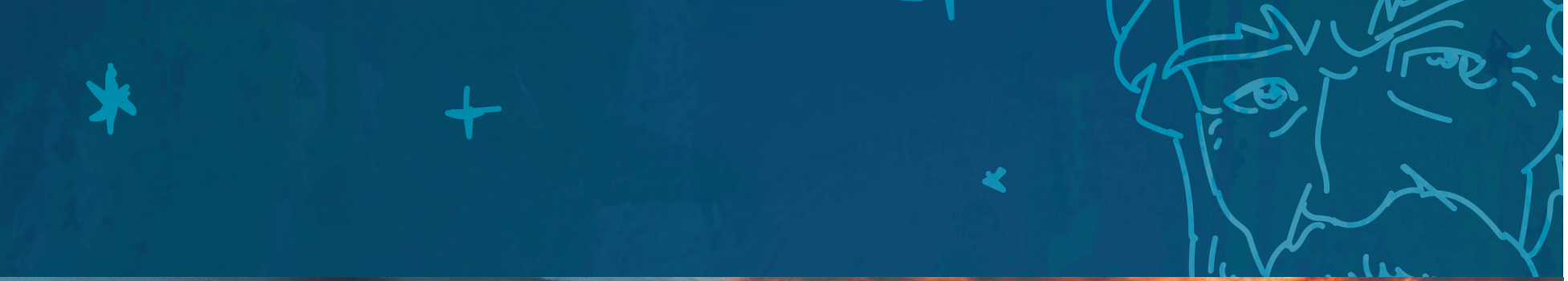
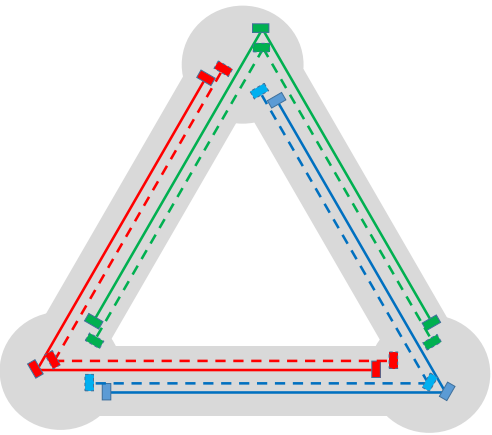




The Einstein Telescope is looking for home

D. D'Urso

University of Sassari

and INFN

On behalf and with the contribution of the ET Collaboration

Outline

- The Einstein Telescope
- Low frequency GW detection and ET Site Characterization
- ET Candidate Site
- Sardinia the Italian candidate site
  - Geological framework
  - characterization measurements
- Site Comparison: seismic noise
- Conclusions

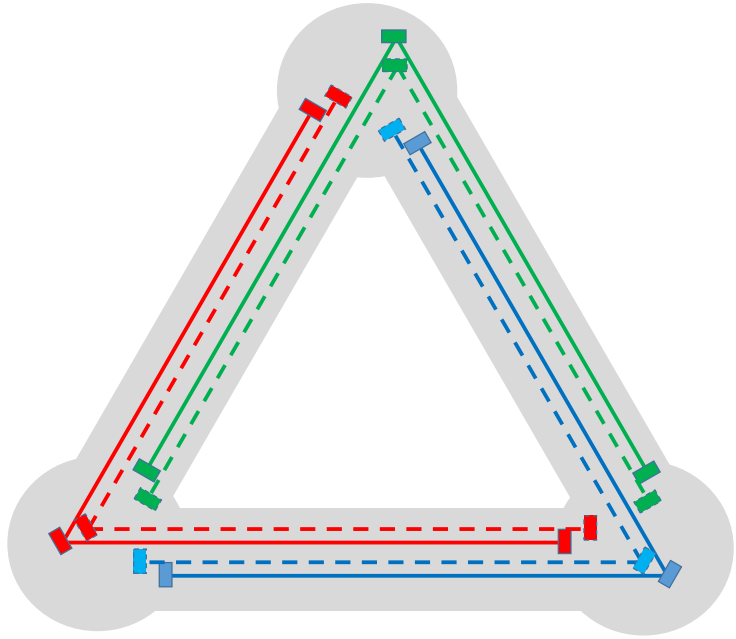
The Einstein Telescope

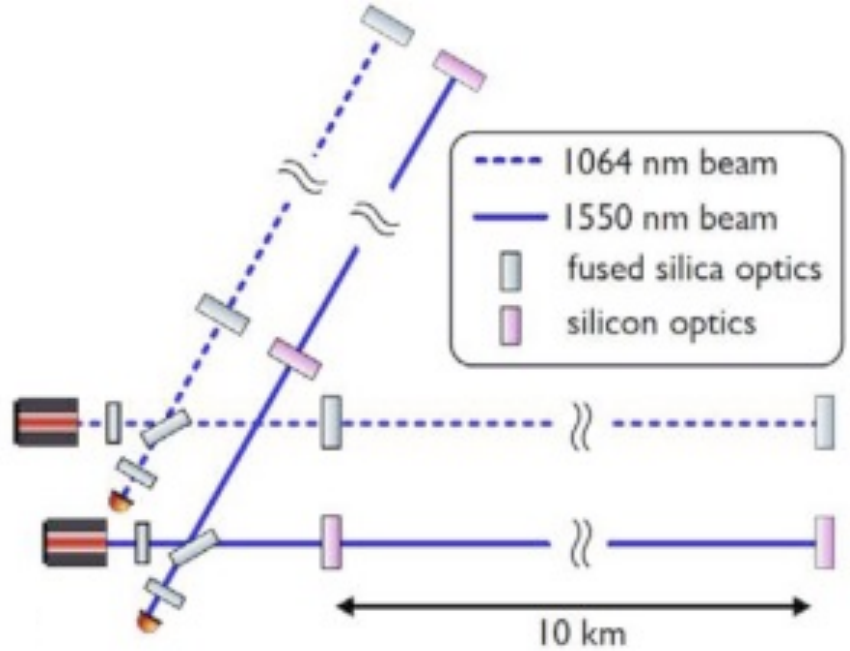
What's the Einstein Telescope (ET)

- **3rd generation GW observatory** Sensitivity aims at least one order of magnitude better with respect to the nominal sensitivity of advanced detectors in all the detection frequency band
- **Precision measurement and a new discovery project.** A wide frequency band observatory
- **Special focus on massive (or intermediate mass) black holes.** Extraordinary sensitivity at low frequency (few Hz)
- **High reliability.** High observation duty cycle
- **Lifetime of several decades,** (50 years in the ET proposal). Capable to host the evolution of the detectors, without limiting their sensitivity

ET Design: key elements

Requirements	Design Specifications
• Wide frequency range • Massive black holes (LF focus) • Localisation capability • (more) Uniform sky coverage • Polarisation disentanglement • High Reliability (high duty cycle) • High SNR	• Xylophone (multi-interferometer) Design • Underground • Cryogenic • Triangular shape • Multi-detector design • Longer arms

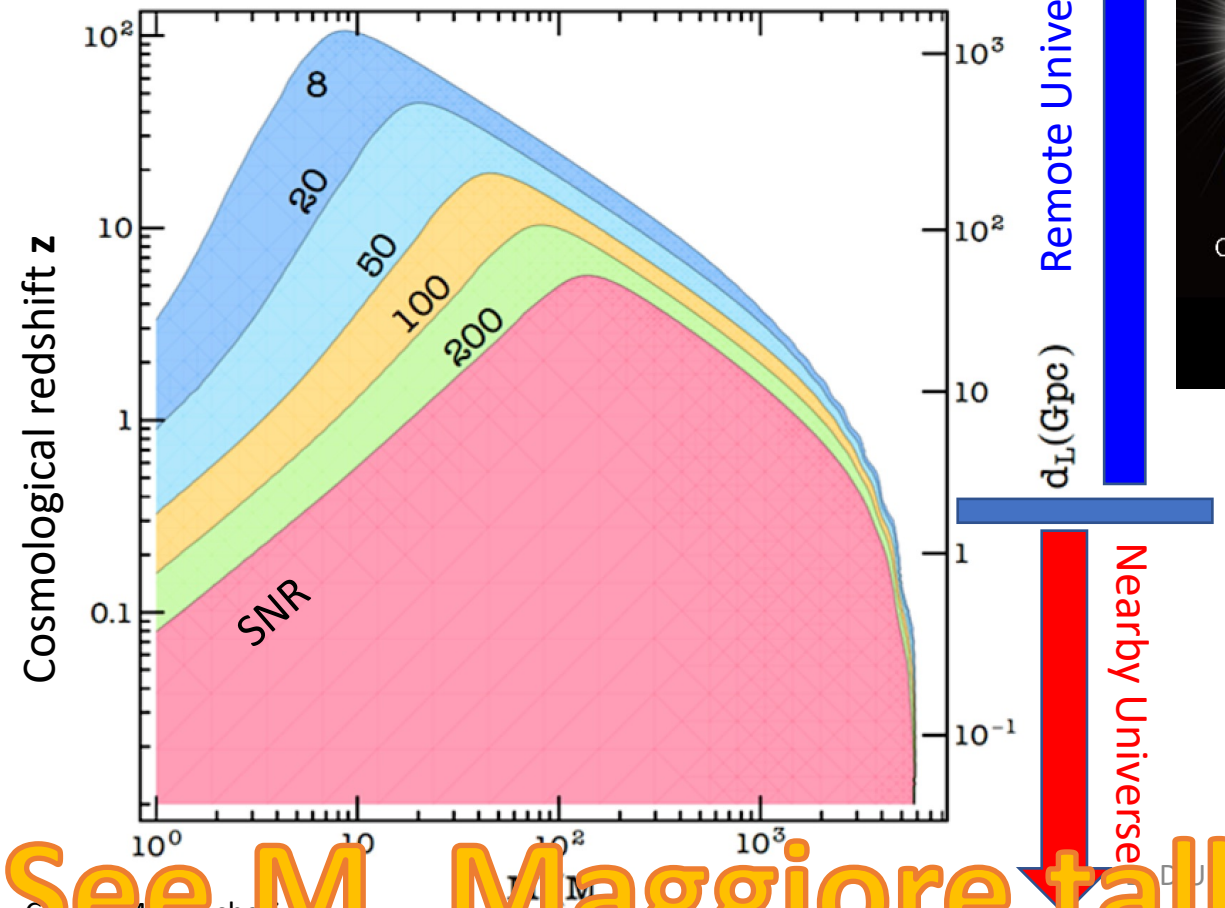


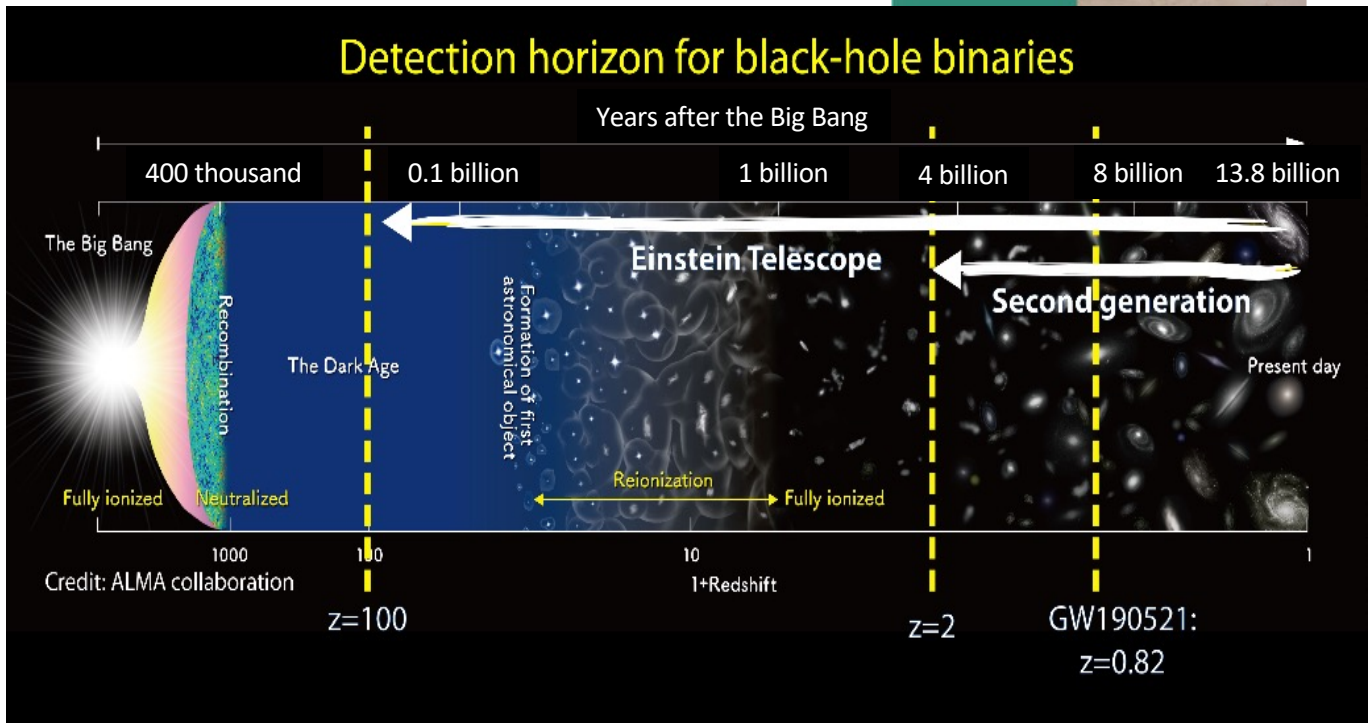


See M. Punturo talk

ET Science in a nutshell: double nature

- ET will be a new discovery machine:
  - ET will explore almost the entire Universe listening the gravitational waves emitted by black hole, back to the dark ages after the Big Bang



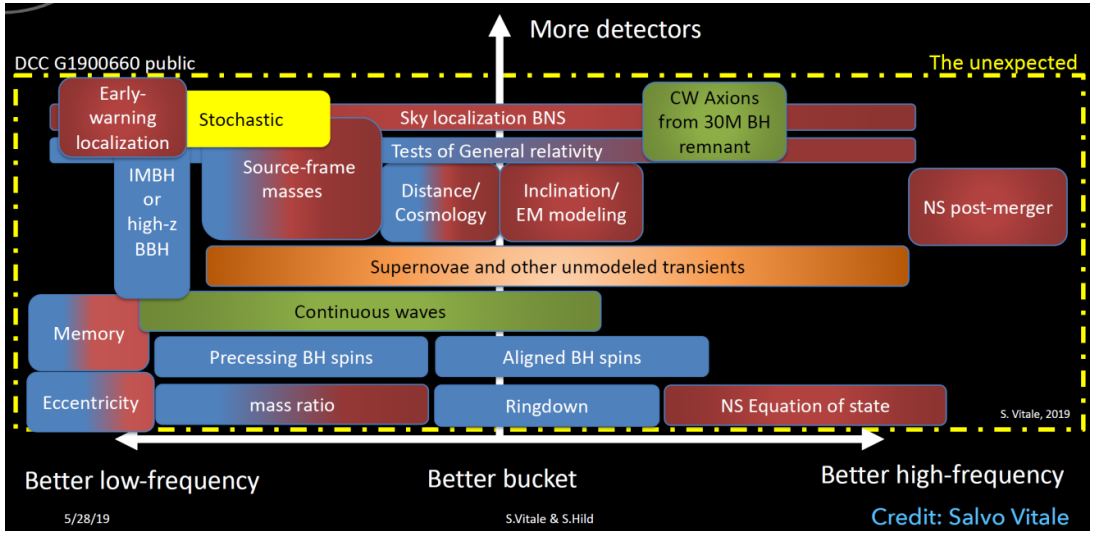


- ET will be a precision measurement observatory:
  - ET will detect, with high SNR, hundreds of thousands coalescences of binary systems of Neutron Stars per year, revealing the most intimate structure of the nuclear matter in their nuclei

