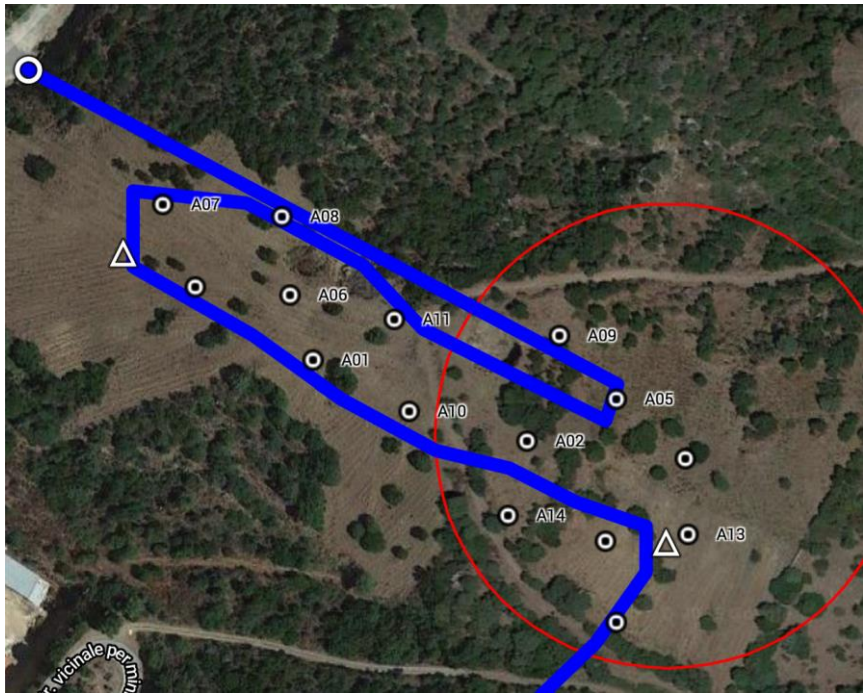


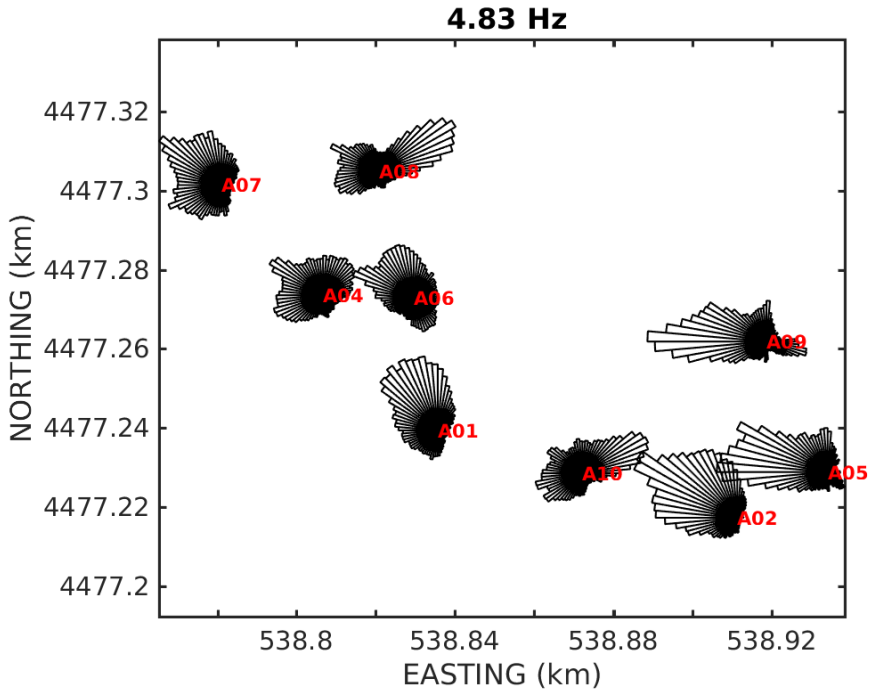
First results at Sos Enattos

Seismometer array results

Polarization analysis

