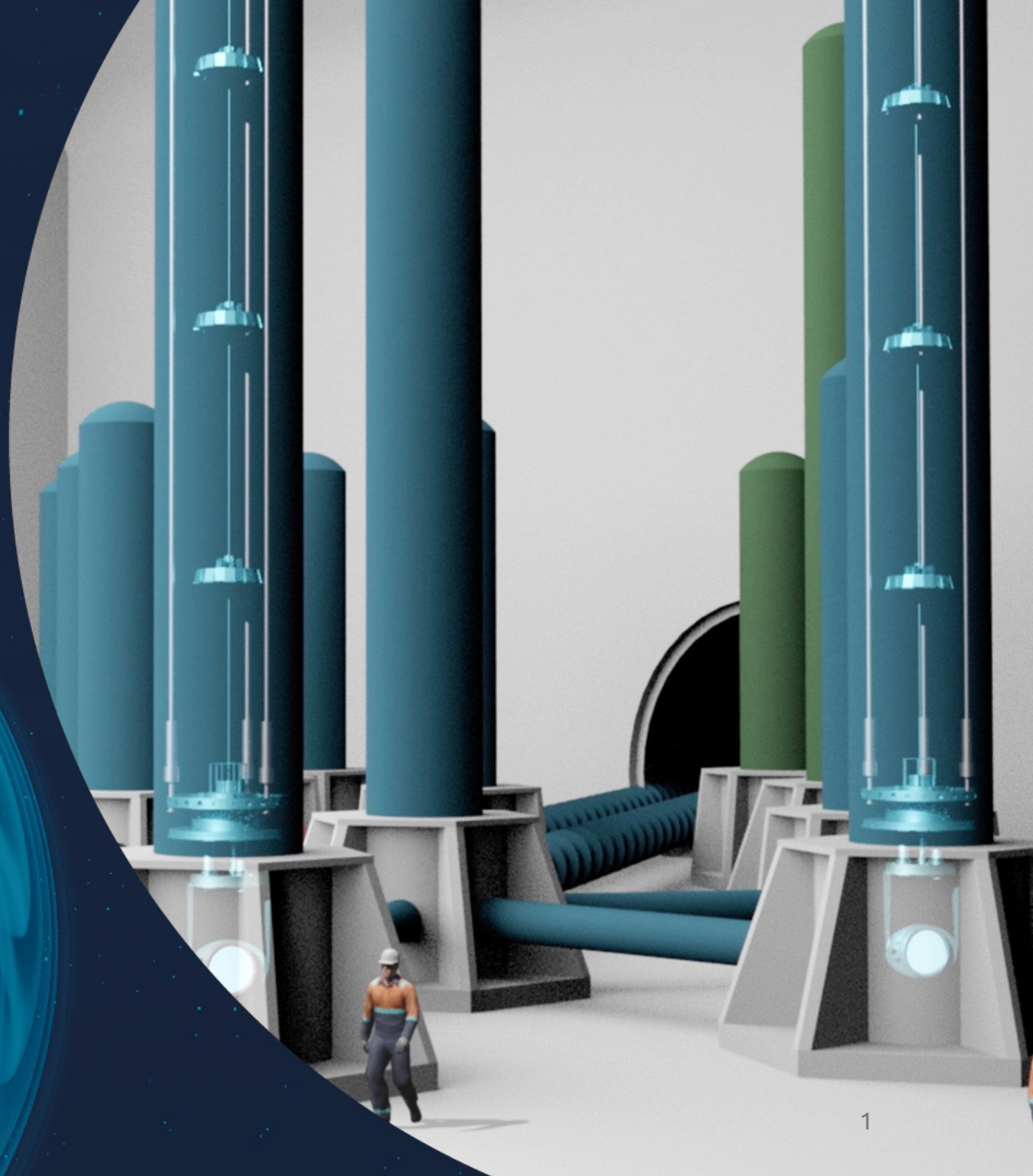
ET ITALY
Einstein Telescope

Site characterization: status and updates



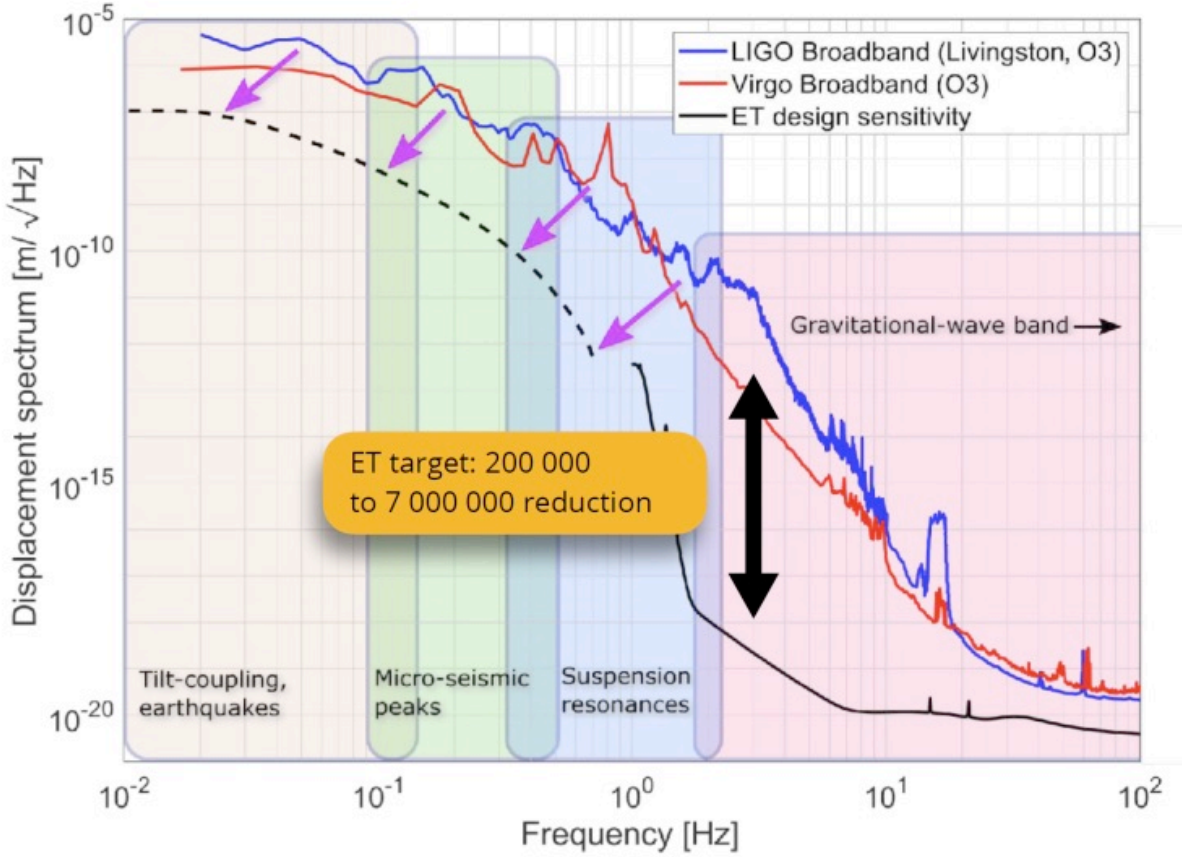
D. D'Urso – ET National Representative

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:

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



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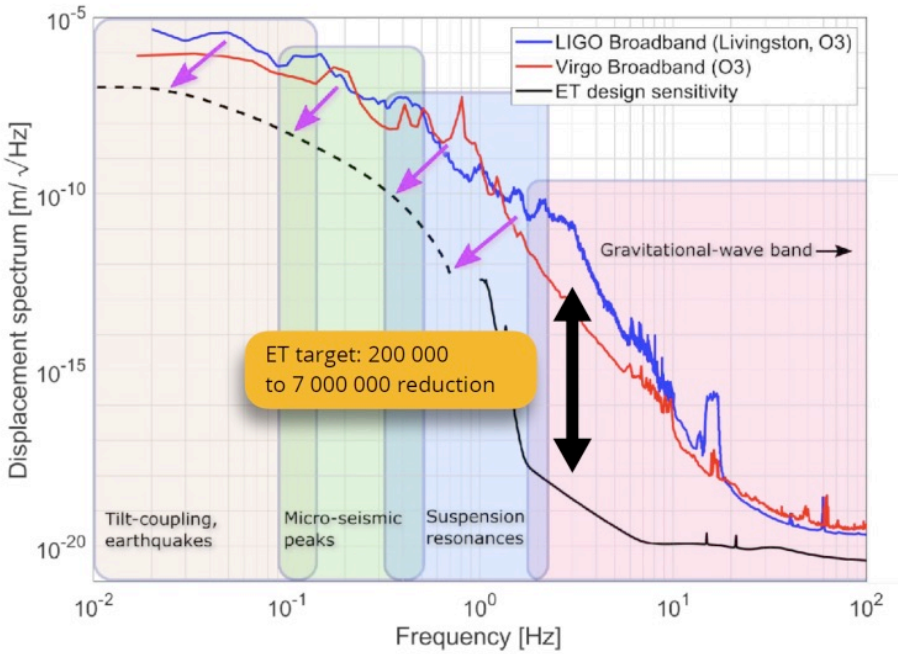
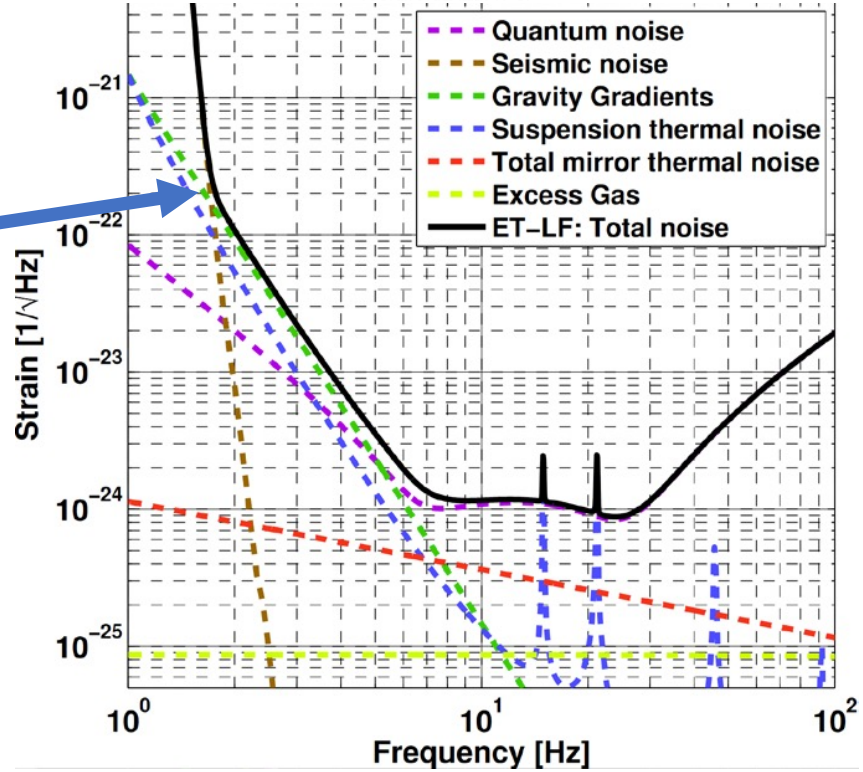
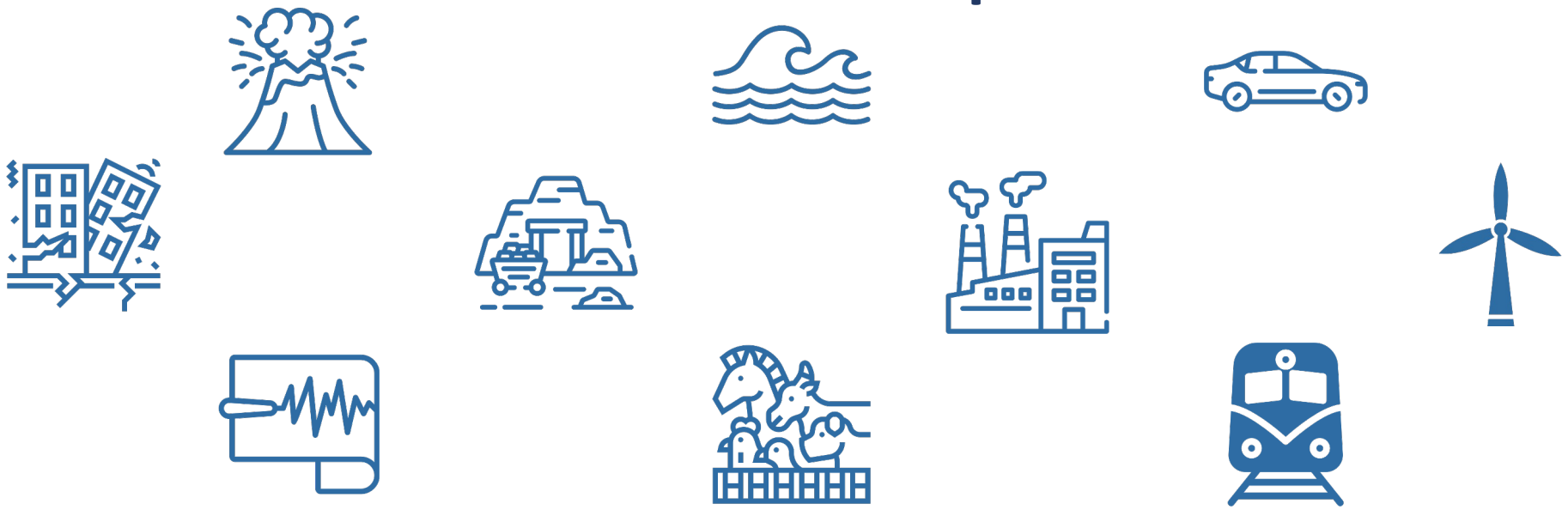