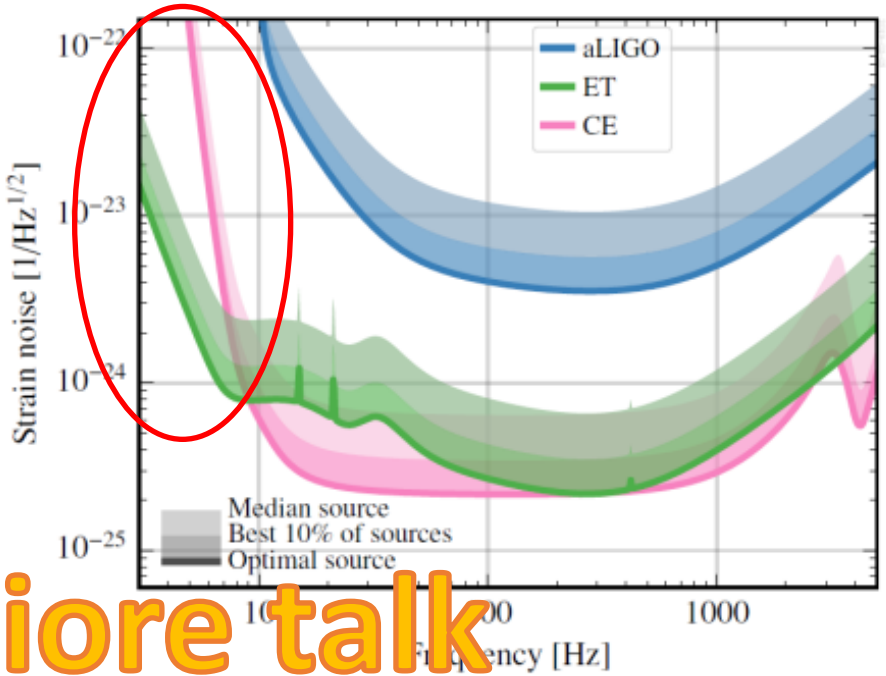
See M. Maggiore talk

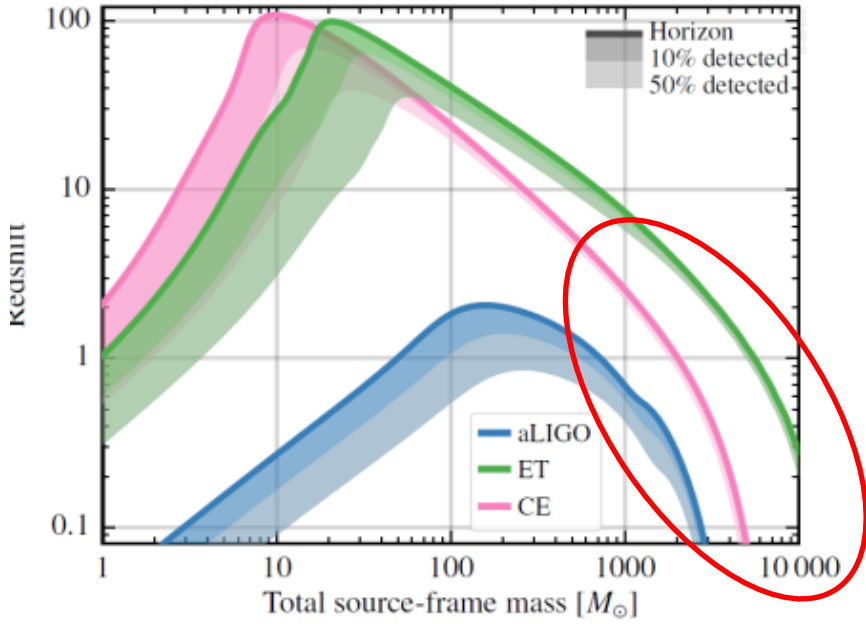
ET Science in a nutshell: double nature

- GW science targets are almost equally distributed in the frequency range accessible by terrestrial GW detectors
- We want to have access both to low and high frequency targets



- ET will be a wide band observatory with a special focus on (intermediate) massive compact object:
  - **Low frequency!**





See M. Maggiore talk

ET TECHNOLOGY (MAIN) CHALLENGES

Challenging engineering

New technology in cryo-cooling

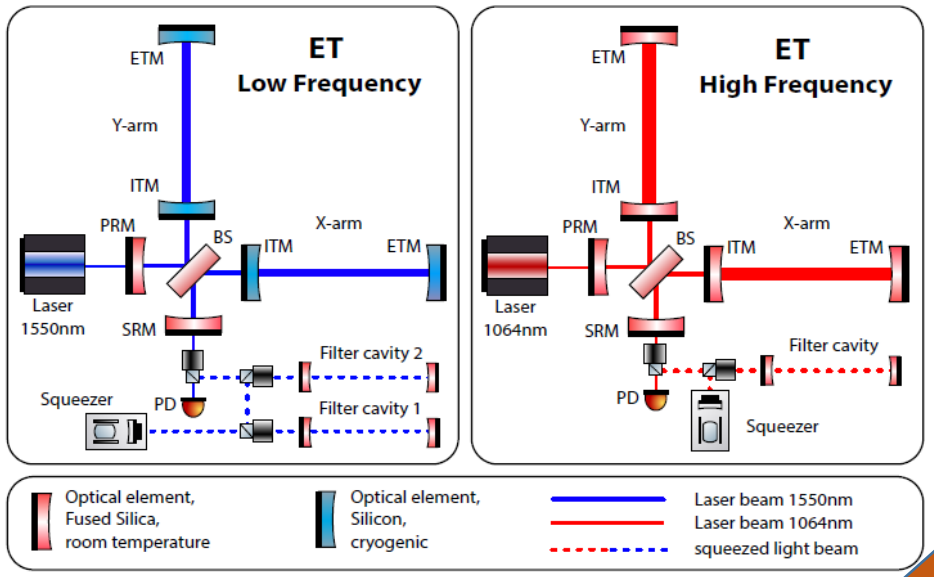
New technology in optics

New laser technology

High precision mechanics and low noise controls

High quality opto-electronics and new controls

- The multi-interferometer approach asks for **two parallel technology developments**
  - **ET-LF**
    - Underground
    - Cryogenics
    - Silicon (Sapphire) test masses
    - Large test masses
    - New coatings
    - New laser wavelength
    - Seismic suspensions
    - Frequency dependent squeezing
  - **ET-HF**
    - High power laser
    - Large test masses
    - New coatings
    - Thermal compensation
    - Frequency dependent squeezing



Evolved laser technology

Evolved technology in optics

Highly innovative adaptive optics

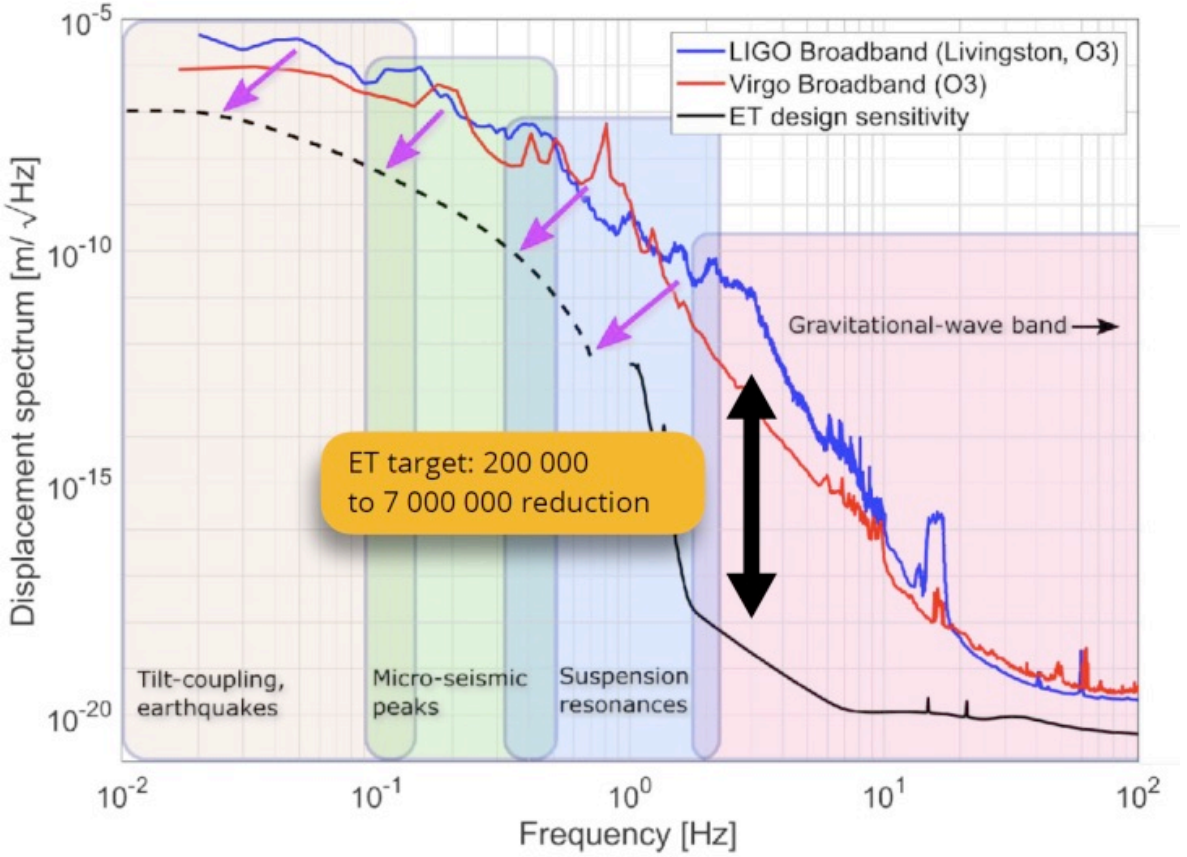
High quality opto-electronics and new controls

Low frequency GW detection and ET Site Characterization

Focus at low frequencies

- LF noise is given by
  - Microseism motion
  - Newtonian noise
  - Thermal noise
  - Upconversion of residual motion into the detection band
  - Control noise
- Newtonian noise crossing:

2 x 10^{-22} $Hz^{-1/2}$ at 1.8 Hz (AdV: 3.2 Hz)



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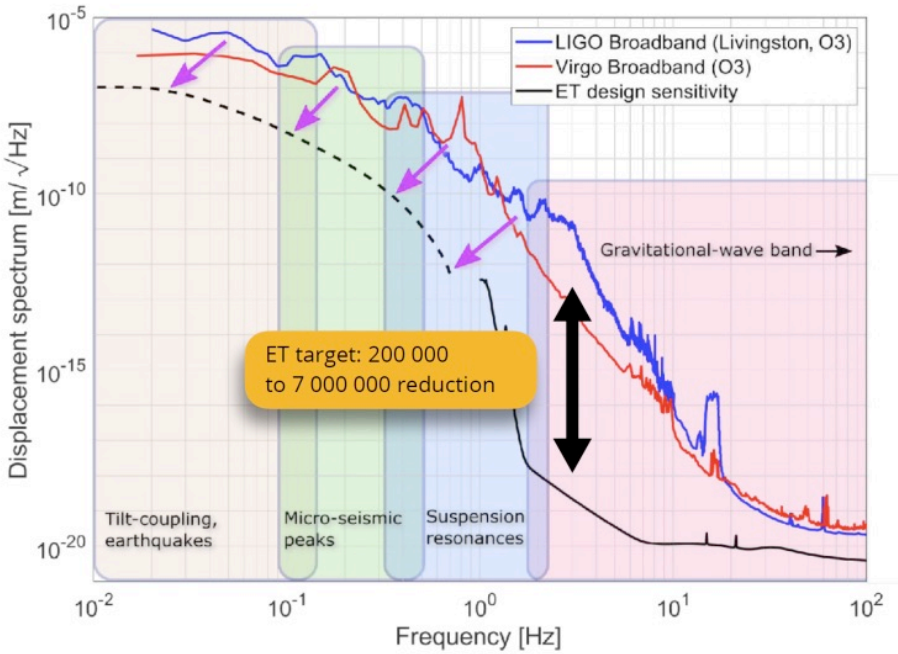
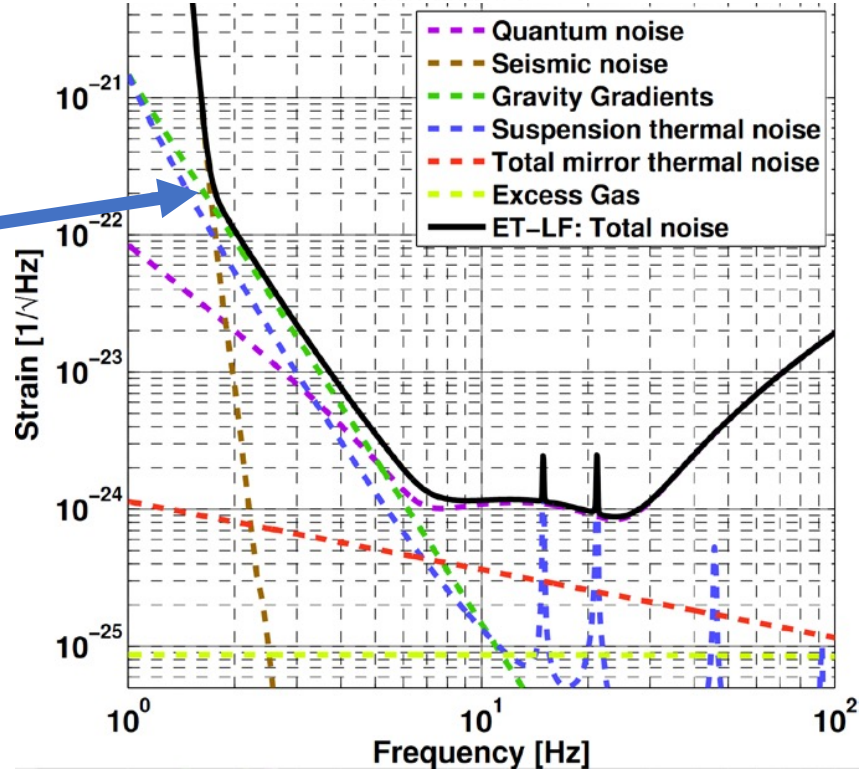
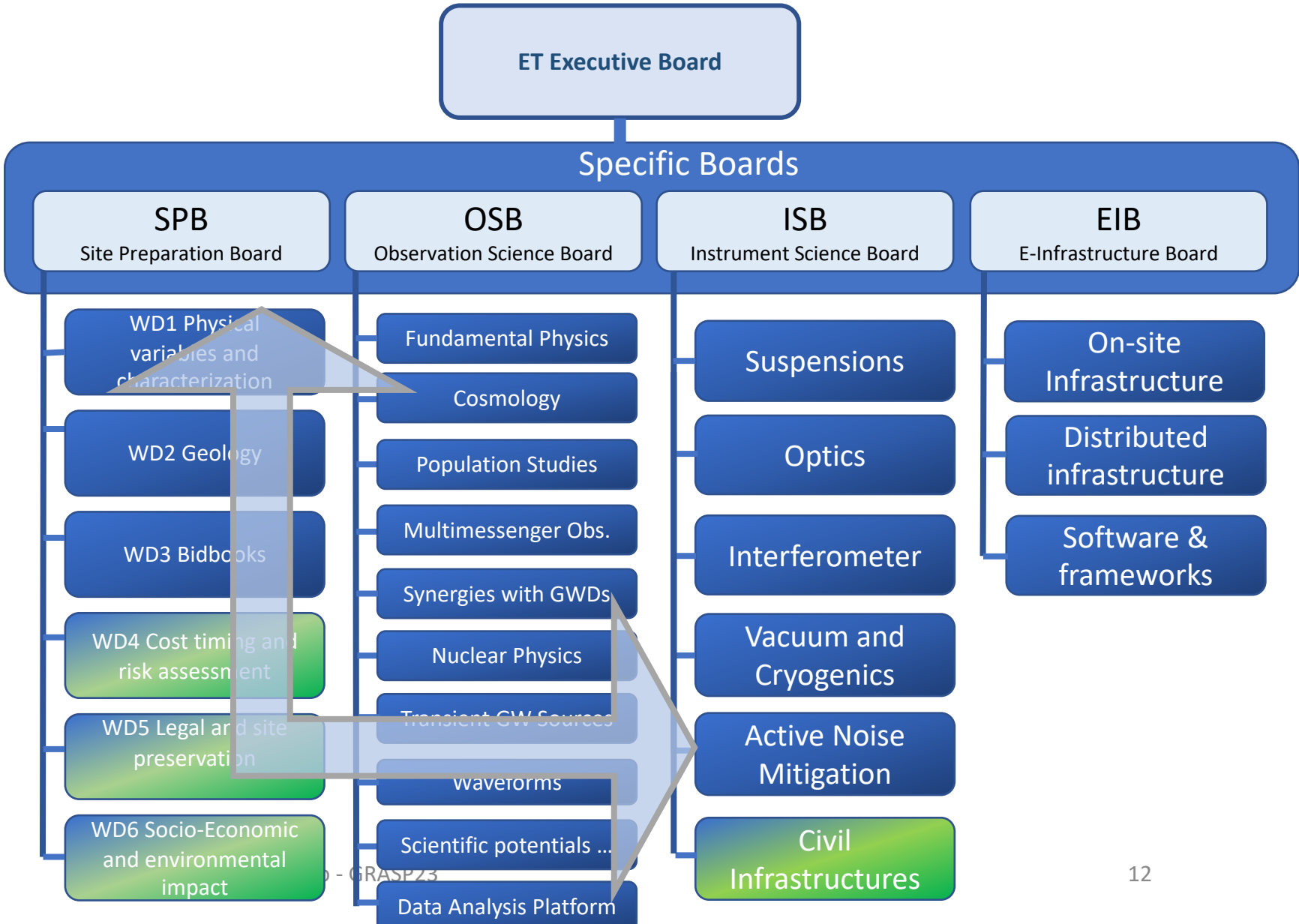