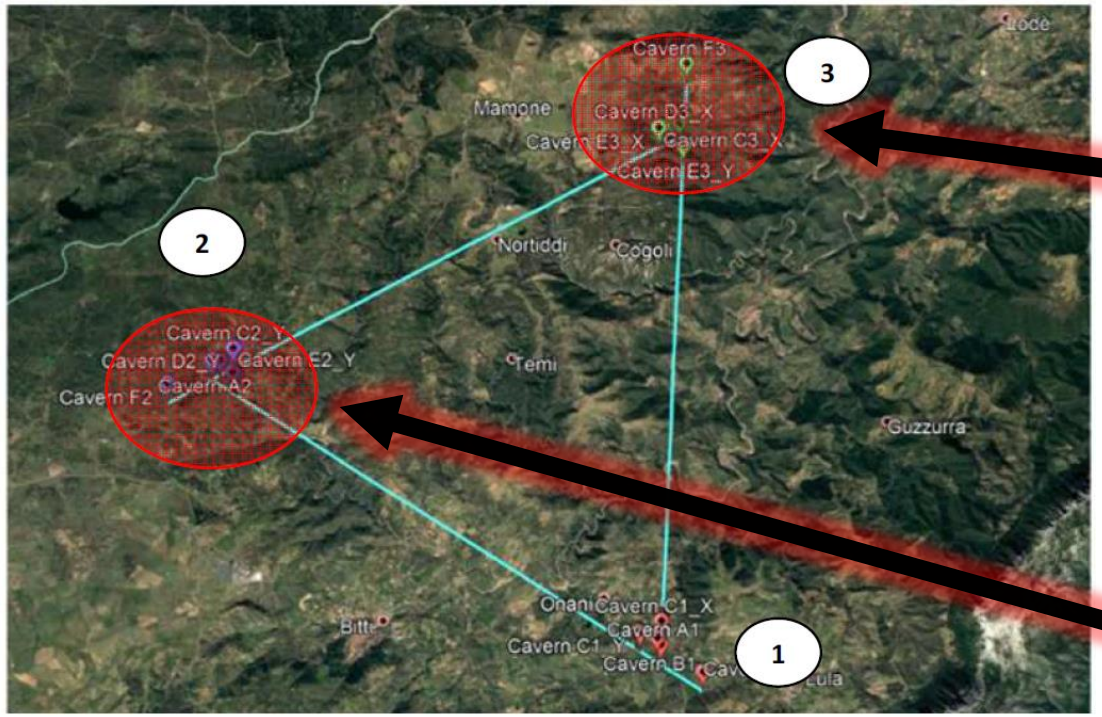
At higher frequencies, the variability of polarization directions throughout the array deployment indicates a strong influence of topography.