Einstein Telescope will be built underground to operate below 10 Hz

Potential **noise sources**, both **natural** and **anthropic** origin,
can affect the **Einstein Telescope** measurements.

Credits to D. Rozza

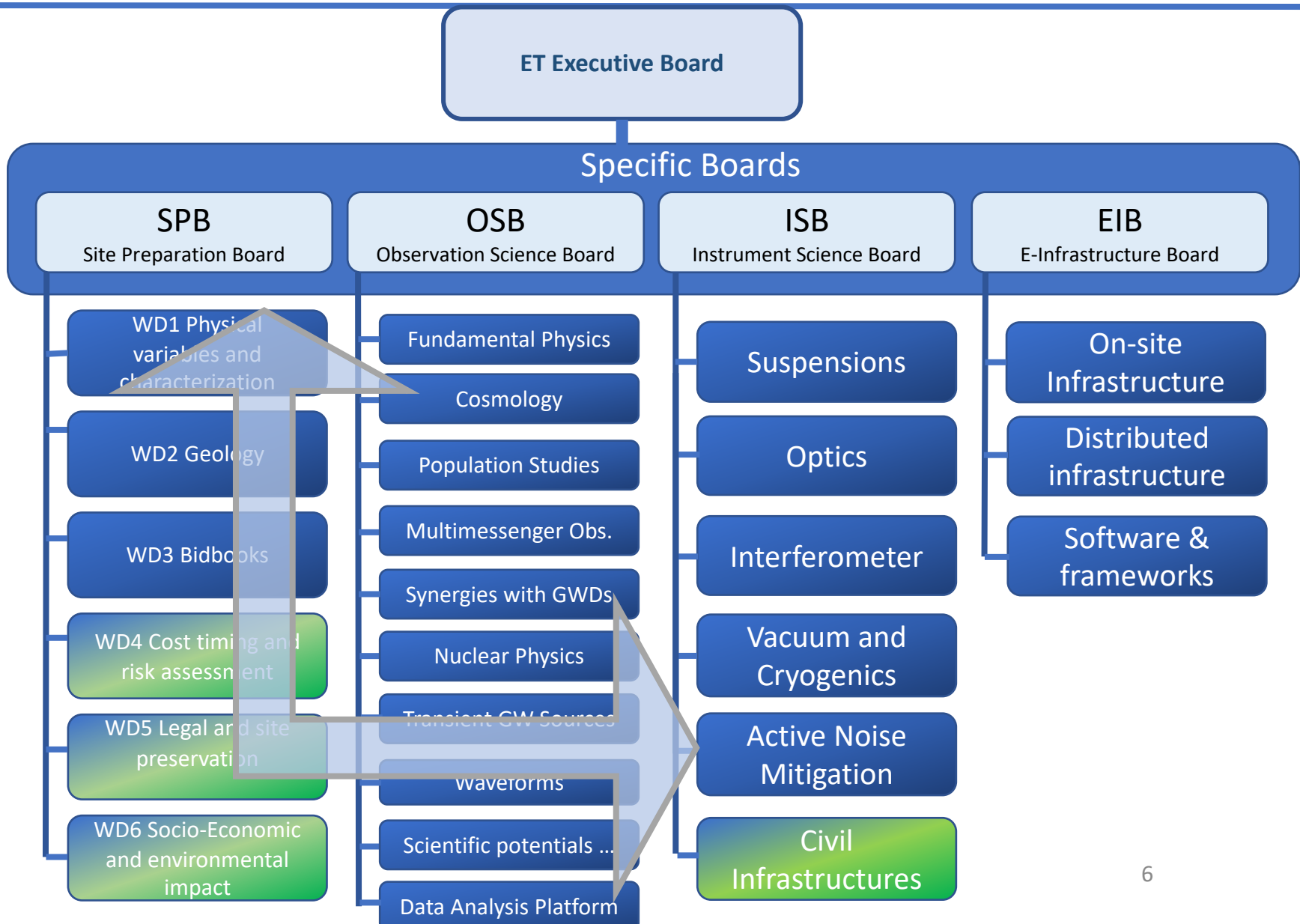


WE WILL SEE THAT THE ITALIAN CANDIDATE SITE IS CHARACTERISED BY:

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

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).



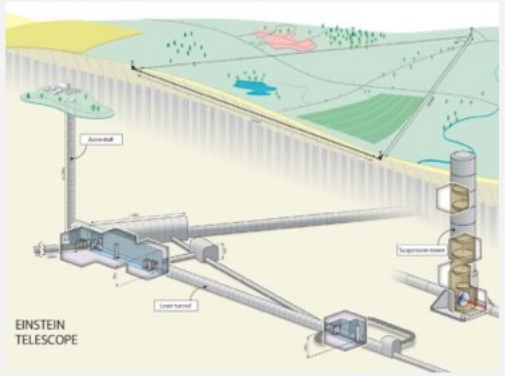
ET Candidate Site

ET candidate sites

- Two sites officially candidate:
  - EMR EUregio, border region between Nederland, Belgium and Germany
  - Sardinia (Sos Enattos area)
- A third potential site is located in Saxony (Lusatia), still not official
- 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
- **12/2023**: Letter from Italian Prime Minister offering 950M€

In the **SOS ENATTOS** former mine area, the **SARGRAV laboratory**, a seed of ET, can host:

- UNDERGROUND EXPERIMENTS
- CRYOGENIC PAYLOADS
- LOW FREQUENCY AND CRYOGENIC SENSOR DEVELOPMENT

that need **LOW SEISMIC** and **ANTHROPOGENIC NOISE**

The Italian Candidature

scientific advisory board


Premio Nobel Giorgio Parisi


Prof.ssa Marica Branchesi

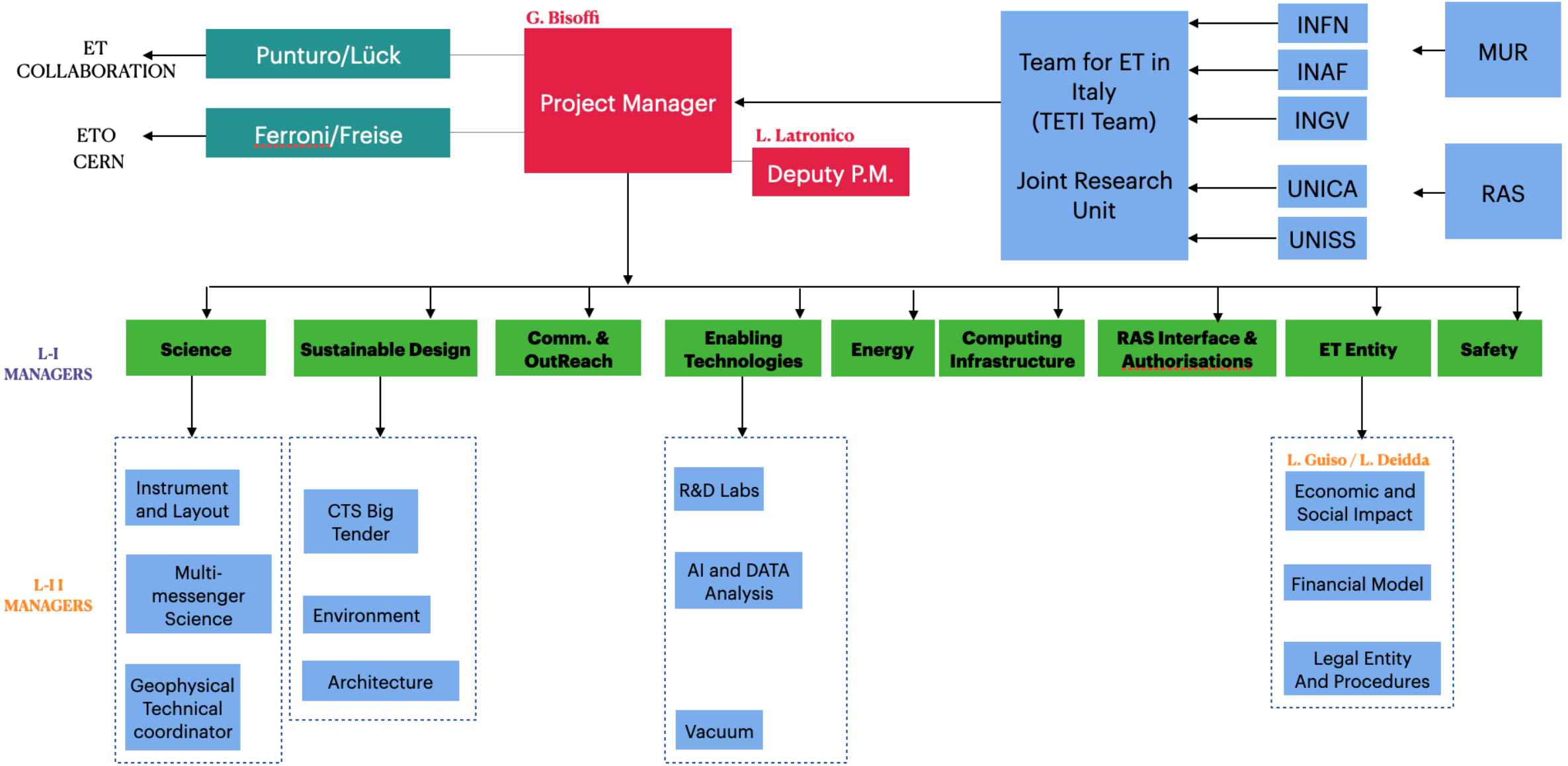

Prof. Fernando Ferroni


Prof. Antonio Zoccoli

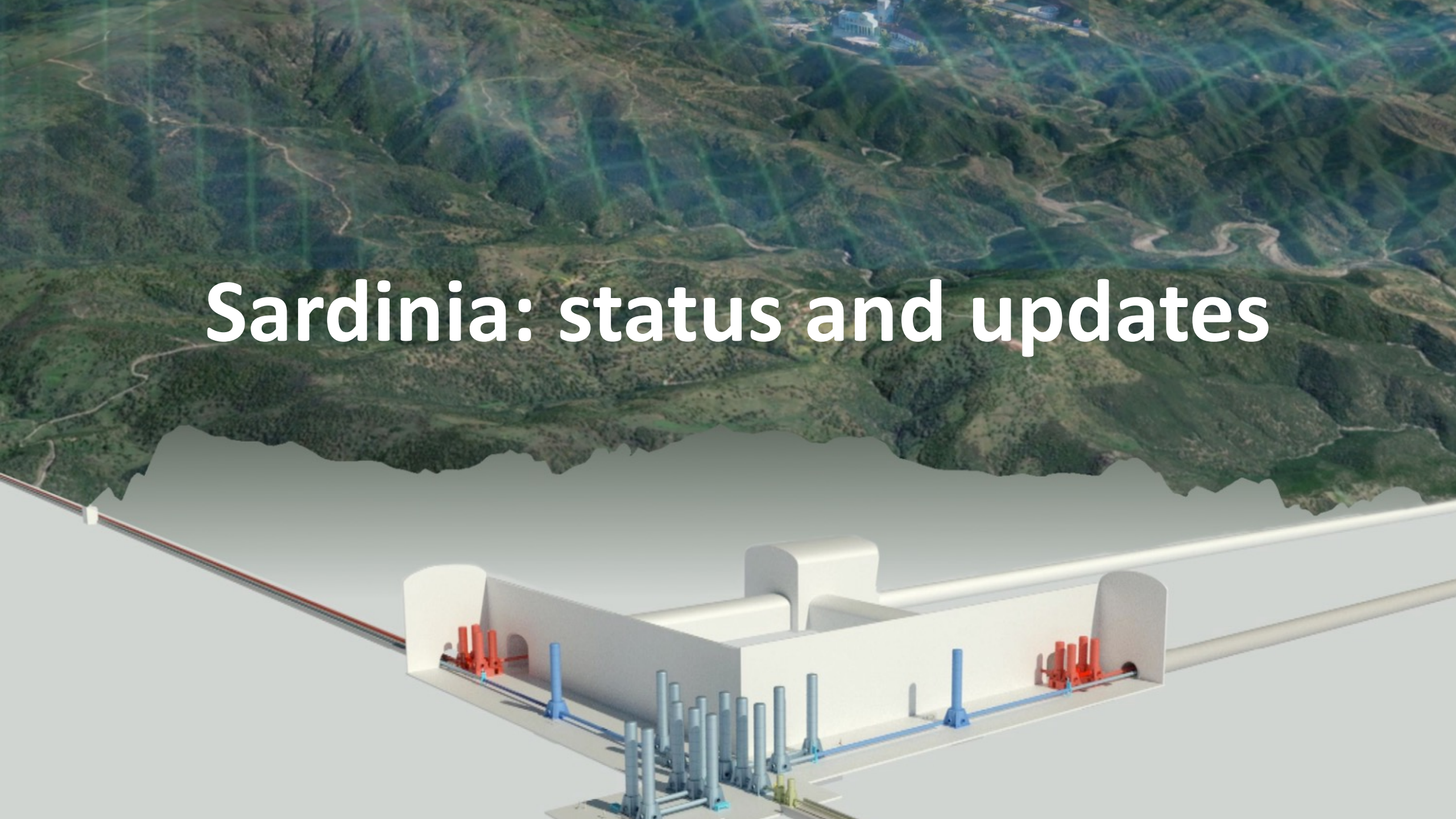

Amb. Ettore Francesco Sequi

- MUR appointed a scientific advisory board for the Minister
  - Regular meetings at MUR in coordination with MAECI
  - Communication with Embassies. Diplomatic activity led by Ambassador E. Sequi
  - Official Italian Web page of the candidature www.einstein-telescope.it
- Coordination table with INAF and INGV to Upgrade Sos Enattos Laboratory and develop Interdisciplinary science, joint political and financial effort
- Project organisation with clear responsibilities to:
  - Bidbook preparation for ET-Sardinia
  - Coordinate ETIC R&Ds during and beyond ETIC project
  - Manage new SOS Enattos infrastructure
- Team led by Luigi Guiso (EIEF, Istituto Einaudi per Economia e Finanza) will update and assess the global economic impact of ET in Sardinia and Italy

The Italian Candidature: TETI



Sardinia: status and updates



Site Candidature Action lines

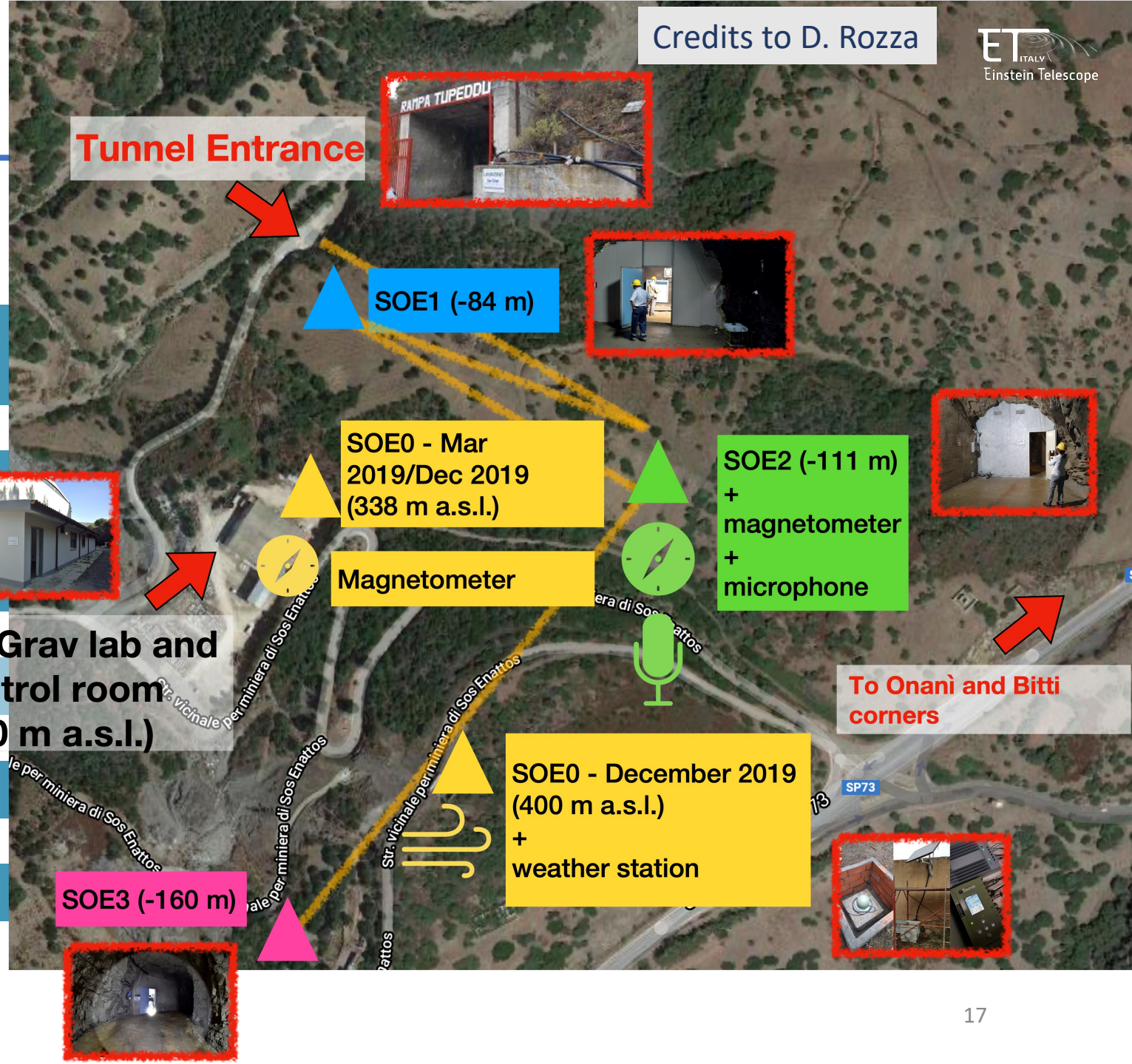
- Site monitoring
  - identification and quantification of local source impact
  - implication for site preservation quality
- Geological studies
  - understanding and characterization of local geology
- Civil and environmental engineering
  - pre-feasibility study
  - geotechnical investigation
  - optimal placement and environmental sustainability of the underground and surface infrastructures

Sardinia:
Site Monitoring

PERMANENT ARRAY since 2019

Since 2019, in Sos Enattos there are:

- 4 permanent seismic stations for long term studies (Trillium 240, 360 and 120 Horizon, Guralp 360)
- 1 weather station
- 1 microbarometer
- 3 magnetometers (MF6-06)
- 2 microphones
- 1 high precision tiltmeter (Archimedes prototype)



PERMANENT ARRAY since 2021

Since 2021, more permanent sensors have been installed at 2 of the proposed vertices (P2, P3)

2 broadband seismometers on surface

2 broadband seismometers in borehole

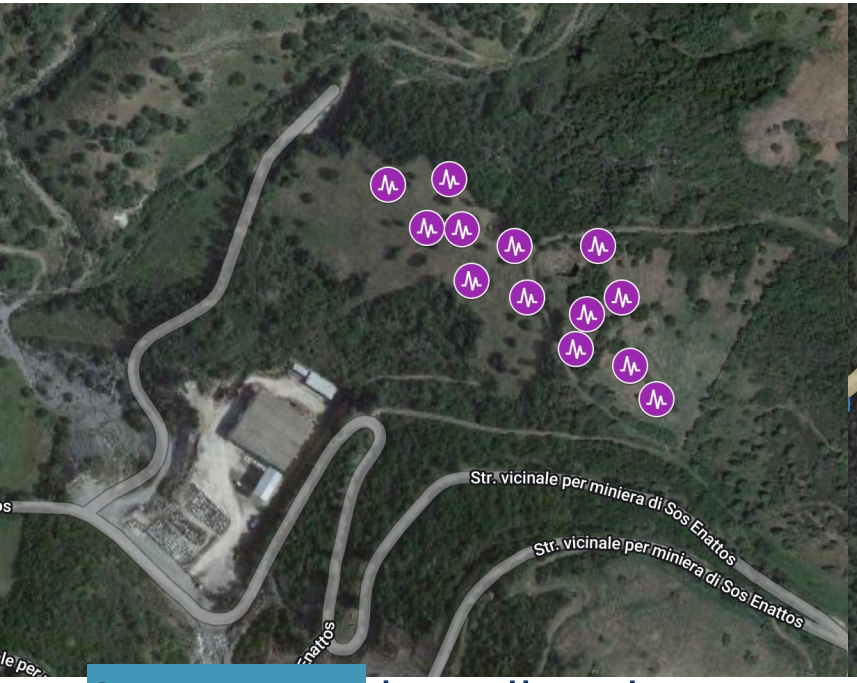
2 magnetometers at P2

- Acoustic measurement campaign at P2 & P3 borehole areas in the next months
- Gravimetric campaign will start soon
- In the next months Sos Enattos area will be reached at 1 TB/s
- New measurement stations in the other candidate vertices

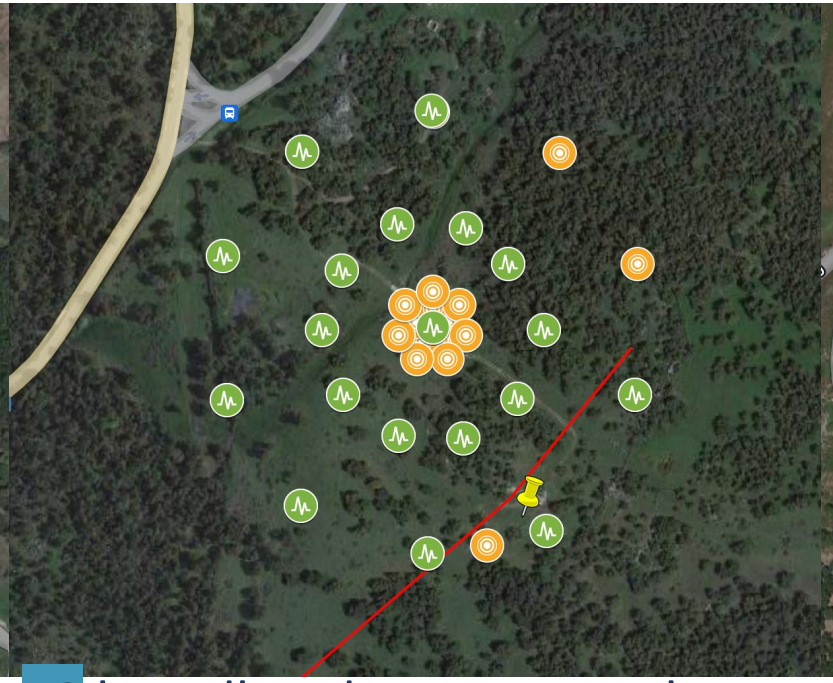
Sardinia: Site Monitoring
Local Noise Sources