Site Characterization in the ET

- **SiteCharacterization** coordinated in the framework of the **ET Collaboration:** Site Preparation Board (SPB).
- Strong interaction with the Active Noise Mitigation division in the Instrument Science Board(ISB).



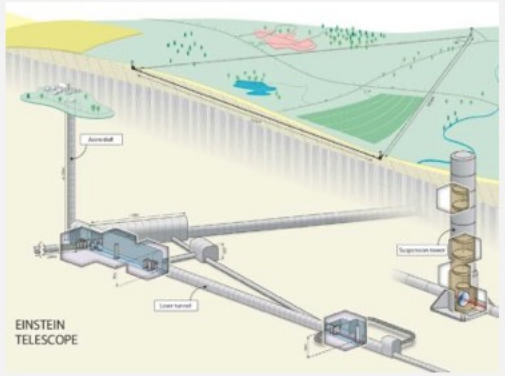
ET Candidate Site

ET site(s)

- Currently there are two sites, in Europe, candidate to host ET:
  - The Sardinia site, close to the Sos Enattos mine
  - The EU Regio Rhine-Meusse site, close to the NL-B-D border
- A third option in Saxony (Germany) is under discussion
- **Site Characterization** is crucial. Environmental noise may strongly limit detector performance (in particular in the LF band): seismic (and Newtonian), magnetic, acoustic noise.
- Overall site evaluation is a complex task depending on:
  - Geophysical and environmental quality
  - Financial and organization aspects
  - Services, infrastructures

Support for EMR Candidature

- Taskforce Belgium, Germany and the Netherlands
- Ecosystem is strengthening. Maastricht as home-base for Project Office
- Strong political and social support, increased focus on education High tech industry and top academia nearby
- Ban on windturbines



5 December 2022

Flanders invests in preparation Einstein Telescope

13 December 2022

Taskforce from Belgium, Germany and the Netherlands strengthens candidacy for Einstein Telescope

16 February 2023

Unanimous support for Einstein Telescope from Belgian ministers for science

Support for Sardinia Candidature

- **10/02/2023:** The Minister of University and Research Bernini has appointed a scientific advisory board
- **21/03/2023:** Visit of Anna Maria Bernini at SOS Enattos and SAR-GRAV Laboratory
- **9/5/2023**: CAGLIARI, Official presentation of Italian Candidature
- **6/06/2023**: Press conference in Roma for official governmental support

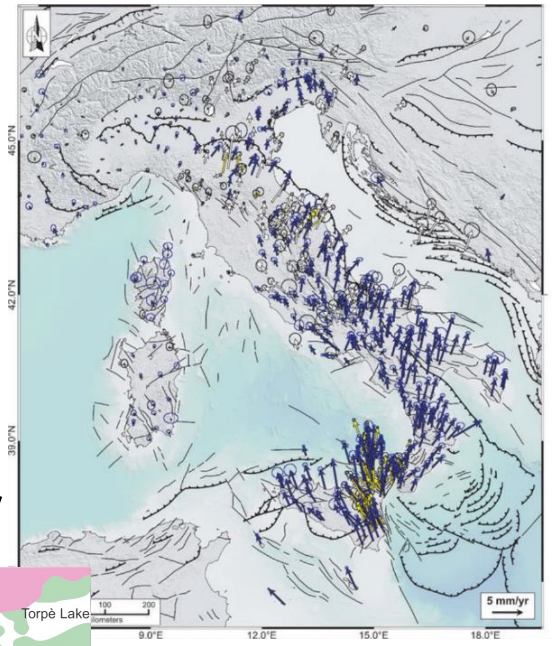
Sardinia the Italian candidate site

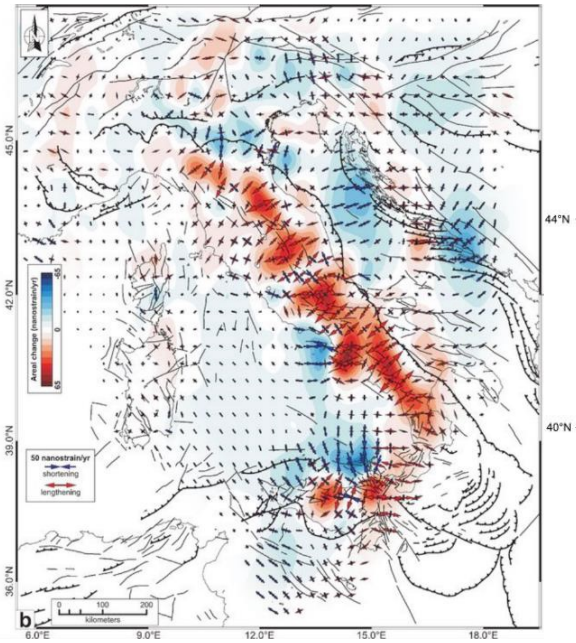
The Italian Site – Sos Enattos area

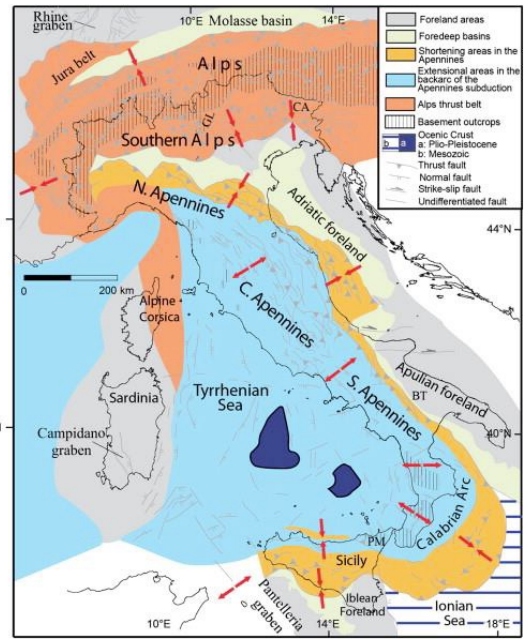
- Sos Enattos: former mine with underground access guaranteed through tunnels and shaft
- In the area of the mine, the SARGRAV laboratory, a seed of ET, aims to host underground experiments, cryogenic payloads, low frequency and cryogenic sensor development that need low seismic and anthropogenic noise

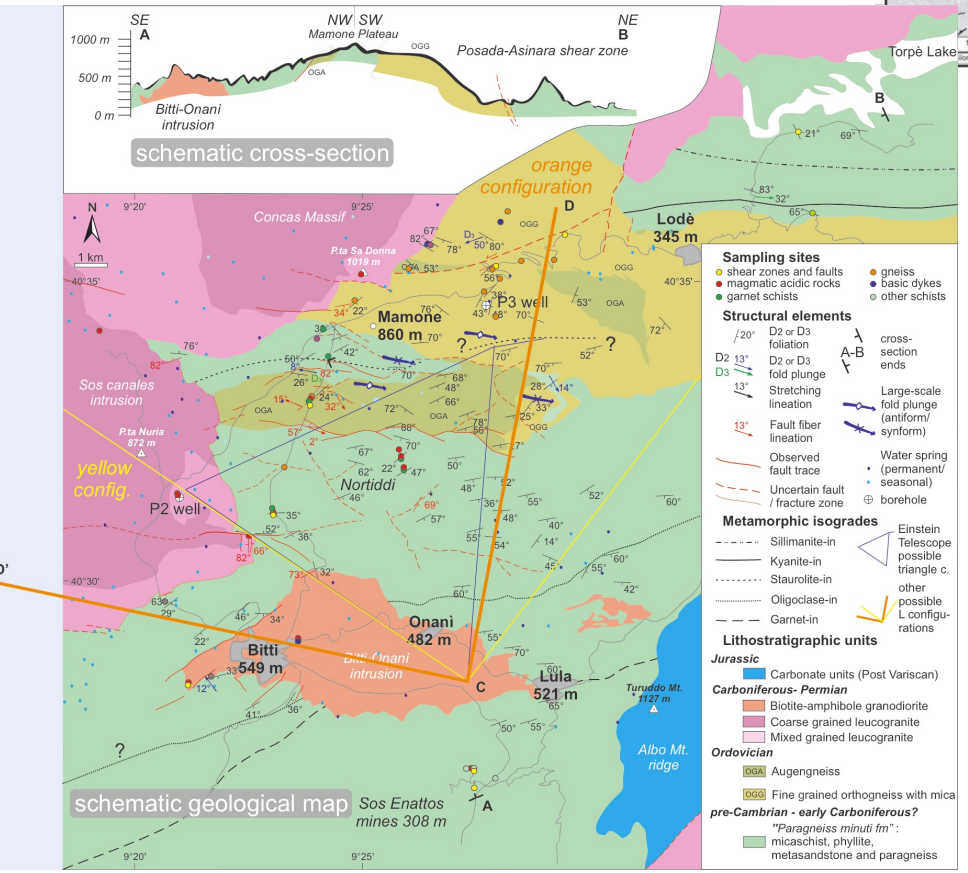
Geological framework

- Corsica-Sardinia microplate is very stable → low crustal deformation
- No significative seismic activity