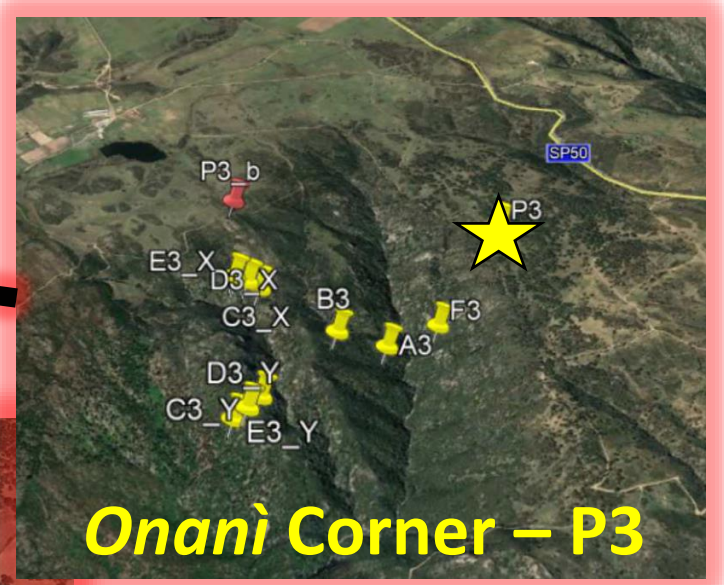
Characterisation of the corners

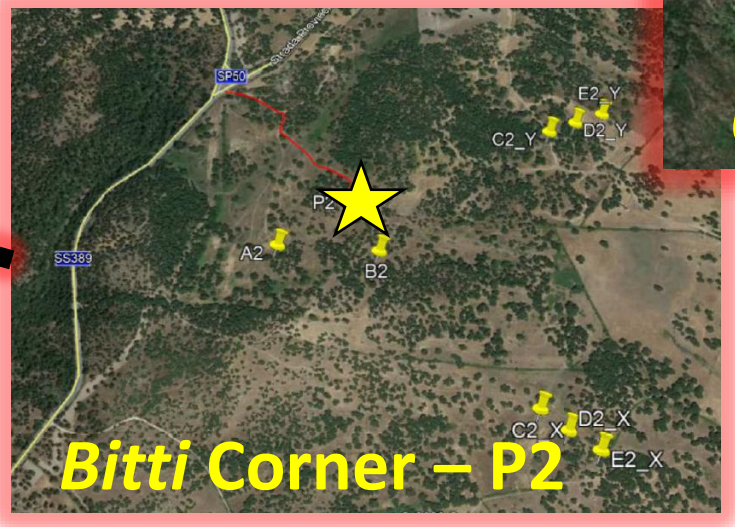
In July 2021 we started the surface and underground seismic and environmental measurements at the other two corners (named *Bitti* and *Onanì*).