TEMPORARY ARRAY for seismic properties and Newtonian noise purposes

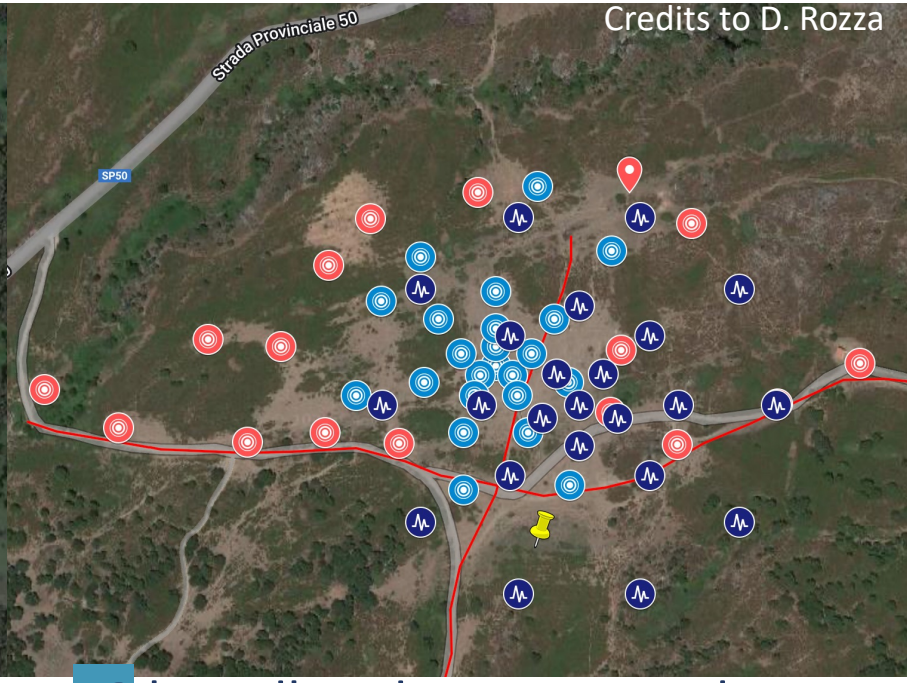
ET ITALY Einstein Telescope



Sos Enattos broadband array (January 2021)

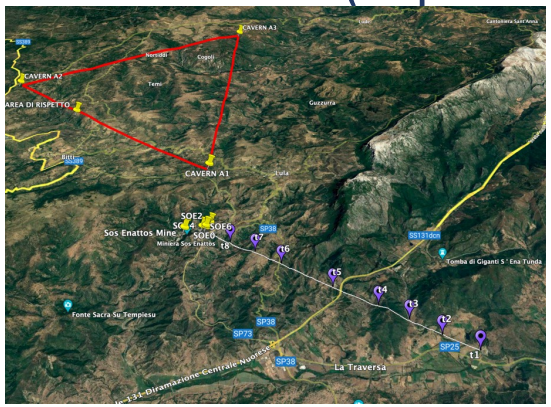


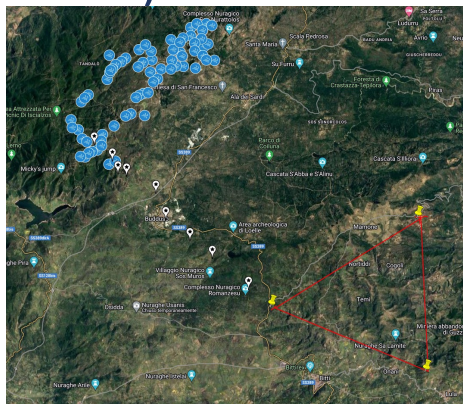
P2 broadband array + geophones (September 2021)



P3 broadband array + geophones (July & Oct 2021)

Explosion broadband array (early 2022)

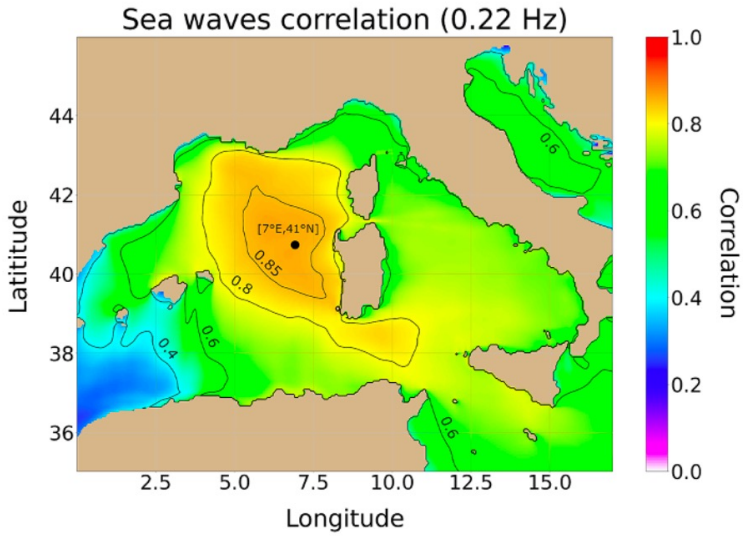




Wind Park broadband array (early 2023)

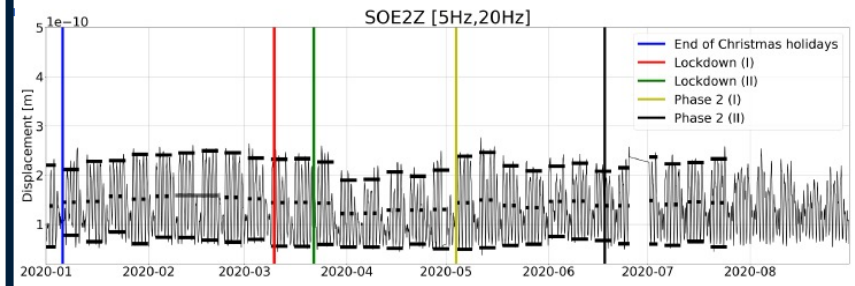
Hunting the noise sources

Sea waves

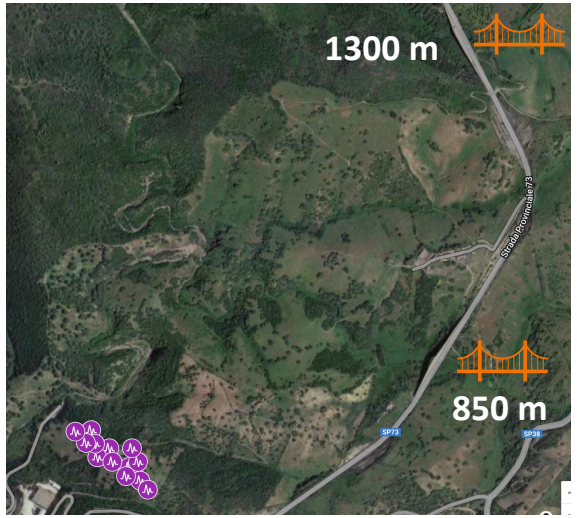


Microseismic (0.05-1Hz) coming from **waves** in the Gulf of Lion (~0.22Hz,NW Mediterranean sea) and Atlantic ocean depending on weather conditions and season.

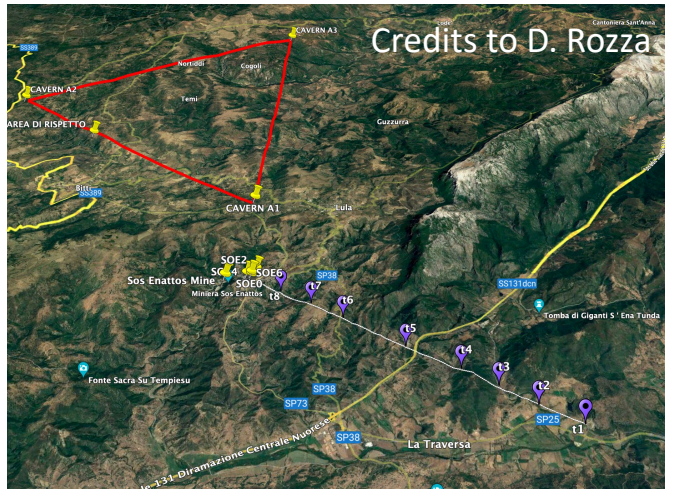
Human activities



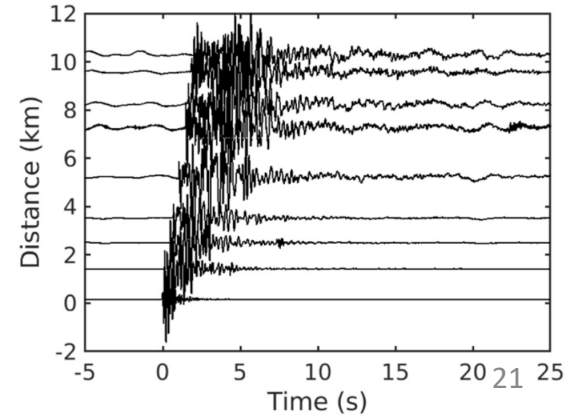
anthropic noise



two bridges



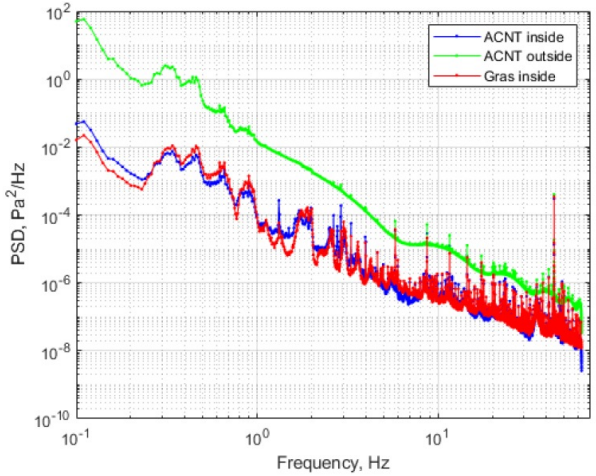
Updates and improves of the resolution of the dispersion curves for **compressional and shear wave velocities**.