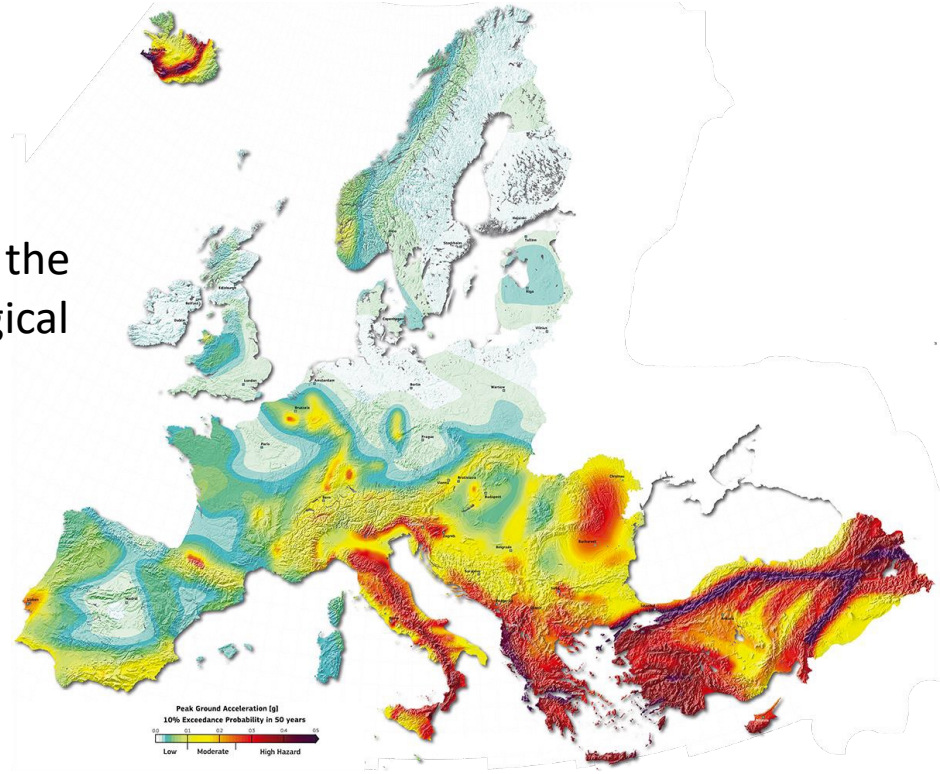






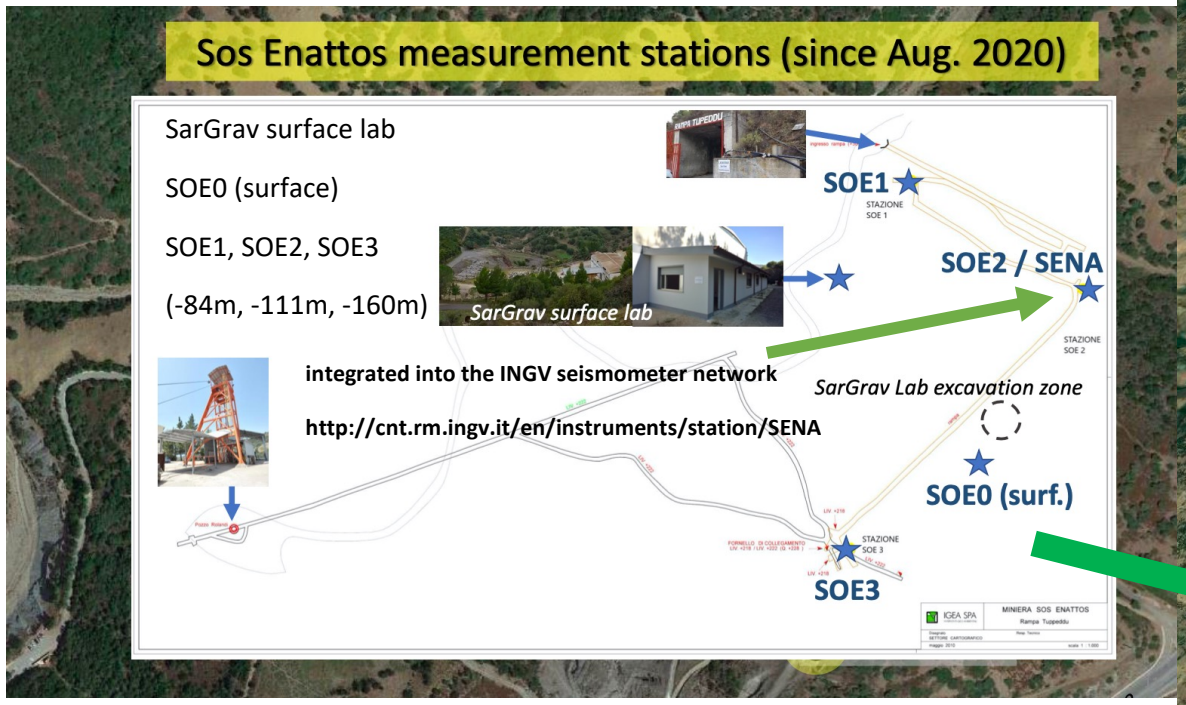


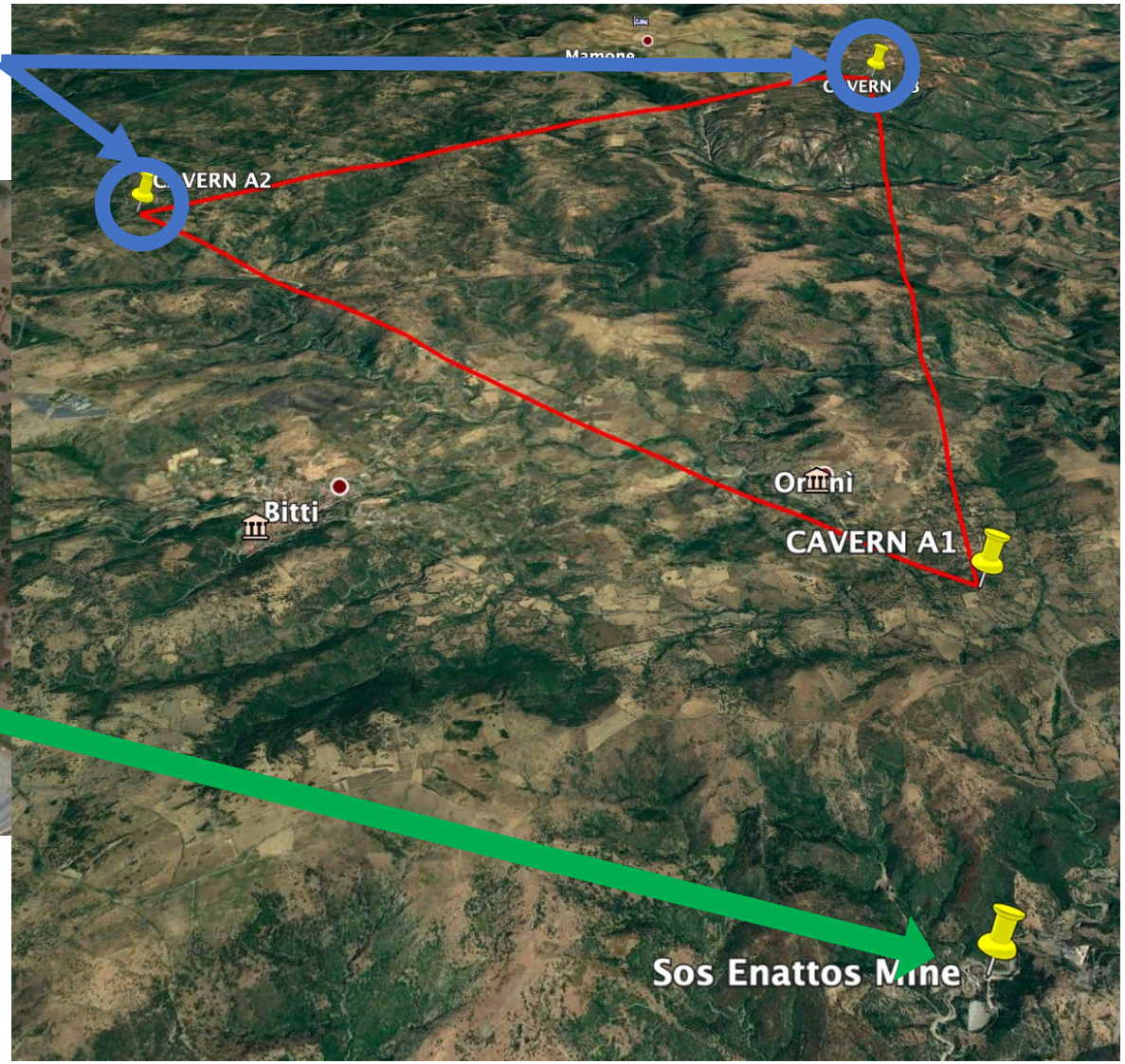
- Lithologies: Orthogneiss, granitoids, micaschists.
- On going geological survey of the area and review of the geological maps.



Measurement in Sardinia

Characterization of the Bitti and Onanì corners:
Surface and underground seismic and environmental measurements



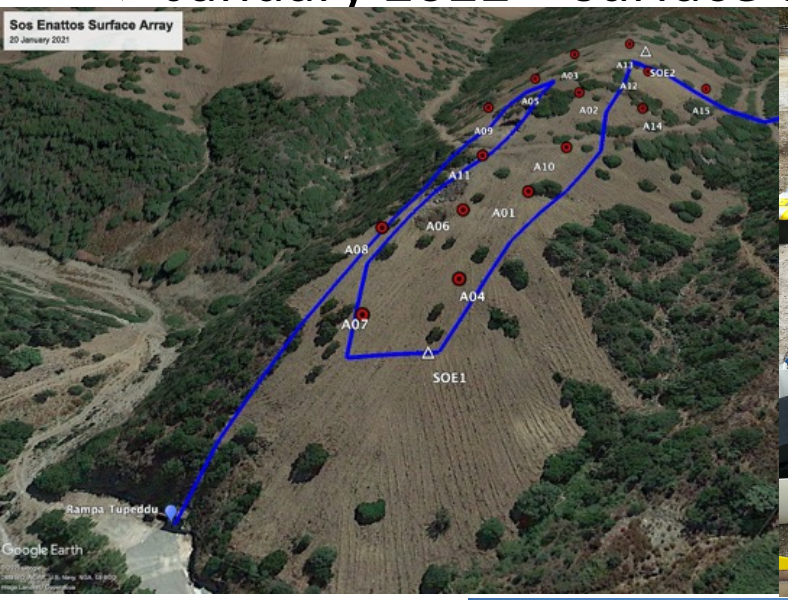


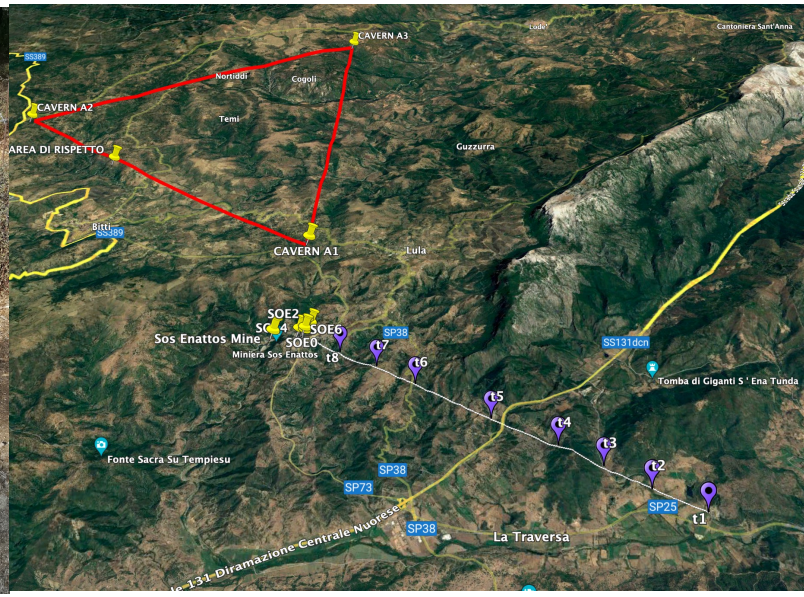
Sos Enattos Site Monitoring

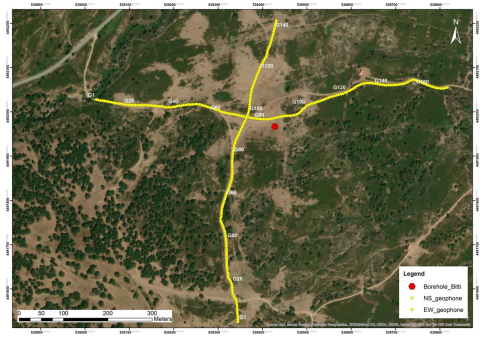
- **Sos Enattos stations**
  - **SarGrav surface Lab+ Control Room**;
  - **SOE0**(surface);
  - **SOE1**, **SOE2**, **SOE3**(-86m, -111m, -160m underground).
- **Sensors currently installed**:
  - 5 broadband triaxial seismometers (*NanometricsTrillium 360, 240, Guralp360 CMG-3TD*);
  - 3 magnetometers (*MF6-06*, N-S at surface, N-S & E-W underground);
  - Several infrasound microphones and microbarometers(surface & underground);
  - 8 short-period triaxial seismometers (*NanometricsTrillium 20PH,* movable array);
  - High Precision Tiltmeter (part of the *Archimedes*experiment @ SarGrav);
  - Weather station (@ SarGravLab).

Measurement campaigns

- January-February 2021 - at Sos Enattos: 15 seismometers
- September-October 2021 - at P2 and P3: 23 seismometers + 40 geophones + optical fiber strainmeter + 1 borehole T120 + 1 posthole T120
- January 2022 – surface campaign during cave explosion: 8 seismometers