***Lula* Corner**

Sos Enattos





☆ : area for boreholes and surface arrays

📌 : proposed locations for ET main caverns

Characterisation of the corners

Bitti corner, borehole area

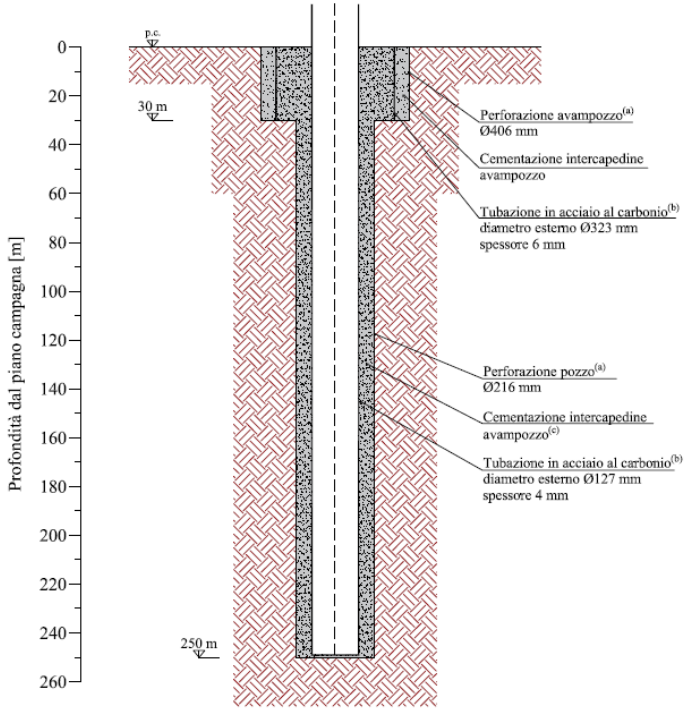
Onanì corner, borehole area

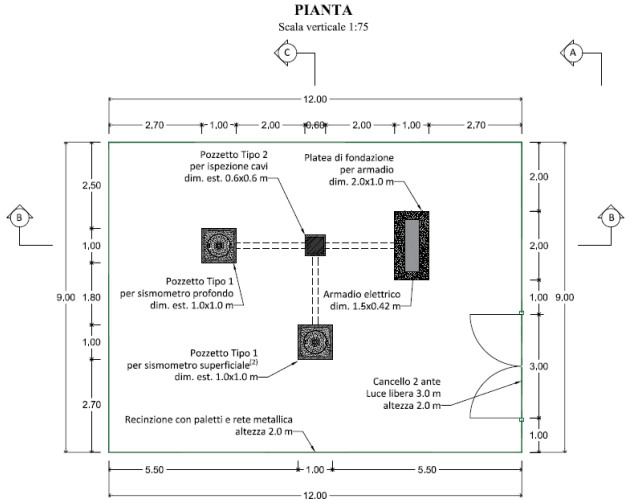
Characterisation of the corners

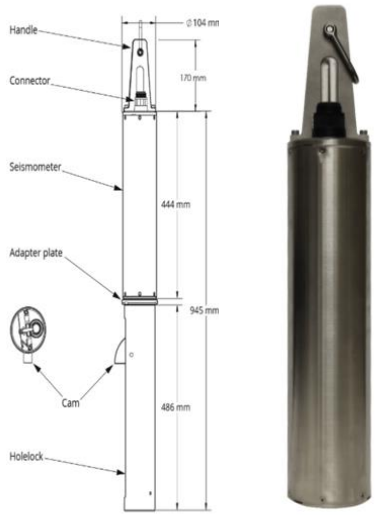
- **Stanziati 410ke presso la Sezione di Roma per i 2 pozzi** nel **2020** (capitolo U1030299999 – fondo *Virgo MIUR ET*)
- RDA 40120 (L.Naticchioni - RM1), CUP: I49E20000030005
- RUP (per RM1): G. Schillaci – LNS, nomina **14.02.2020**
- Progettazione supportata DICEA Sapienza (RDA 26681 RM1)
- Affitto terreno vertice di Bitti con RDA 29445 & 38536 RM1 + autorizzazioni per entrambi i vertici
- Progetto esecutivo e allegati tecnici validati il **14.07.2020** dall'ufficio RUP
- Procedura negoziata approvata con delib.12519 GE del **16.09.2020**
    - Importo soggetto a ribasso: **249.2k**
    - Oneri sicurezza: **14.7k**
    - Somme a disposizione SA ed IVA22%: **146k**
- Manifestazione interesse 28.9.2020 - 15.10.2020, scadenza gara (pres. offerte): **27.11.2020**
- Aggiudicataria *Samminiatese Pozzi s.r.l.* (delib.12650 GE del **17.12.2020**)
- Direzione Lavori (RDA 46862 RM1): *Davide Boneddu*
- Contratto firmato ricevuto il **17.3.2021**, consegna lavori **15.4.2021** (deadline 15.10.21)
- Scavo del primo pozzo al vertice di Onanì iniziato il **27.4.2021**

Characterisation of the corners

- Excavation of two boreholes (265m and 280m deep) at the corner points P2 and P3. The drilling and consolidation of the boreholes has been started in April 2021 and **completed in July 2021**.
- The borehole concrete walls are equipped with optical fiber strainmeters (coll. with KIT)
- Installation of borehole seismometers (Trillium 120BH) + Trillium 120H at surface for comparison (vault installation) in Sept. 2021.







Characterisation of the corners

Characterisation of the corners

- Active seismic measurements at P2 and P3 with a vibration source (minivib vehicle) with hundreds of geophones installed in the field (~1km strings and array) and downhole + optical fiber strainmeter in July 2021;
- Data is being processed and analysed.

Collaboration of:
INFN, **INGV**, **KIT**

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Karlsruher Institut für Technologie