Hunting the noise sources

INFRASOUND MEASUREMENTS

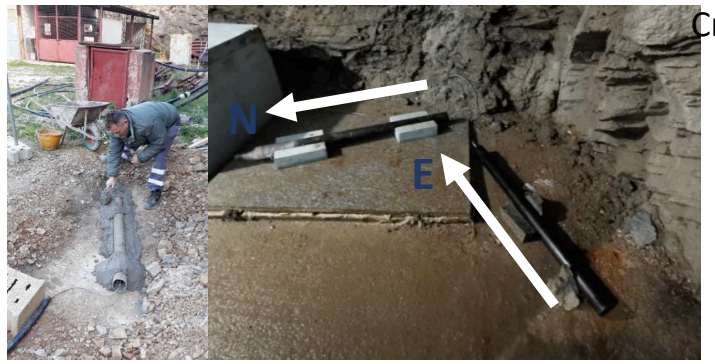
4 microphones installed along the underground tunnels for long term characterization in a joint Italian-Polish-Hungarian collaboration (*PolGrav-AstroCeNT, Wigner Research Centre*)



Credits: T. Bulik

MAGNETIC NOISE

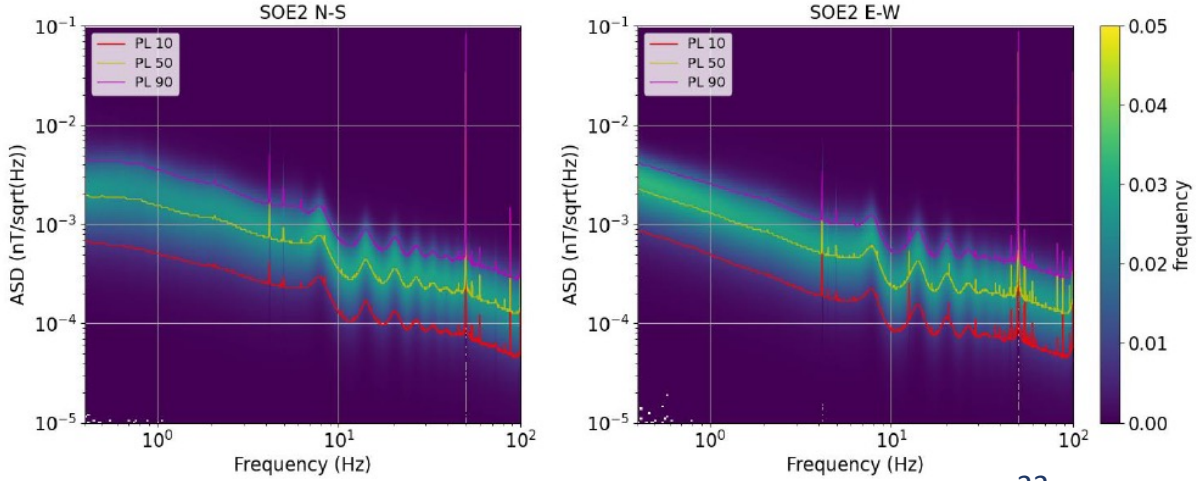
Credits to D. Rozza



Most important mechanism in ET-LF:

- **Geomagnetic pulsations Pc1** (0.2-5Hz);
- **Schumann resonances** (5-100Hz)

Artificial LF sources (e.g. 50-60Hz powerlines)



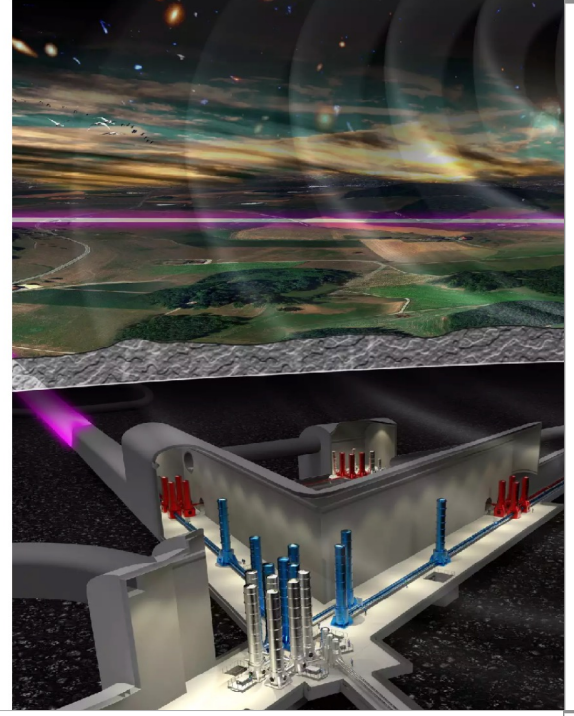
Credits: R. De Rosa, R. Romero

EGU European Geosciences Union

Vienna, Austria & Online | 14–19 April 2024

Results from WINES: Wind turbIne Noise assEsSment in the Italian site candidate for *"Einstein Telescope"*, the 3rd generation gravitational wave detector.

G. Diaferia, C. Giunchi, I. Molinari, M. Olivieri, F. Di Felice, A. Contu, D. D'Urso, L. Naticchioni, D. Rozza

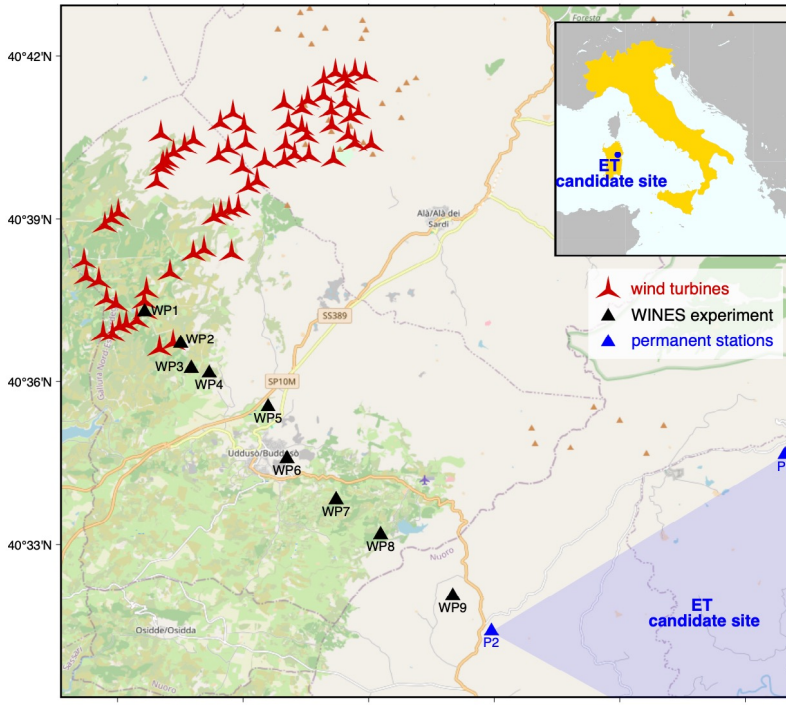


The Italian candidate site

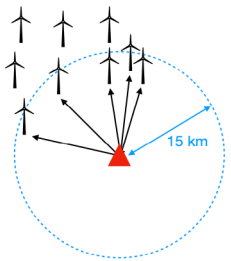
One of the **largest wind park** in Italy is just **15 km** away from the **ET candidate site**

WINES experiment to **record** and **characterize** the wind park related **seismic noise:**

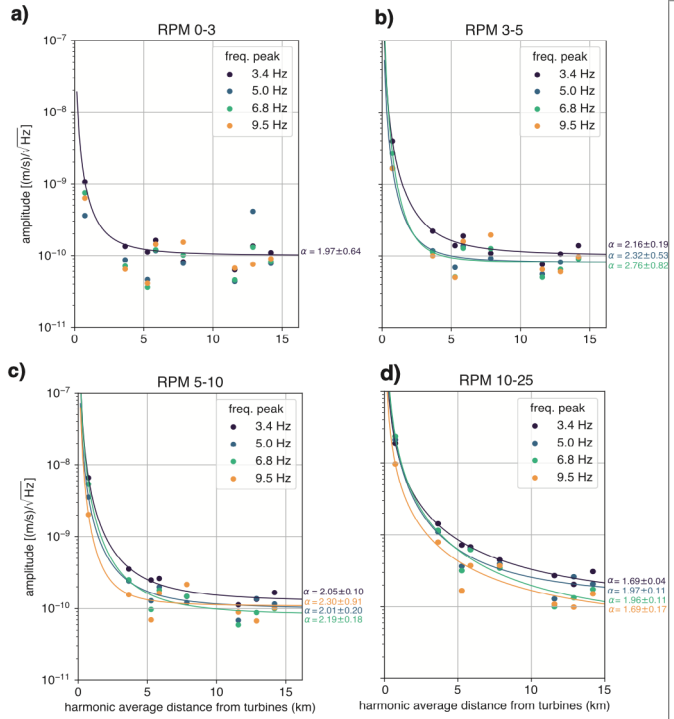
- **9 broad-band** seismic stations
- **~13 km** linear array
- **~2 months** of recording (8/04-30/05/2023)



amplitude decay



- for each station, we take the **number (N) of turbines within 15 km**
- calculate **harmonic mean distance** of all **N stations**
- **divide** the spectral amplitude by $N^{1/2}$ based on the assumption that turbines are **quasi-random noise source**, **adding in quadrature**
- **fit** with a $1/r^{\alpha}$ model



CONCLUSIONS

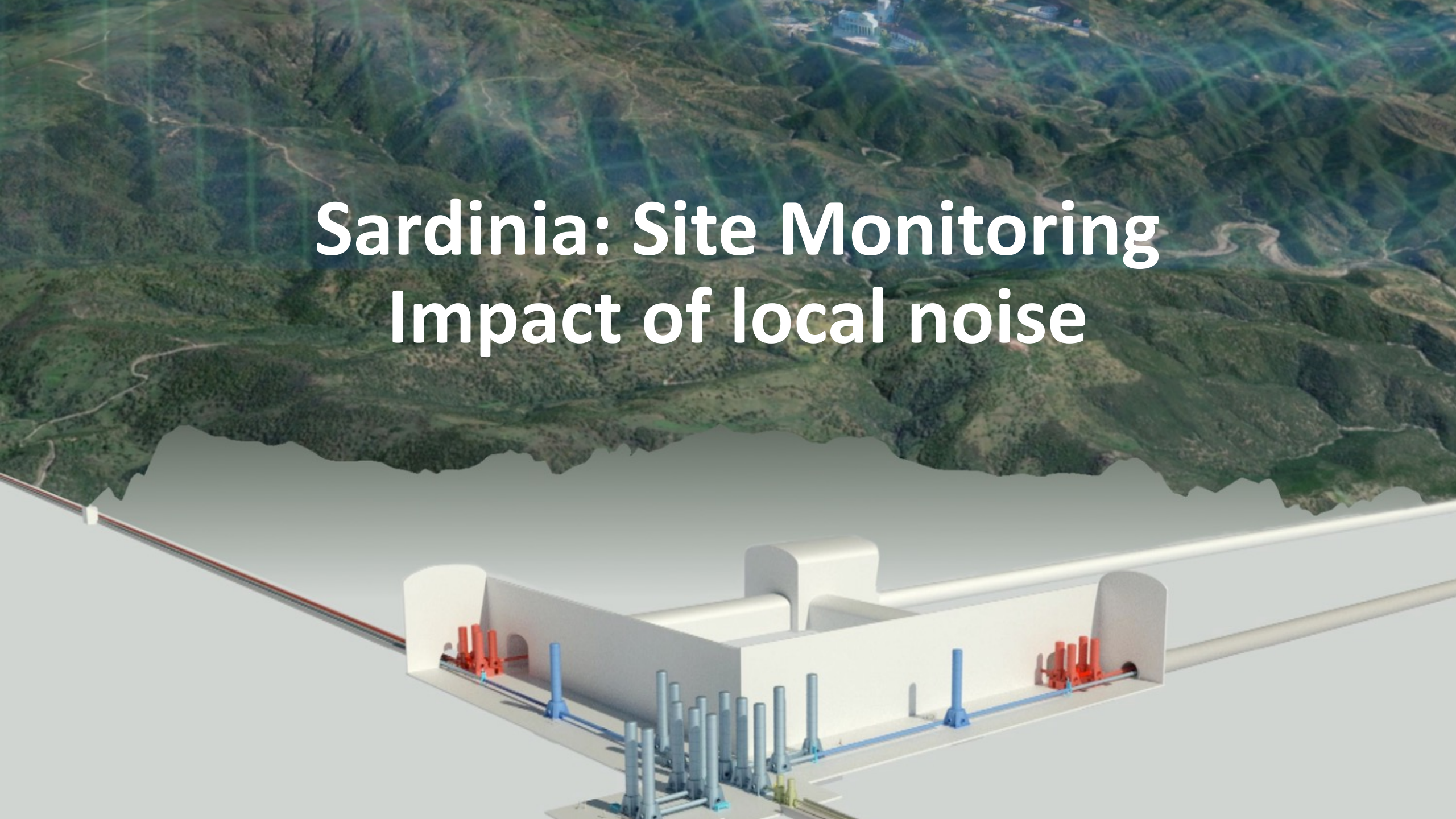
- the wind park generates a **substantial amount of seismic noise.**
- the generated seismic noise has **clear peaks** that can be **traced up to 13 km**, when the the wind park **runs at full capacity**
- the **amplitude decay** is rather homogenous across frequencies and for a wide range of RPM.
- the **homogeneity of the amplitude decay** reflects the good geomechanical characteristics of the local terrain

PUBLICATIONS:

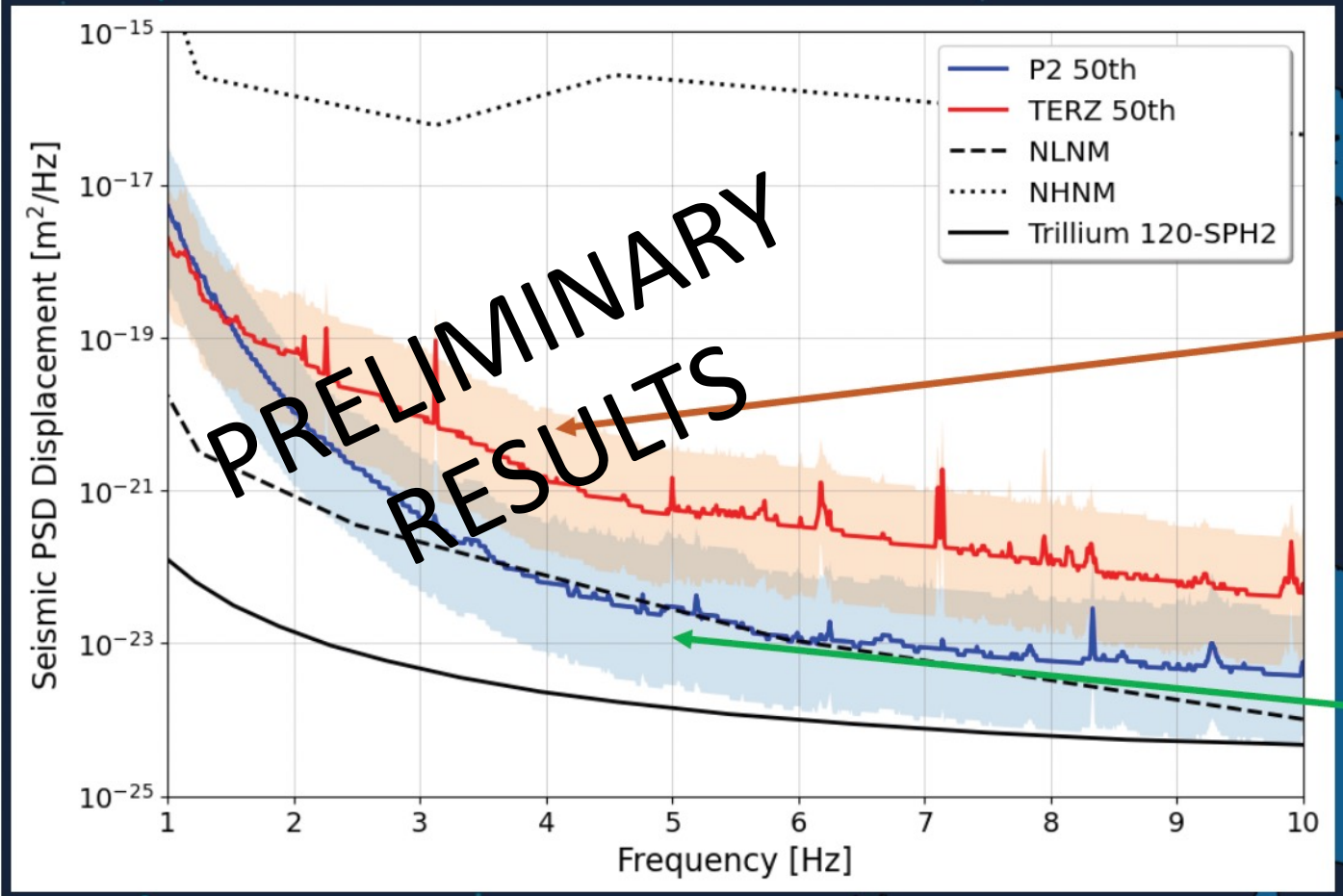
- L. Naticchioni et al., ***Microseismic studies of an underground site for a new interferometric gravitational wave detector***, **CQG**, 2014, https://doi.org/10.1088/0264-9381/31/10/105016
- L. Naticchioni et al., ***Characterization of the Sos Enattos site for the Einstein Telescope,*** **JPCS** 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***, **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 Italian candidate site for the Einstein Telescope***, 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, https://doi.org/10.22323/1.441.0110.
- A. Allocca et al., ***Thermal noise-limited beam balance as prototype of the Archimedes vacuum weight experiment and B-L dark photon search***, **EPJP** 139:158, 2024, https://doi.org/10.1140/epjp/s13360-024-04920-x

+ several internal notes, reports and talks

Sardinia: Site Monitoring
Impact of local noise



ITA vs EMR



Seismic noise / frequency

https://indico.ego-gw.it/event/710/contributions/6467/attachments/3562/6370/go

Credits to D. Rozza and M. Di Giovanni

Defining a procedure to quantify site dependent effects on GW detections

Generate noise following the sensitivity curves modified according to actual site noise;

↓

Inject a signal and calculate matched filter SNR (or other equivalent quantities);

↓

Focus on different frequency bands according to the different sources:

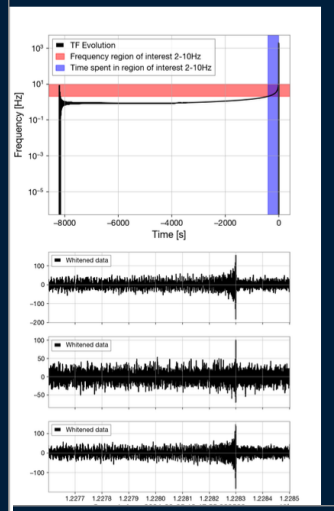
- Low frequency to assess the impact over early warning for BNS mergers (order of KHz)
- Low-mid frequency to assess the impact over IMBH mergers (order of 10 Hz)

Comparison of the different SNR values should help in determining the impact of site noise over GW detections;

The following slides will show a first basic implementation of this procedure.

GW150914-like event at cosmological distance

M1 = 35 M_sun
M2 = 30 M_sun
D = 4000 Mpc (z = 1)



T 2 Hz - 10 Hz	T 2 Hz - to merger	Design SNR 2 Hz-10 Hz
400 s	403 s	41

P2 10%	P2 50%	P2 90%
43 (+5%)	42 (+2%)	40 (-3%)

TERZ 10%	TERZ 50%	TERZ 90%
42 (+2%)	37 (-10%)	27 (-35%)

In current generation detectors, similar signals last few hundred milliseconds from 20 Hz to merger

GW170817-like event at cosmological distance

M1 = 1.4 M_sun
M2 = 1.4 M_sun
D = 1000 Mpc (z = 0.2)

T 2 Hz - 10 Hz	T 2 Hz - to merger	Design SNR 2 Hz-10 Hz
20 h	-	18.2

P2 10%	P2 50%	P2 90%
19.3 (+6%)	19 (+4%)	17.7 (-3%)

TERZ 10%	TERZ 50%	TERZ 90%
18.6 (+2%)	15.7 (-24%)	11 (-39%)

SNR fractions with respect to design are compatible with the previous cases.

Credits to D. Rozza and M. Di Giovanni

Conclusions

This preliminary study therefore aims at assessing the **impact** of site dependent noise over a class of particular GW source.

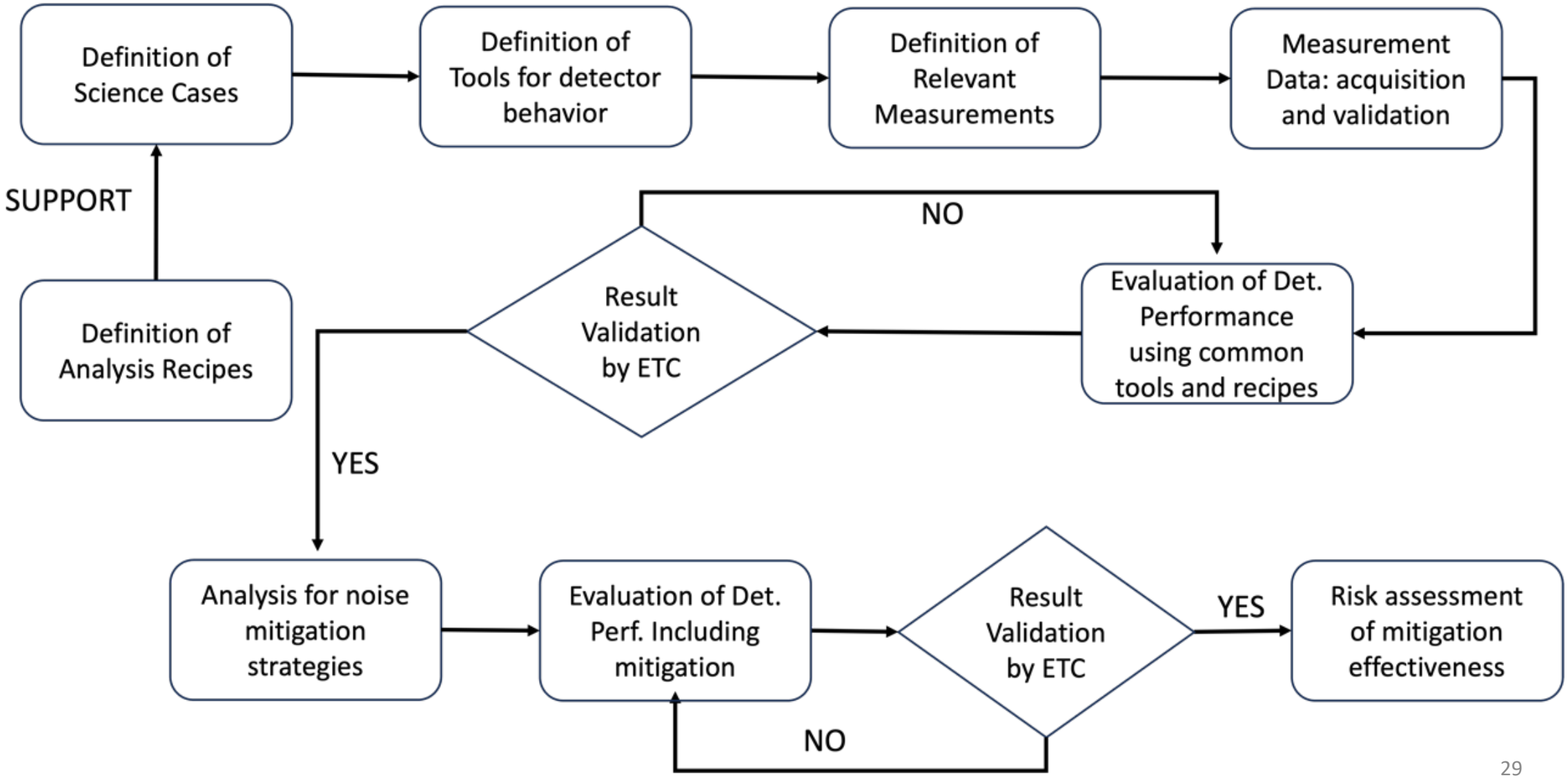
The **Newtonian noise** can limit the ET sensitivity between 2 and 10 Hz.

We performed the NN comparison between the **two sites**.

Site noise seems to have an **impact over the observed SNR** in the considered frequency band.

SNR performance is consistent between different sources.

Reduced SNR at low frequency can seriously hinder early warnings for compact object mergers.