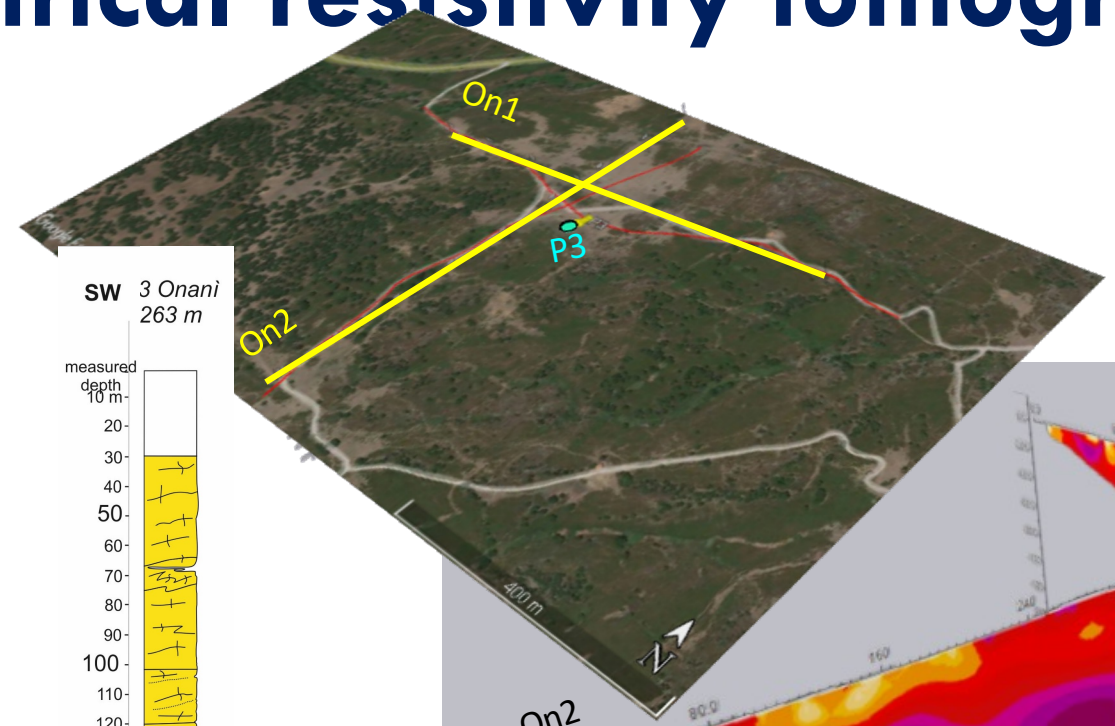


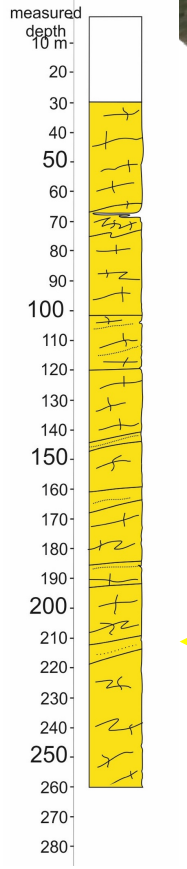


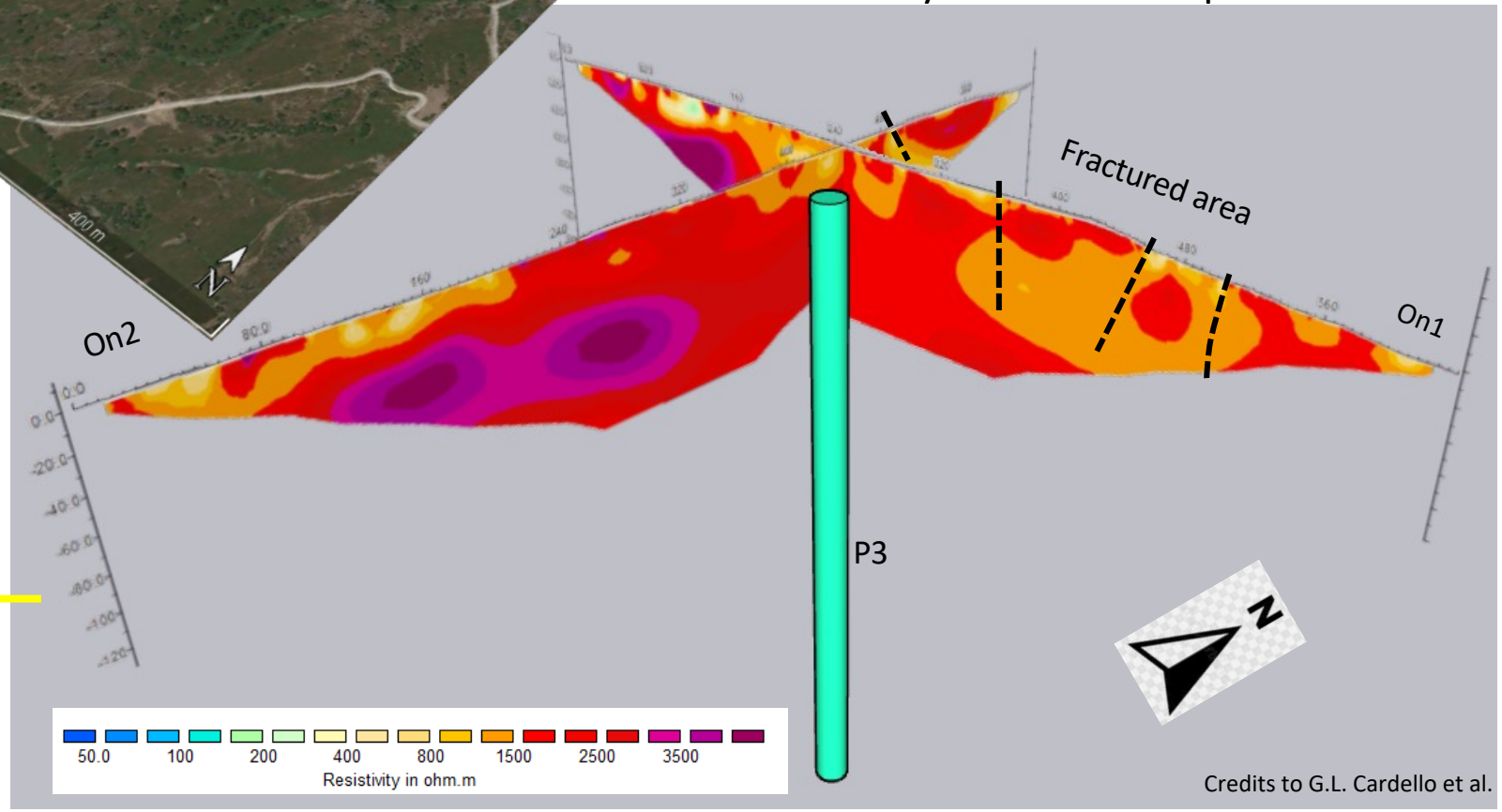
Electrical resistivity tomography

conductive layer occurs either as:

- a discontinuous and well-localized layer near the surface (up to 20 m thick)
- a broader anomaly zone of values around 1000 Ωm that locally occurs at a depth of 30-90 meters.





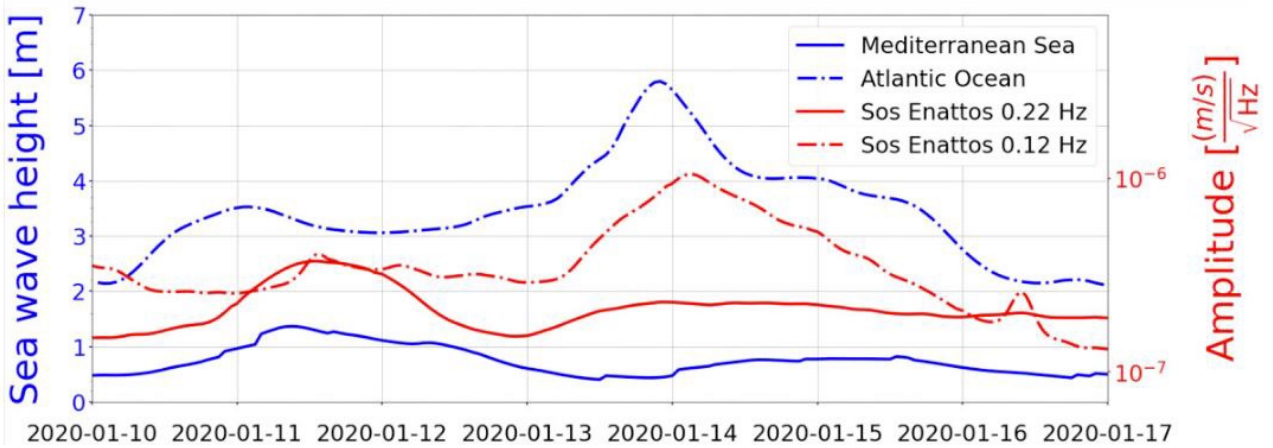


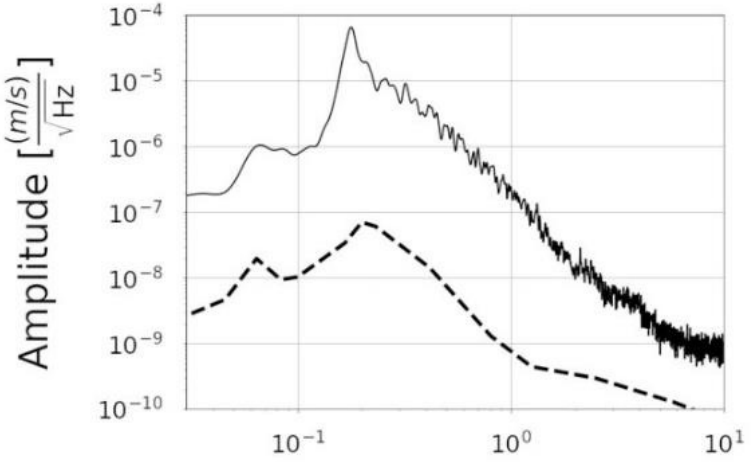
Published results

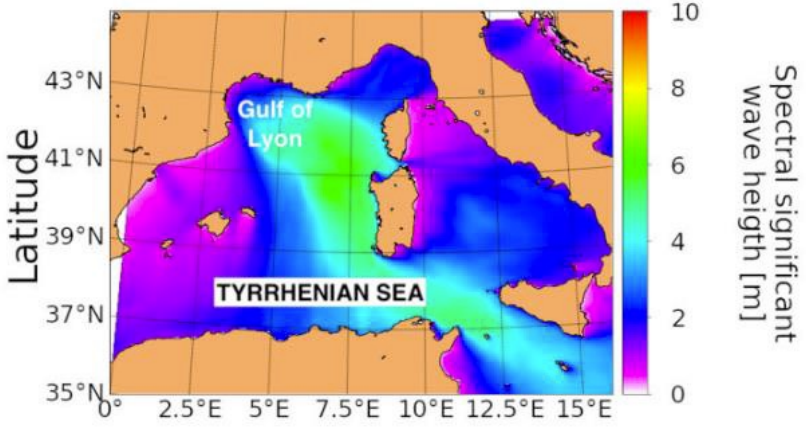
- L. Naticchioni et al., Microseismic studies of an underground site for a new interferometric gravitational wave detector, CQG, 2014, https://doi.org/10.1088/0264-9381/31/10/105016
- L. Naticchioni et al., Characterization of the Sos Enattos site for the Einstein Telescope, JPCS1468, 2020, https://doi.org/10.1088/1742-6596/1468/1/012242
- 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, Eur. Phys. J.Plus, 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**, *Eur. Phys. J. Plus***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, Geophysical Journal International, 2023, https://doi.org/10.1093/gji/ggad178
- G.Saccorotti et al., Array analysis of seismic noise at the Sos Enattos mine, the Italiancan didate site for the Einstein Telescope, Eur. Phys. J.Plus, 2023, https://doi.org/10.1140/epjp/s13360-023-04395-2.
- L. Naticchioni et al., Results of the site characterization in Sardinia for the Einstein Telescope, PoS Proc. Sci., 2023,inpreparation

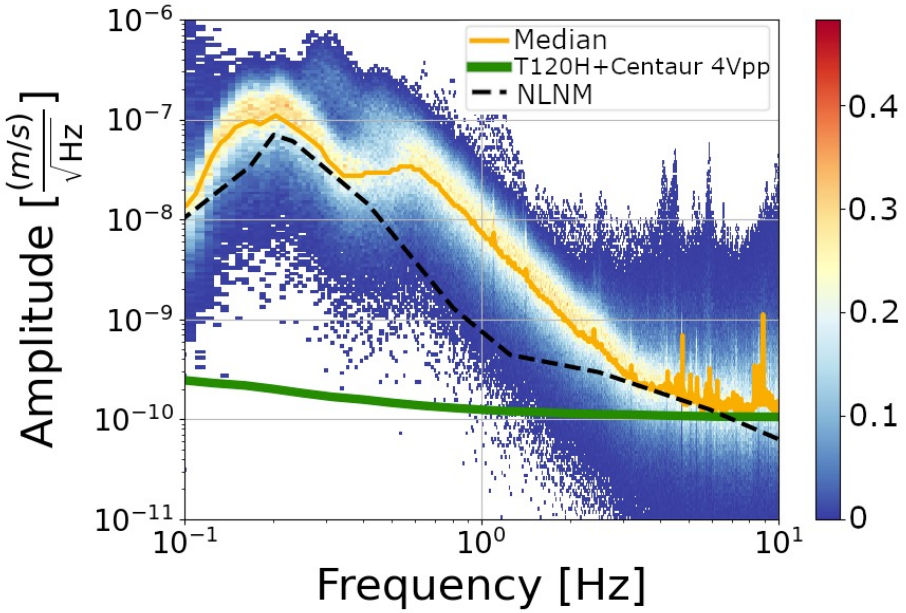
Sos Enattos seismic noise

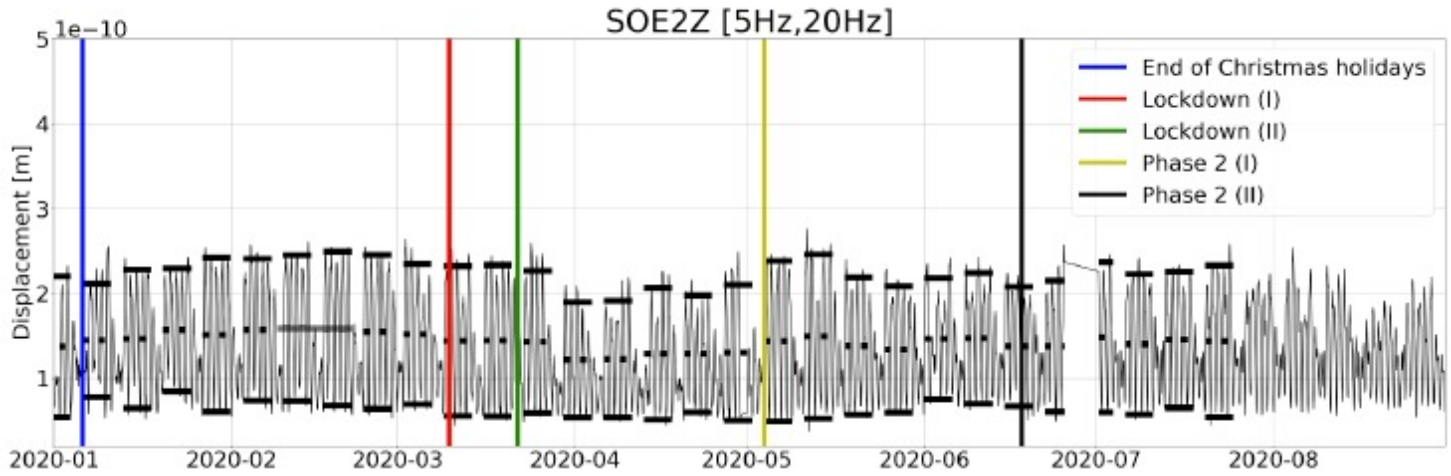
- In the microseismic band (0.05-1Hz) the main spectral feature at ~0.22Hz is produced by the waves in the Gulf of Lion (NW Mediterranean sea). Depends on weather conditions → seasonal pattern.
- At higher frequencies, anthropic noise pattern observed.







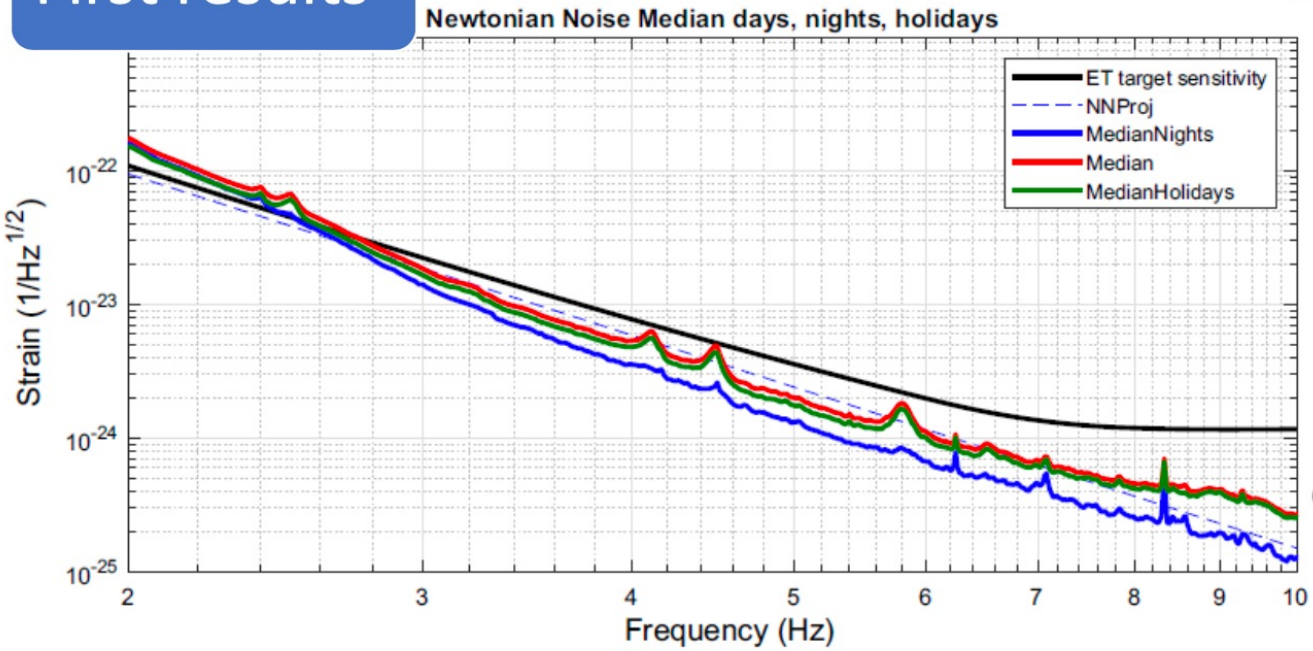




The Sos Enattos site

First 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)