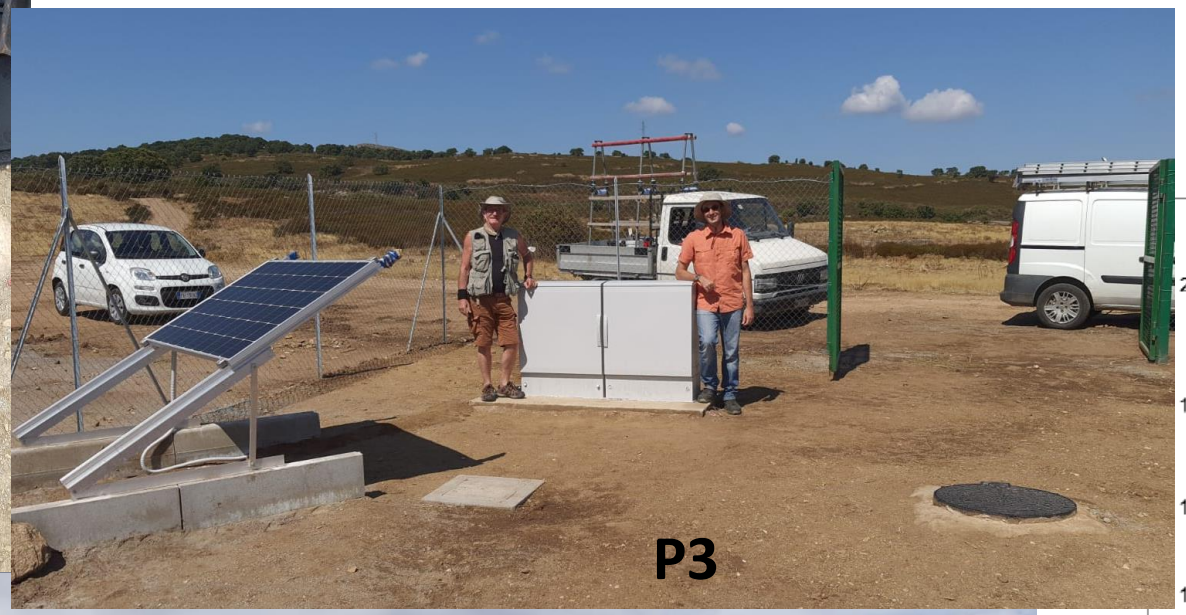
Characterisation of the corners

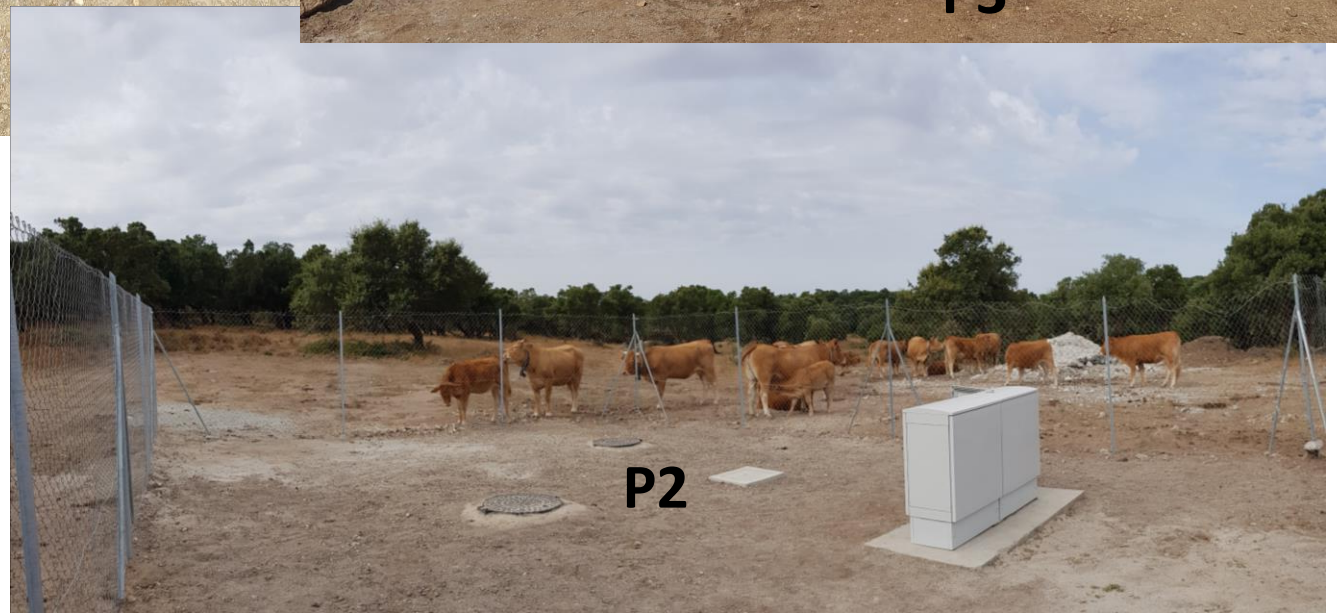
- From Sept. 1st we are finalising the surface infrastructure at P2 and P3 (box for instrumentation, power, network…);
- Active seismic measures at P2 on Sept. 3-4 (INGV);
- From September 9th we will start the deployment of borehole and surface seismometers at P2 and P3;
- From Sept. 16th seismic array measures (INFN/INGV) at P2 (2 weeks, 21 Trillium seismometers + 40+ geophones)
- From Oct.1st seismic array measures (INFN/INGV) at P3 (as above)