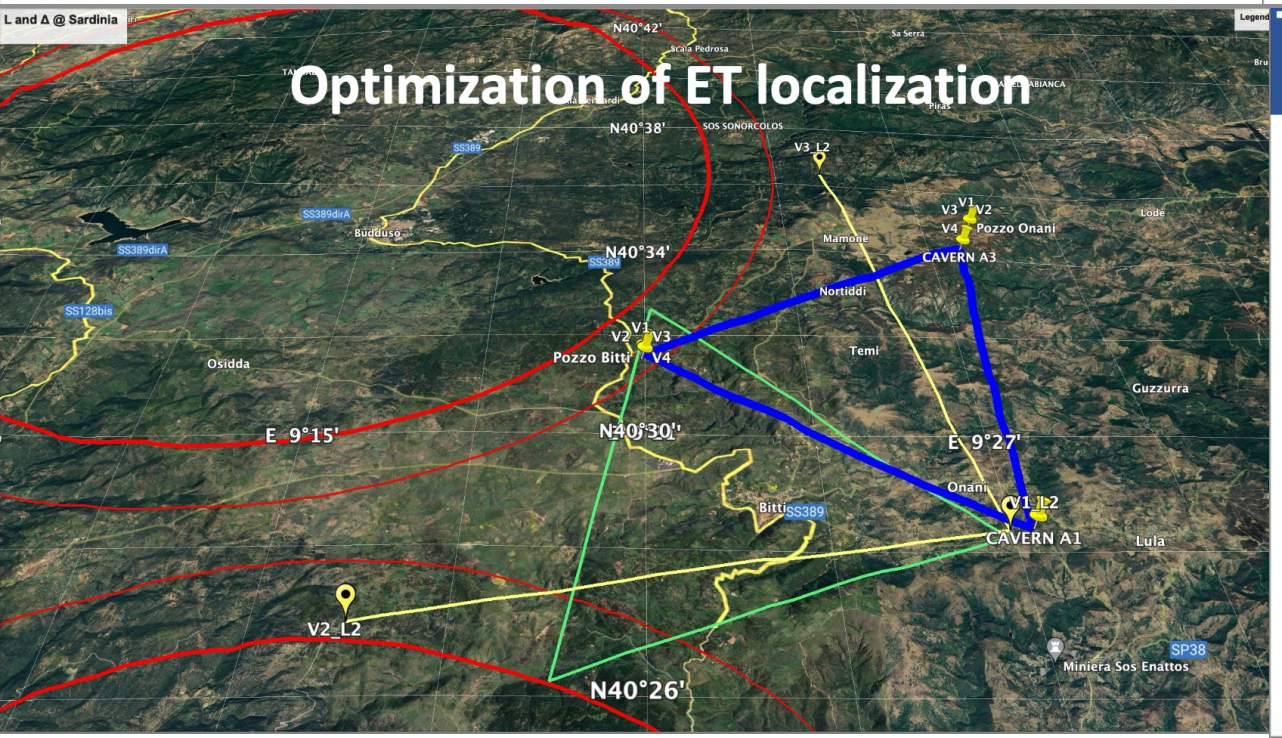

Definition of Science Cases
Definition of Tools for detector behavior
Definition of Relevant Measurements
Measurement Data: acquisition and validation
SUPPORT
NO
Definition of Analysis Recipes
Result Validation by ETC
Evaluation of Det. Performance using common tools and recipes
YES
Analysis for noise mitigation strategies
Evaluation of Det. Perf. Including mitigation
Result Validation by ETC
YES
Risk assessment of mitigation effectiveness
NO

ET ITALY
Einstein Telescope

ET Localization in Sardinia

Recommendation for Localization Sardinia

- Minimum Depth in Sardinia 120 m
- Distances from identified possible local source noise
  - minimum distance from the nearest **existing wind turbine 13 km**, optimal distance 15km
  - minimum distance from **Nuoro industrial area 13km**, optimal distance 15km (conservative indication, no specific noise from existing human activity)
  - minimum distance from two **existing bridges 2 km**, optimal distance 3 km



Special case: L Localization

- The ET-2L solution requires coordination between the positions of the 2Ls in order to maximize the ET potentialities
  - maximize the distance between the 2Ls
  - relative angle of ~ 45° between them to maximize parameter estimation (see CoBa study)
  - avoiding a perfect 45° alignment, it corresponds to the impossibility of measuring a specific physics goal: stochastic background of gravitational waves
  - Possible range [35°, 43°] and [47°, 55°]
- It is necessary to consider a possible L in the EMR area

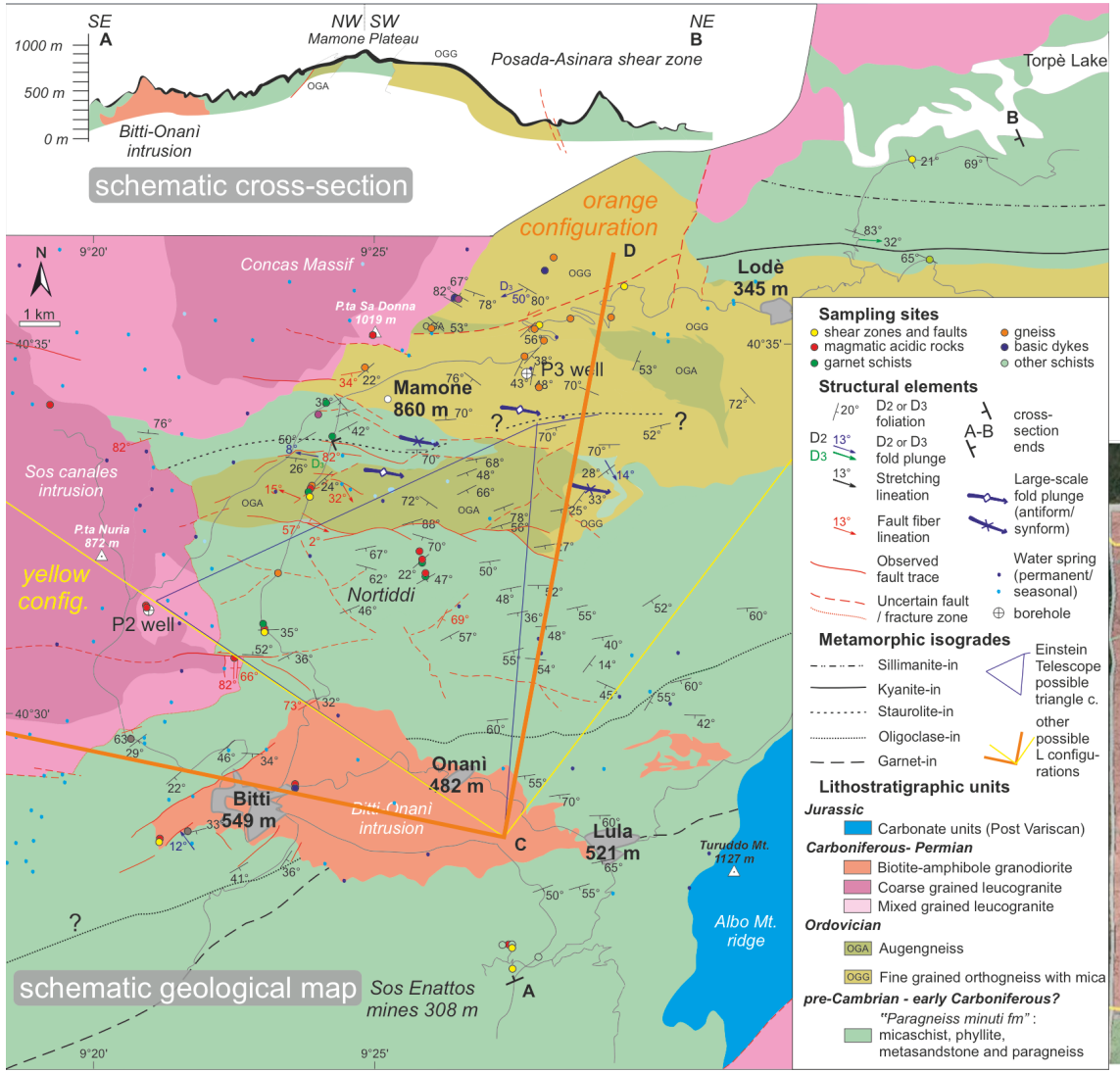
General remarks

- Reduce impact of existing and future local noise source
  - distance may depend on geology and on the noise source under consideration
- Accommodate the infrastructure taking into account geological and geotechnical configuration
- The goal is to build a unique and challenging machine, able to be in operation for 50 years, **underground to detect low frequency signals** not to have **the best underground system of caverns and tunnels ever built**

Sardinia: Geological Studies

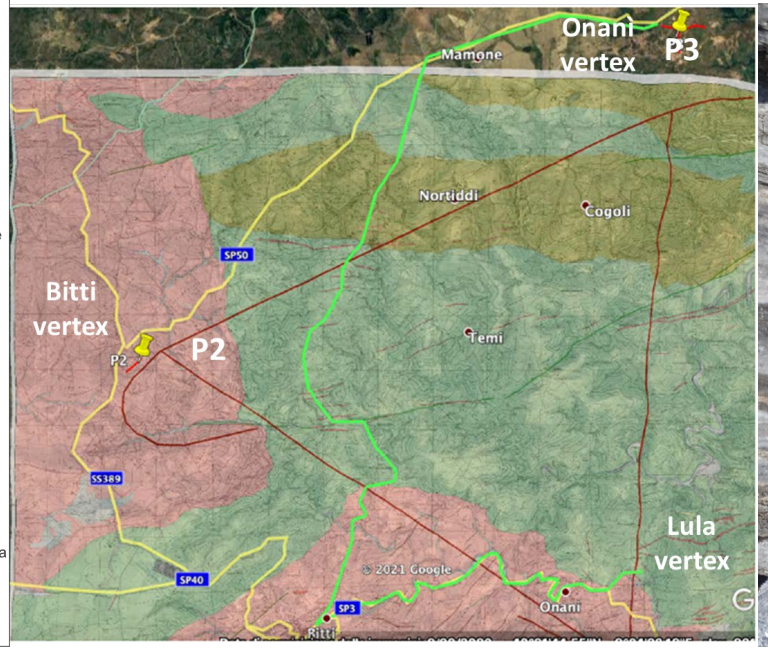
The ET Italian candidate site is located in the stable VARISCAN BASEMENT OF SARDINIA

Credits to D. Rozza

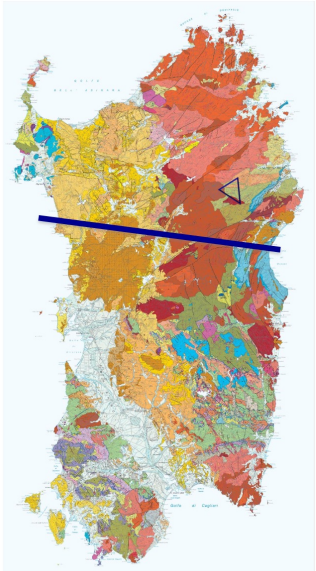


LITHOLOGIES: Orthogneiss, granitoids, micaschists.

P2 and P3 are the borehole locations optimization is ongoing.

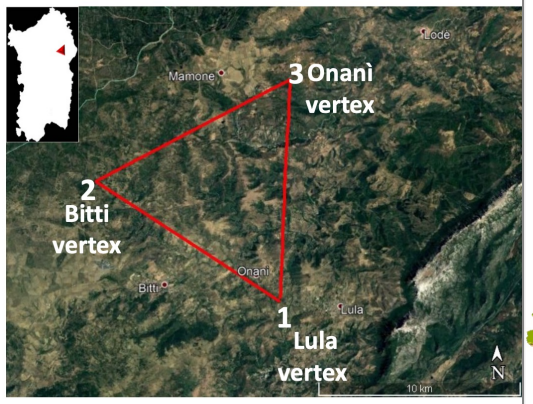


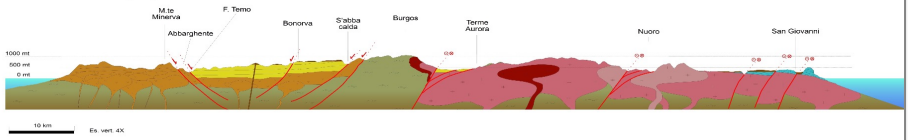
Geological comparison: the ET Italian candidate



Sardinia is rich in granites (red), derived from the solidification of magma over 300 million years ago, and even older metamorphic rocks (green). There are regional faults that resulted from the movements the island underwent during the Mesozoic (blue) and Miocene (orange) periods.

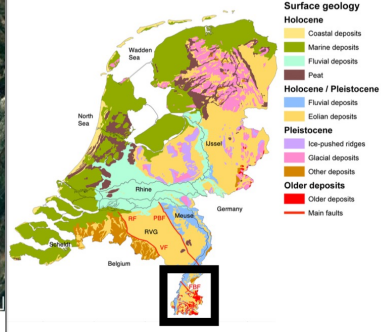
In the last few million years, the island has been essentially tectonically quiet.