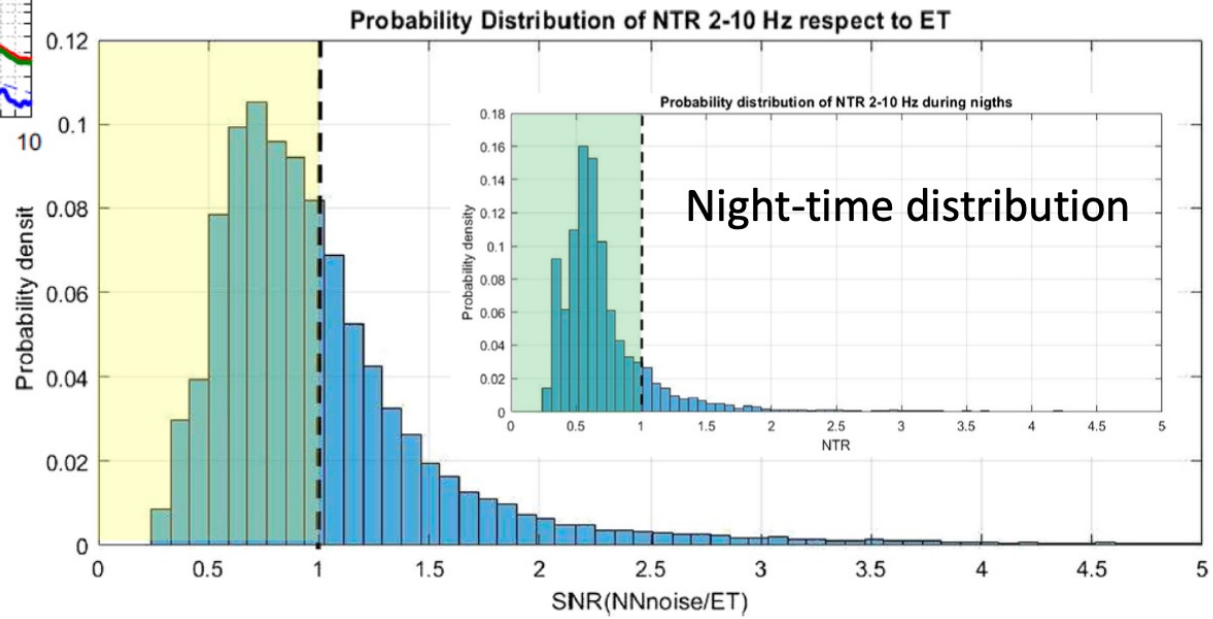
$$\mathrm{NTR} = \sqrt{\frac{1}{\Delta f} \int df \frac{\tilde{N} * \tilde{N}}{S_h}}$$

PSD of NN

PSD of ET sensitivity

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

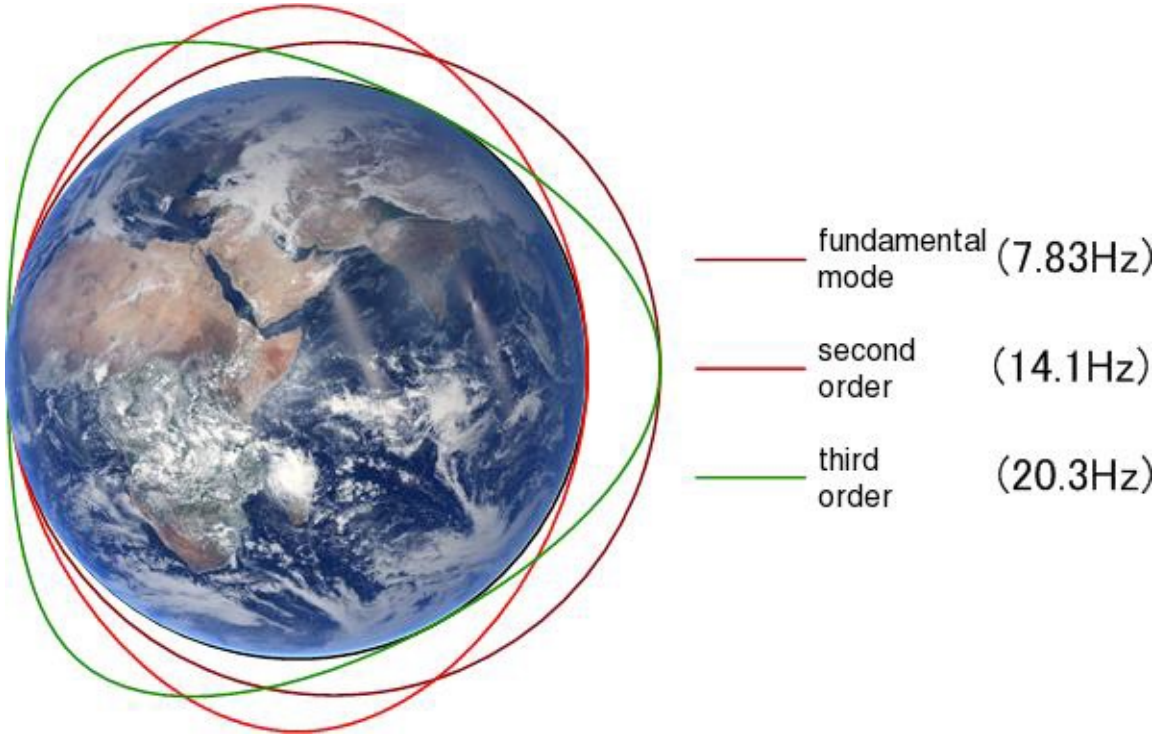
→Need for moderate NN subtraction only for a limited time



Credits to L. Naticchioni

Magnetic Noise

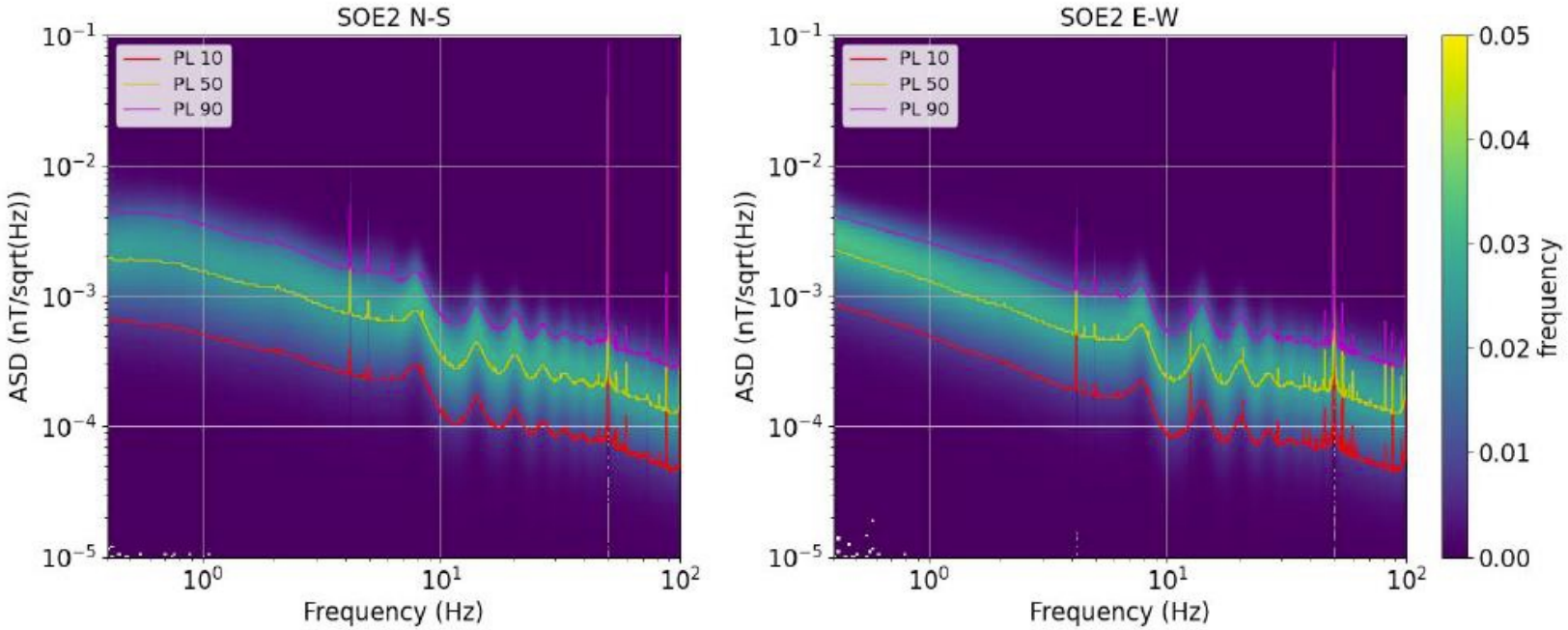
- In the band of interest of ET the main direct disturbances come from ULF (10^{-3}-3Hz), ELF (3- $3 \cdot 10^3$Hz) up to VLF (3-30 kHz) frequency bands.
- Main natural magnetic noise is in ULF and ELF, produced by resonance phenomena in the magnotosphere and/or in ionosphere cavities



- Most important mechanism in ET-LF:
  - ❑Geomagnetic pulsations Pc1 (0.2-5Hz);
  - ❑Schumann resonances (5-100Hz)

- Artificial LF sources in ELF

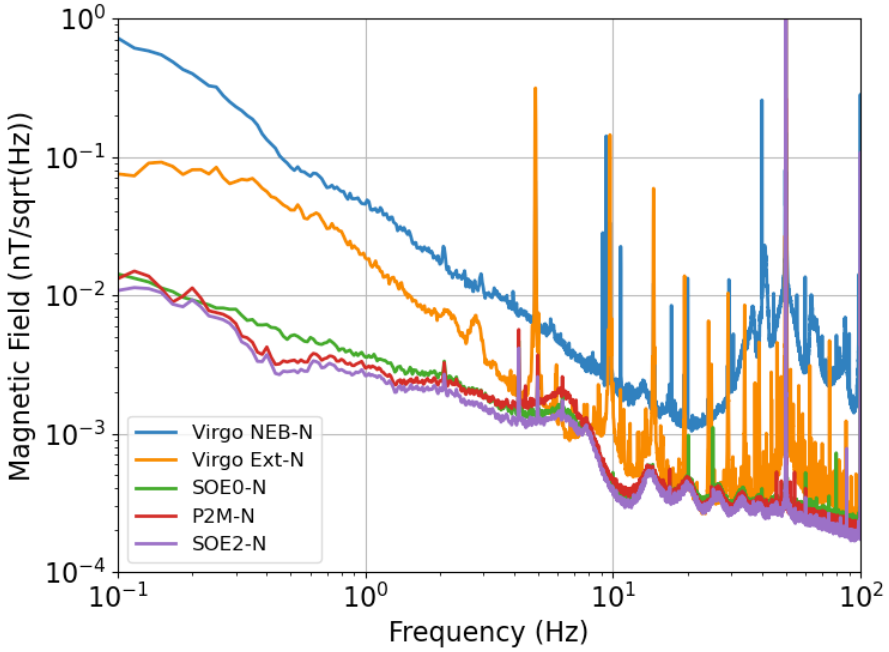
(e.g. 50-60Hz powerlines)

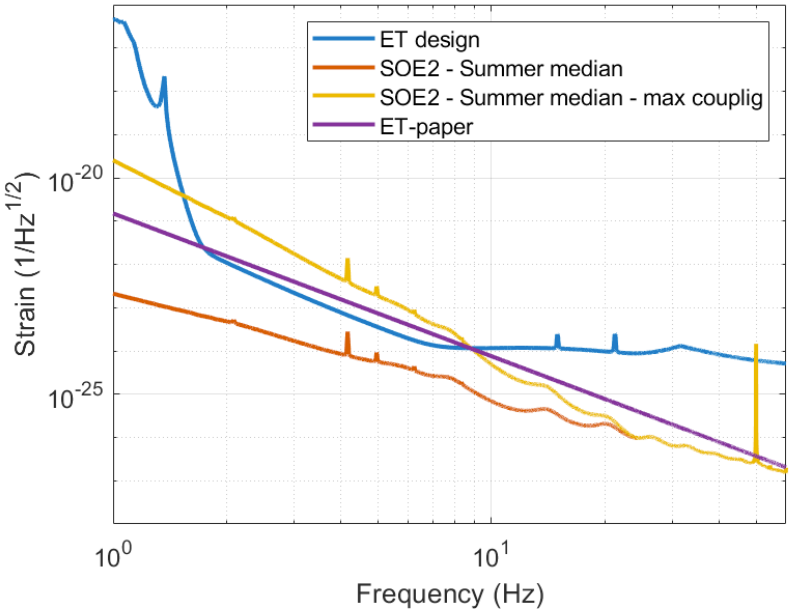


Credits to R. De Rosa

Magnetic noise

- The EM noise is strongly dependent on the location, mainly for the impact of the anthropogenic contribution
- From the on-site measurements it is possible to estimate a lower limit for the EM noise projection on the ET sensitivity.

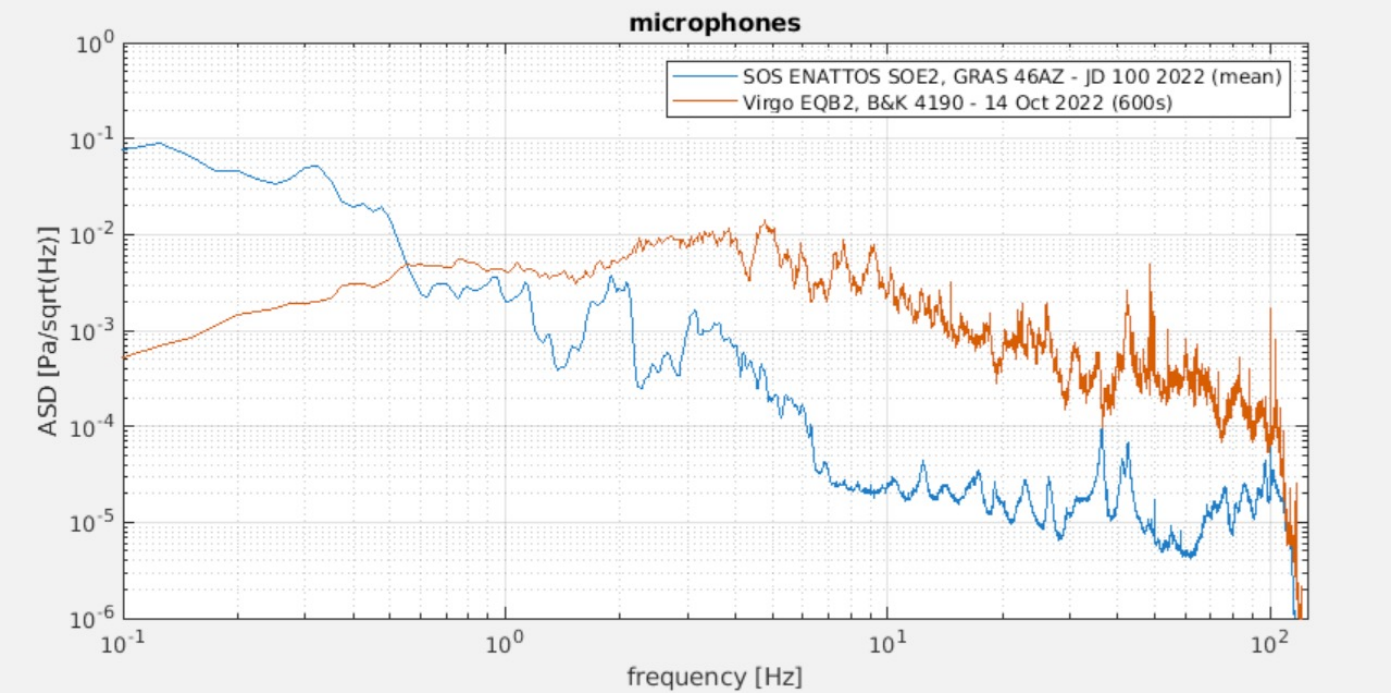




Credits to R. De Rosa

Acoustic noise

- 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.