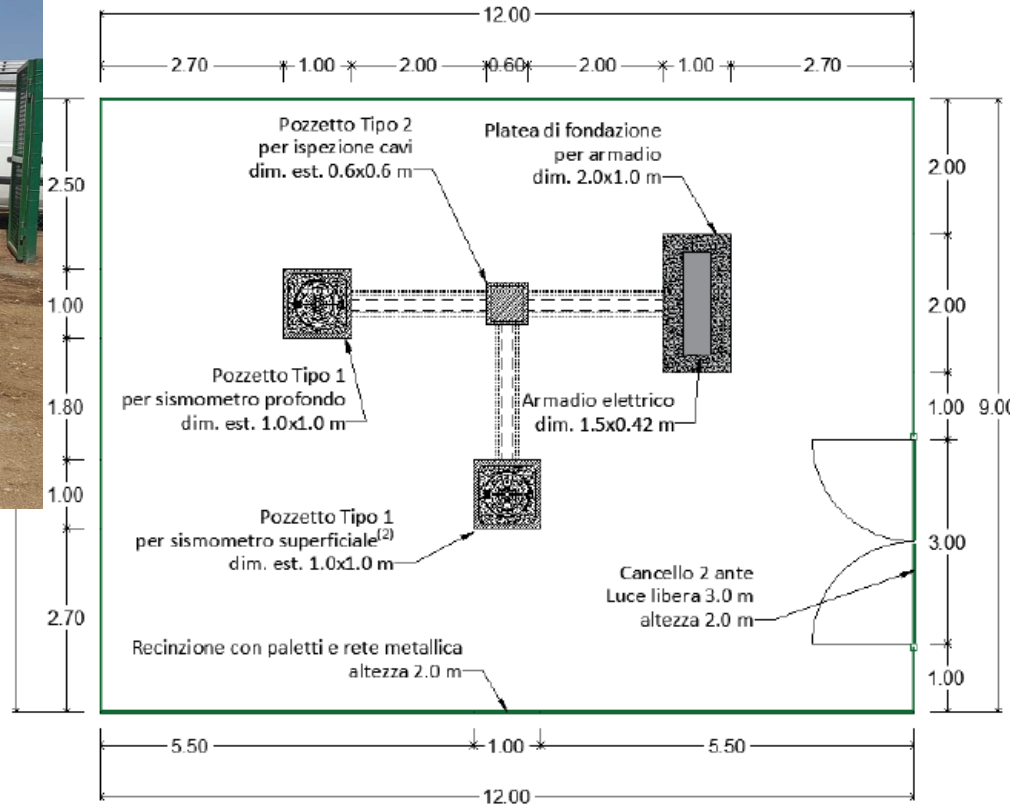
NB:

- From Sept.3rd georesistivity measures at P3 and P2
- From mid-Sept. installation of magnetic monitoring system at P2
- Planned participation of GSSI, KIT (geophones+opt fiber strainmeter), NIKHEF and PolGraw to the seismic array measures with additional sensors

Characterisation of the corners







WORK IN PROGRESS!!!