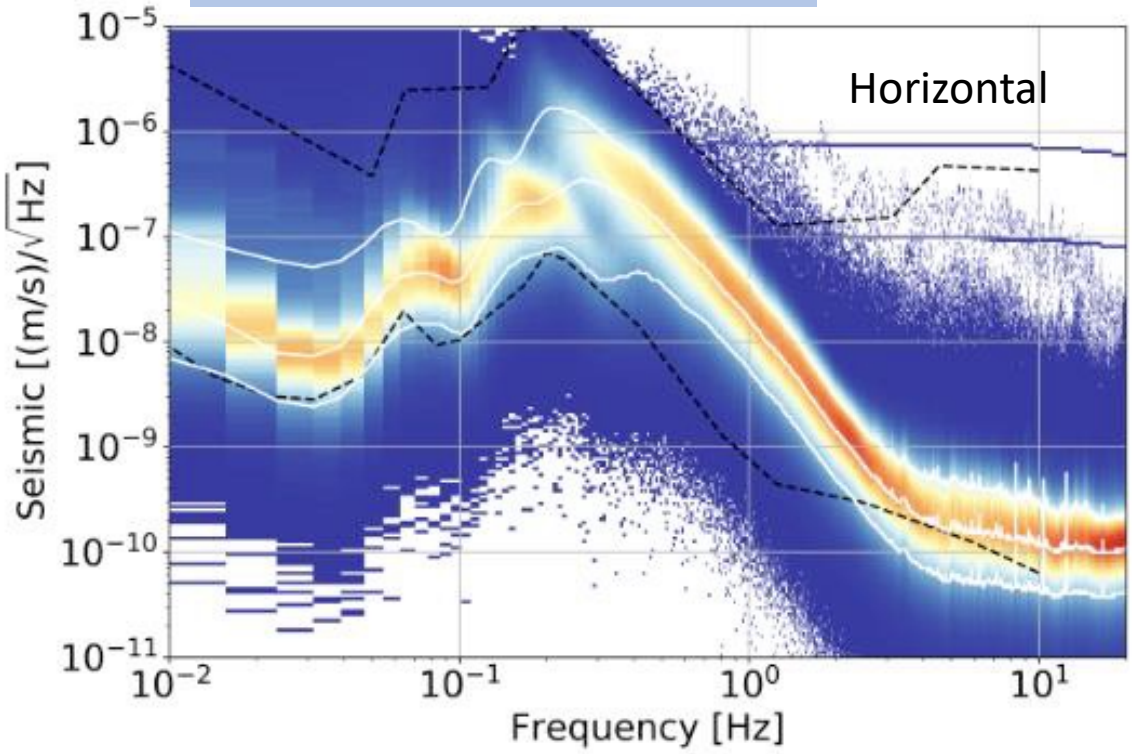


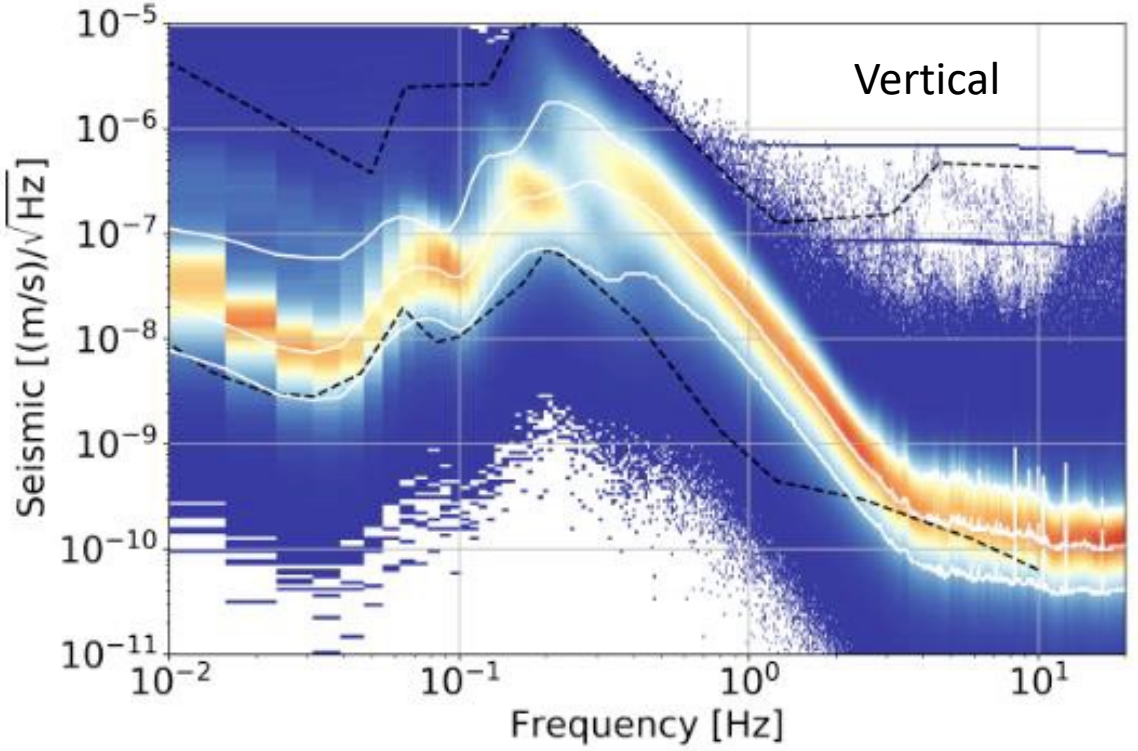
Credits to R. De Rosa

Borehole measurments

Preliminary results

PPSD - P2 borehole seismometer



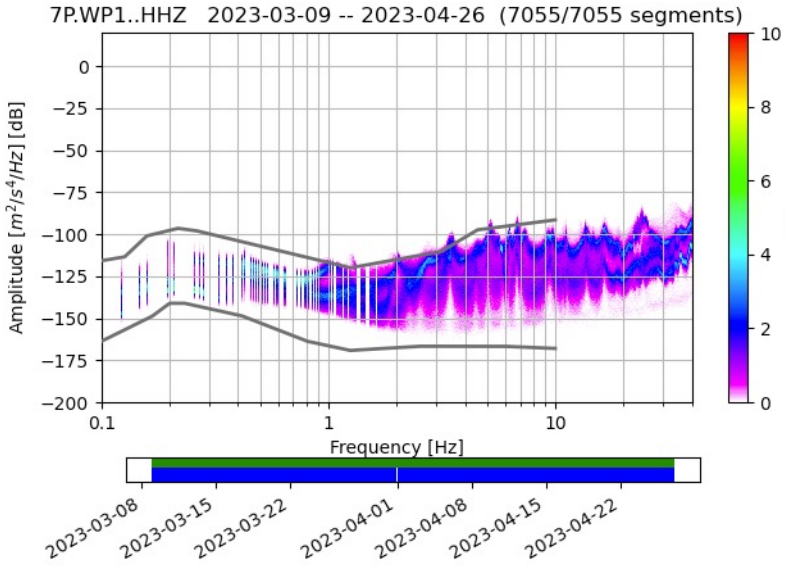


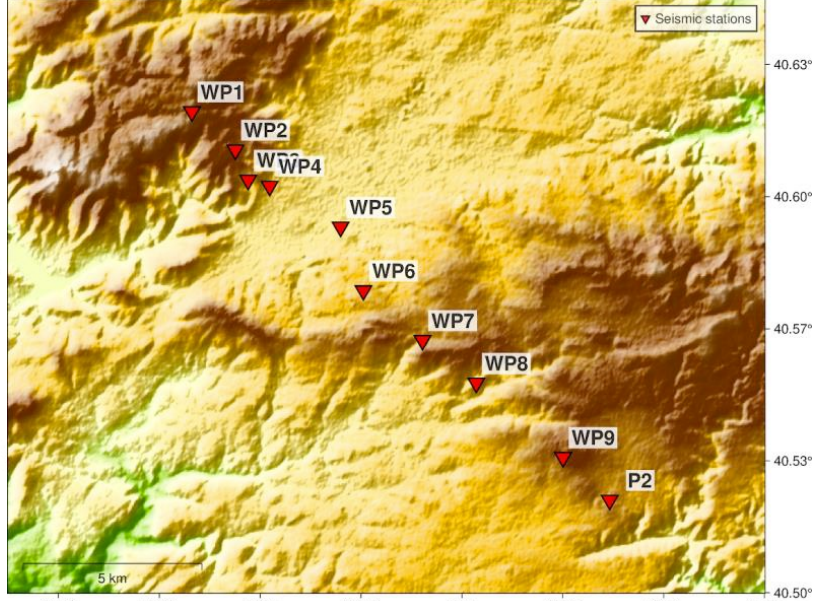
Very low noise background in the 2-10 Hz band, sometimes even **below** the Peterson's **New Low Noise Model**!

Credits to L. Naticchioni

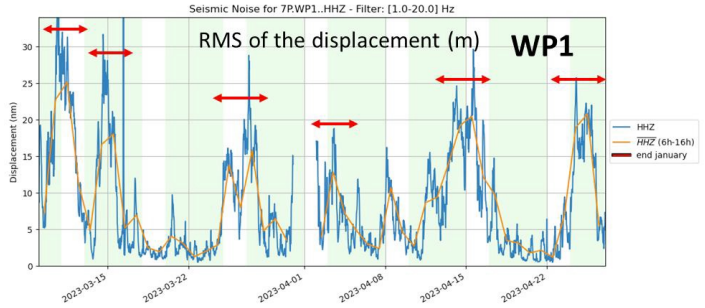
Site preservation: interaction with wind farm

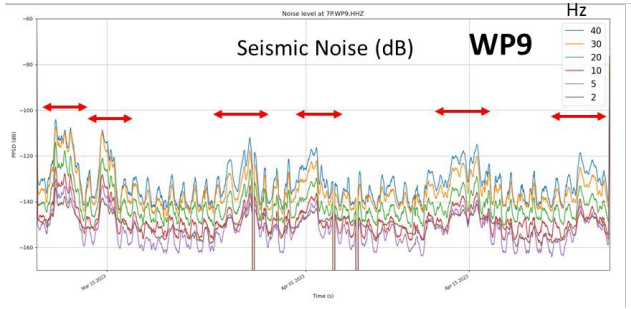
- Main peak at ~3Hz + harmonics close to the wind farm (WP1);
- Only main peak + first few harmonics close to P2, visible wrt to the low background (NLNM);
- Wind-correlated increase of noise rms;
- Analysis ongoing: spectral features and correlation with wind measured at weather stations close to the windfarm and with rotational speed of wind turbines.
- Goal: derive the attenuation function for a better definition of exclusion zones.

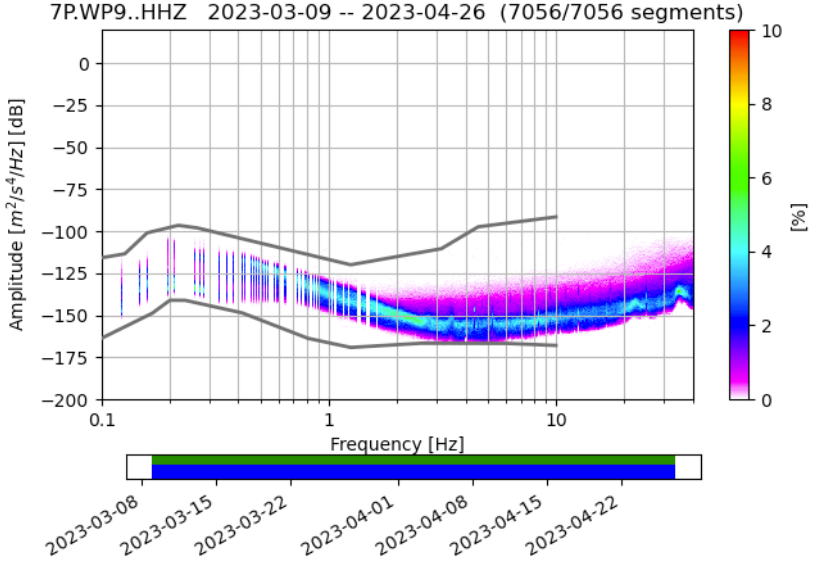




Preliminary results



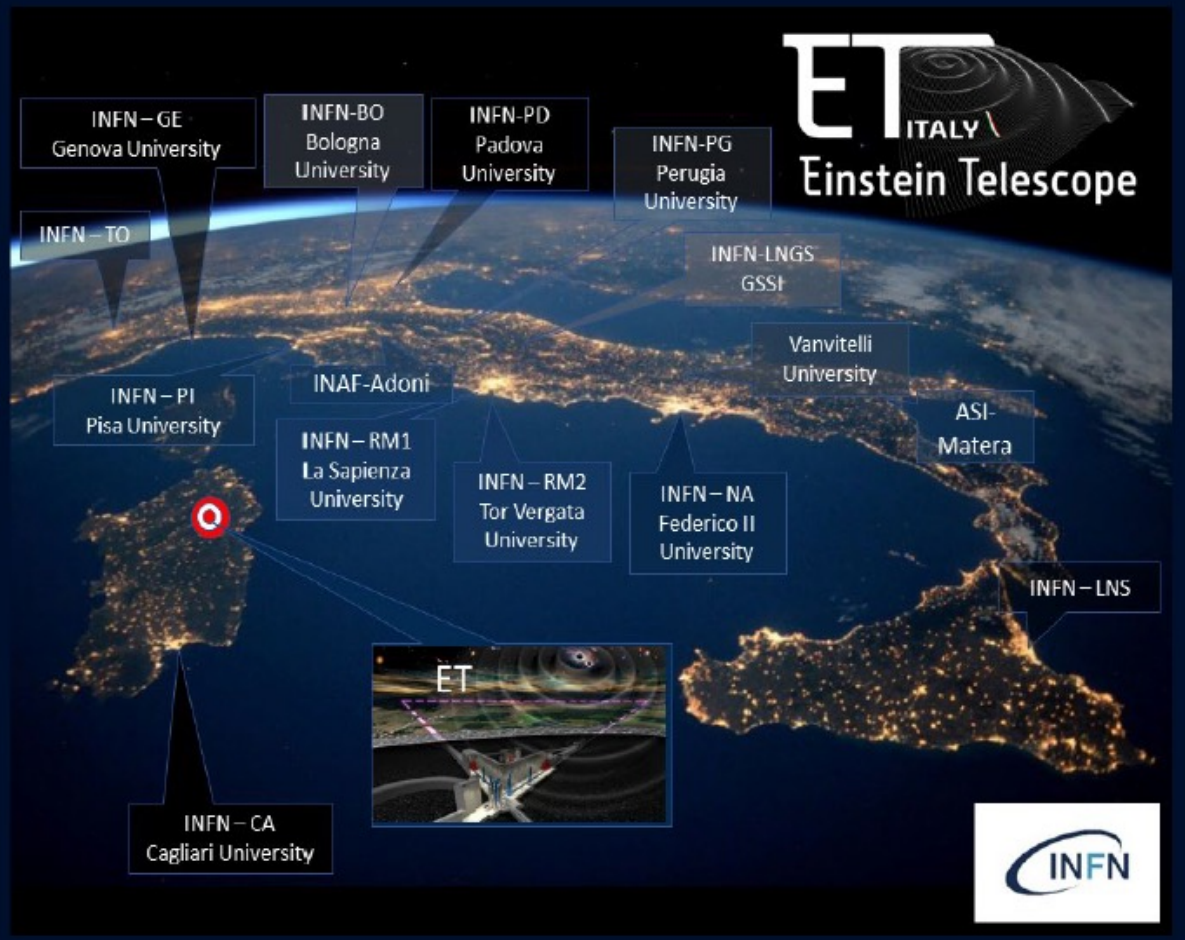




ETIC Project

- ETIC is a Project funded by the Italian Ministry for University and Research (MUR) with 50M€ for 30 (36) months within the PNRR (NRRP National Recovery and Resilience Plan)
- It started the 1st of January 2023
- ETIC is lead by INFN, it involves other 2 national research institutions:
  - INAF (Italian institute for Astrophysics)
  - ASI (Italian Space Agency)
- and 11 Italian universities for a total of 27 operating units (INFN and INAF Units, Department of physics, civil engineering, architecture)

ETIC Einstein Telescope Infrastructure Consortium

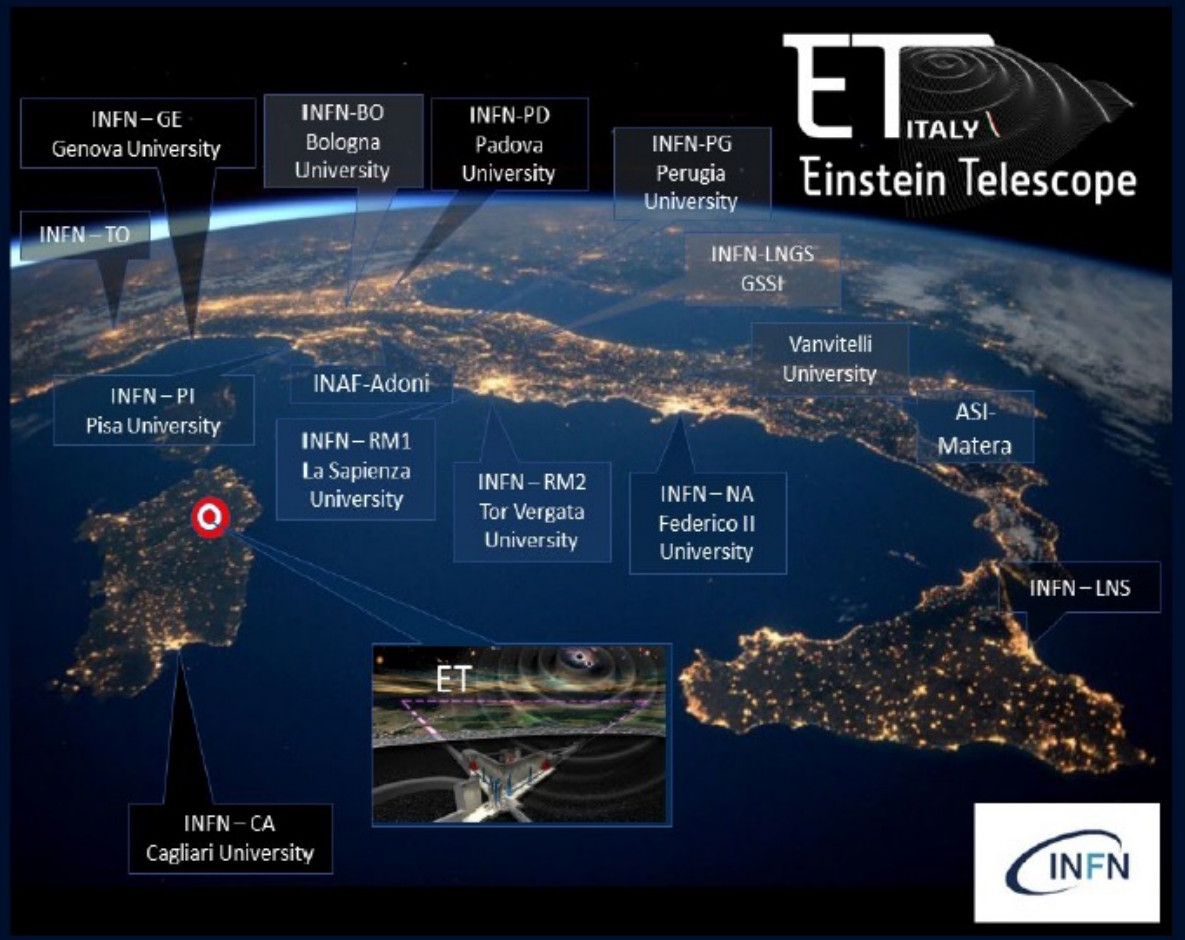


ETIC targets

https://web.infn.it/einsteintelescope/index.php/it/home-it-it/infrastrutture-e-labs

- The ETIC aim is twice:
  - Realize a network of research infrastructures located in the participating laboratories or universities addressed to the ET enabling technologies
  - Realize a feasibility study of ET in Sardinia, key element of the Italian bidbook, including geotechnical and engineering studies

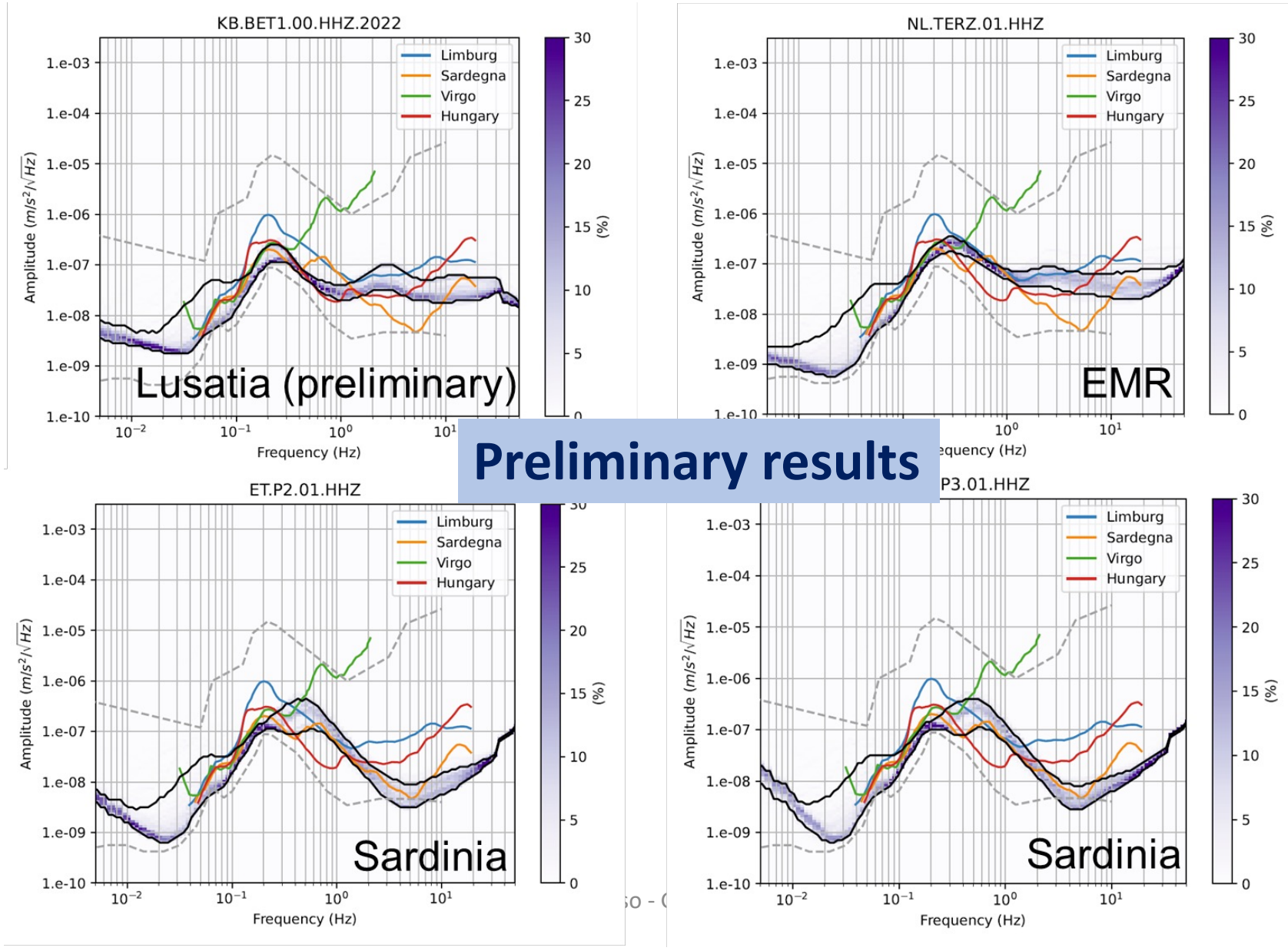
ETIC Einstein Telescope Infrastructure Consortium



Site comparison: Seismic noise

Site comparison: borehole measurements

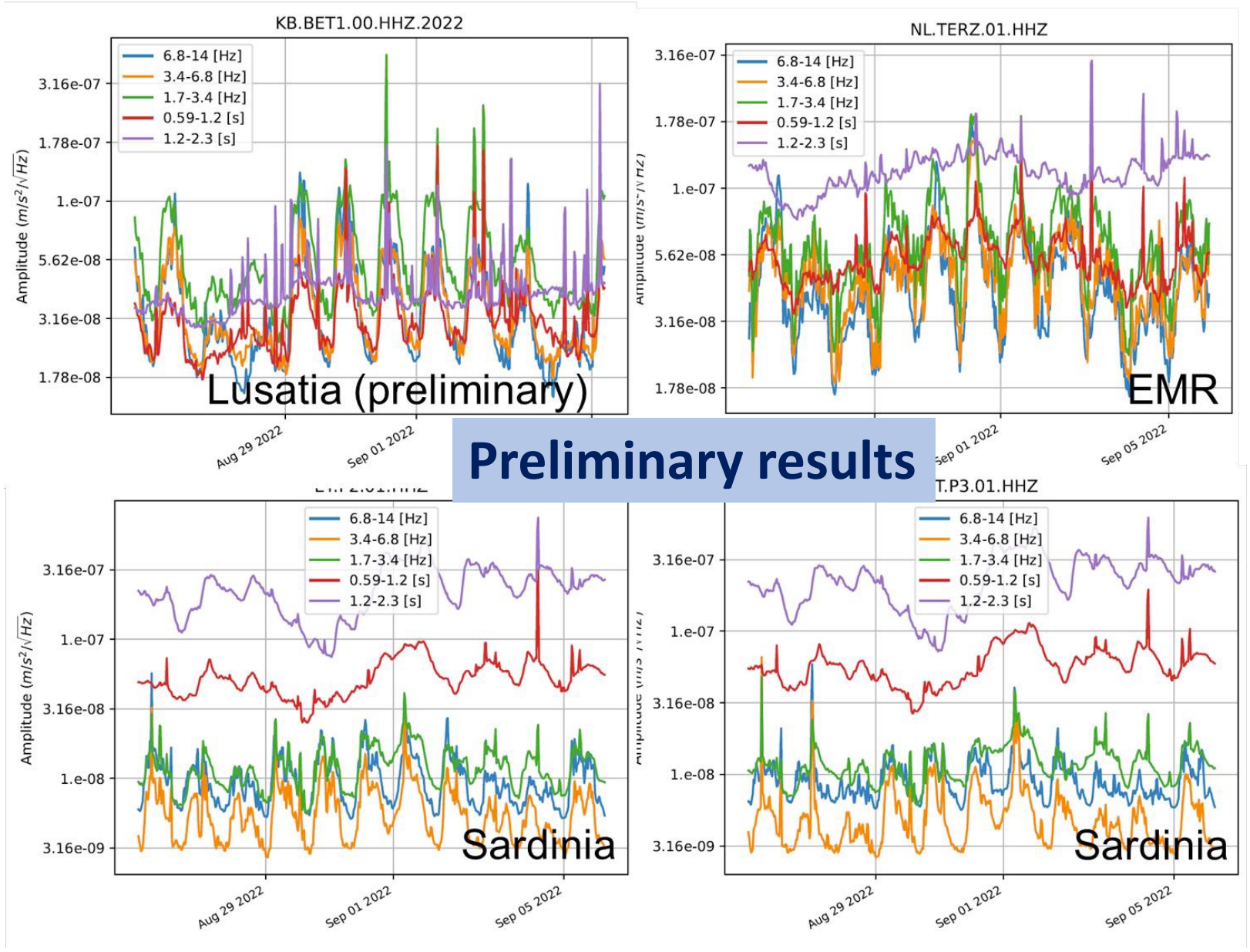
A. Rietbrock et al., ET-SPB Workshop 2023



Preliminary results

Site comparison: borehole measurements

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



Conclusions

- Einstein Telescope is a complex enterprise
- ET Collaboration has been just formed. Funding agencies and governments are setting up structures to manage the project
- Two official site candidates: EMR and Sardinia
  - Strong political support
  - Site characterization on going
- Sardinia geologically very quiet. Very low anthropic noise.
- Large array of permanent sensors deployed at the Sos Enattos mine where is working the SarGrav Laboratory.
- Two instrumented boreholes and magnetic stations at the two triangle corners
  - very low seismic noise in the ET-LF band, even below the Peterson limit
  - Newtonian noise compatible with ET sensitivity curve

Conclusions (2)

- Low electromagnetic noise
- Acoustic noise measurement on going
- Local noise sources under study
  - local activities
  - wind farm
- Call for tender for a feasibility study of ET in Sardinia (triangle and L configuration)
- From the geological and physical (and political) point of view Sardinia is an optimal candidate to become the home of the Einstein Telescope


Thanks
for your attention!!!