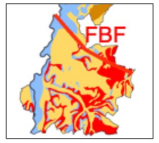


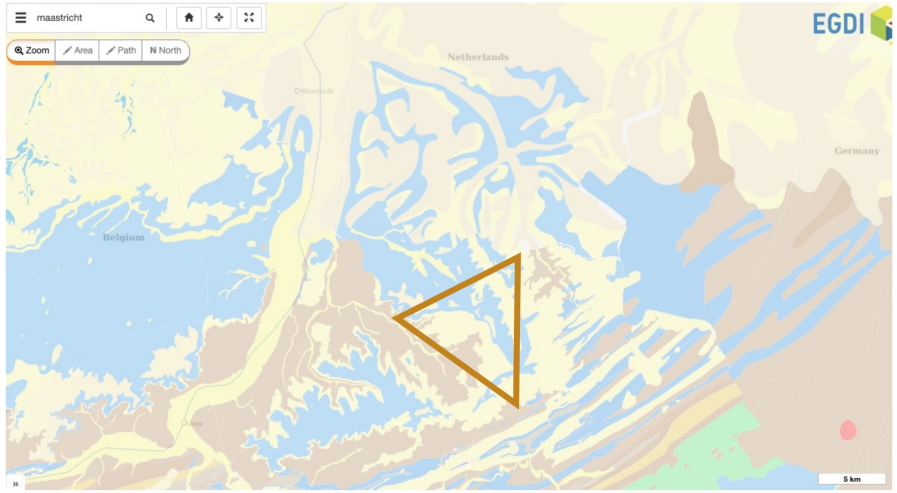


Geological comparison: the Belgian-Dutch site

Sedimentary rocks and recent sediments







https://www.europe-geology.eu/data-and-services/map-viewer/

FAULT CONTACTS with IMPERMEABLE GOUGE

Dating the illite contained in fault debris allows us to obtain ages of the most recent fault activity in the area from faults that have already shown post-Variscan evidence.

DERISKING: In areas affected by polyphasic tectonics, we could potentially exclude recent coseismic reactivation at the site.

Nine samples of fault debris have been sent to Australia for dating using the K-Ar method.

Credits to L. Cardello

RESULTS APPROACHING!

EXPECTED RESULTS (2024-2025)

Insights on the reduction of the potential risk of the candidate site from Italy for ET

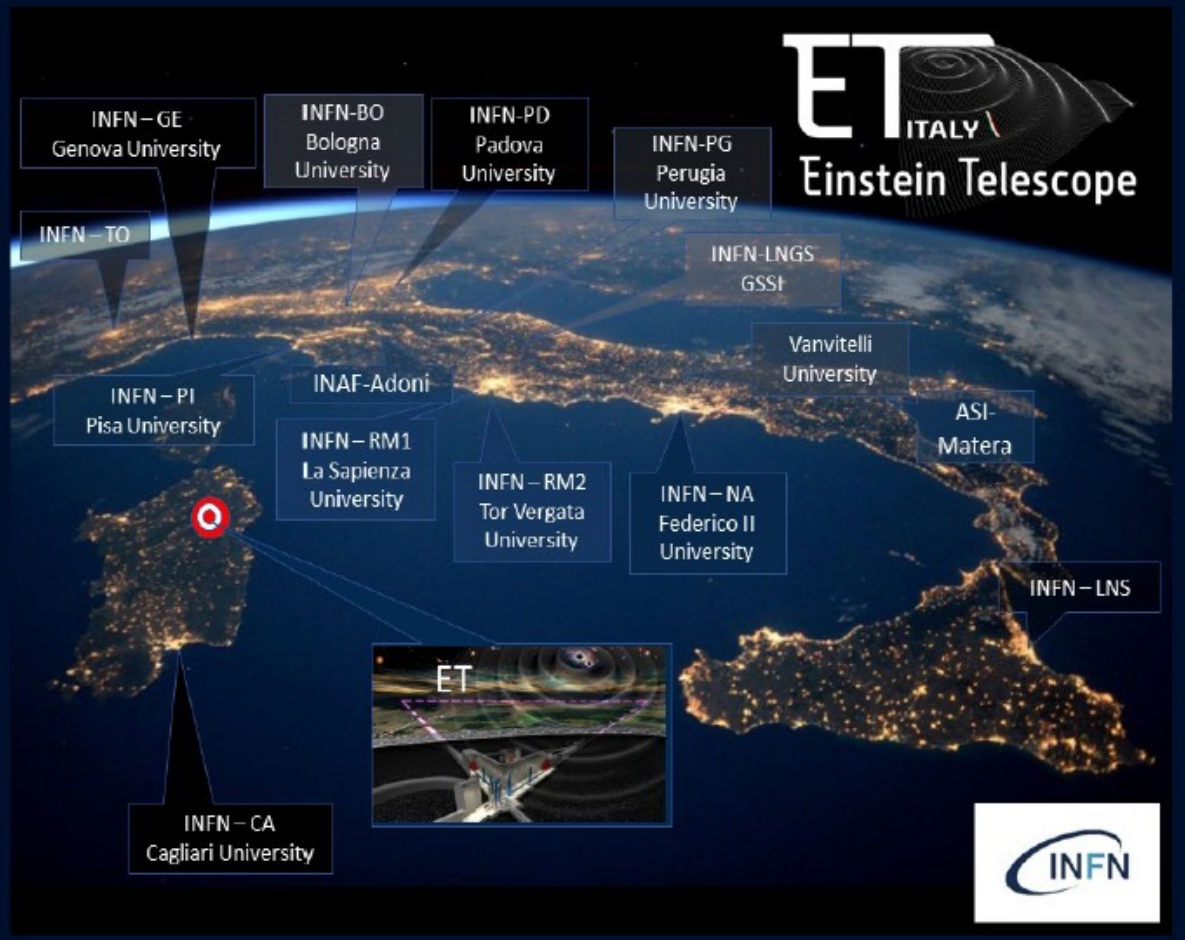
- ❖ Fault dating
- ❖ Completion of rock cooling dating
- ❖ Estimation of tectonic stability/erosion
- ❖ … a new dataset is coming from the contractor's exploration!

Sardinia:
Civil and environmental engineering

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



PNRR ETIC WP6: Gara d'Appalto da 14M€+IVA

- Appalto per lo "Studio propedeutico allo sviluppo del progetto di fattibilità tecnica ed economica dell'osservatorio di onde gravitazionali Einstein Telescope nella Regione Sardegna, in diverse configurazioni, comprensivo della esecuzione delle indagini e dei sondaggi e della valutazione preliminare di impatto ambientale, per le opere infrastrutturali, in sotterranea e in superficie, edili e impiantistiche."
- 6 febbraio 2024 aggiudicazione della gara
- http://wwwhz6.ansa.it/canale_scienza/notizie/ricerca_istituzioni/2024/02/06/-einstein-telescope-cordata-italiana-vince-studio-di-fattibilita_c58ab3e1-d0f7-4b90-b0e7-86b78a8b6f18.html
- Inizio attività 19 febbraio 2024
- Previsione fine appalto 30 giugno 2025
- Tempo a disposizione 18 MESI (è necessario rispettare i tempi del PNRR)

PNRR ETIC WP6:

per rispettare i tempi del PNRR le seguenti attività sono urgenti e sono già iniziate:

POSIZIONAMENTO PER LA CONFIGURAZIONE A 'TRIANGOLO' (T11km) (entro marzo 2024)

POSIZIONAMENTO PER LA CONFIGURAZIONE A 'ELLE' (L16km) (entro aprile 2024)

RILIEVI E INDAGINI DI SUPERFICIE NEI VERTICI (per T11km ed L16km)

PIANO DELLE INDAGINI E DEI SONDAGGI (entro maggio 2024)

INDAGINI E SONDAGGI IN PROFONDITA' (giugno 2024)

Activity Plan for the Preliminary Site Condition Assessment

Credits to G. Sappa

- Lidar survey for scanning the the ET area with 3D restitution
- 80 surveys for the determination of the geostructural characteristics of rocks outcropping
- Geological, geomorphological and hydrogeological surveys for the definition of geological characteristics of the area
- Environmental investigations to identify underground gases
- n. 20 geognostic surveys for a development of 5000 m of drilling
- installation of n.10 piezometers for a total of 2500 m of pipes installed
- Clearing mines and explosive ordnance
- Collection of n.50 soil samples and n.250 rock samples
- n.4 Lugeon permeability tests in each survey point for a total of n. 80 tests
- Video inspection of 2000 m of perforations
- n.10 dilatometric tests for each survey for a total of n.200 tests
- n.30 SPT tests
- n.4 Down-Hole tests (1000 measuring points)
- n.4 Cross-Hole tests (1000 measuring points)
- Indirect seismic investigations of the refractive type surveys

Reference geodetic network

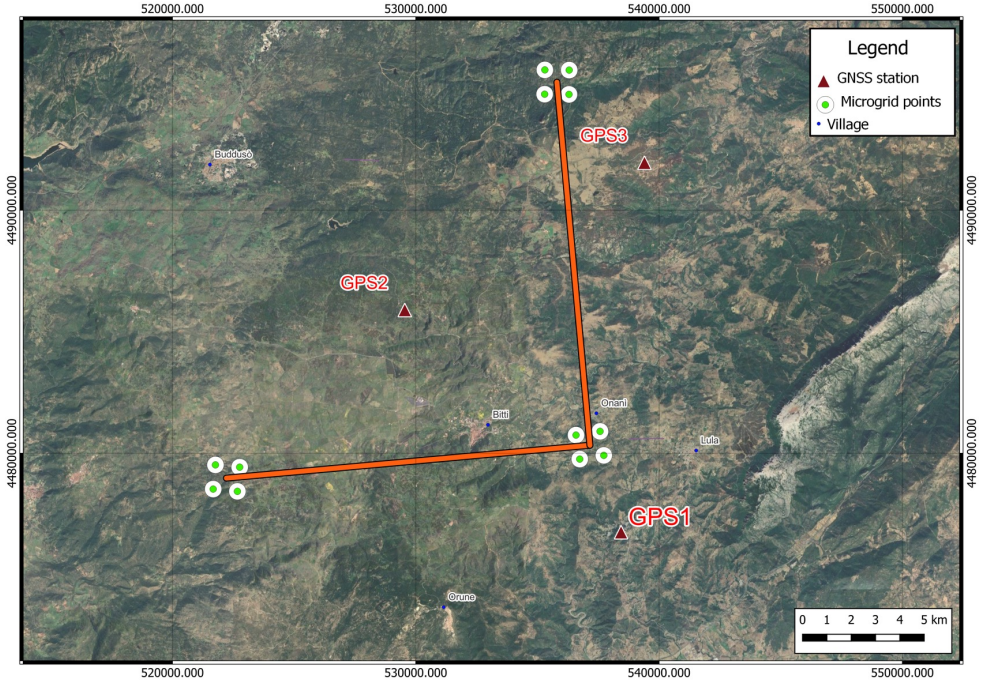
Credits to G. Sappa

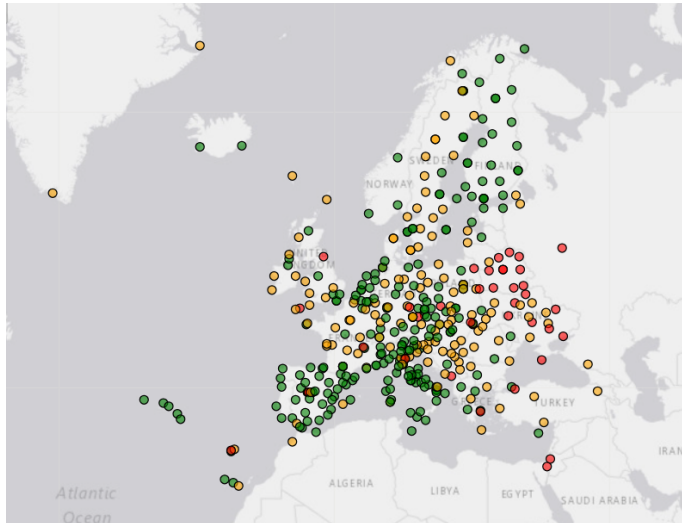
SURFACE NETWORK

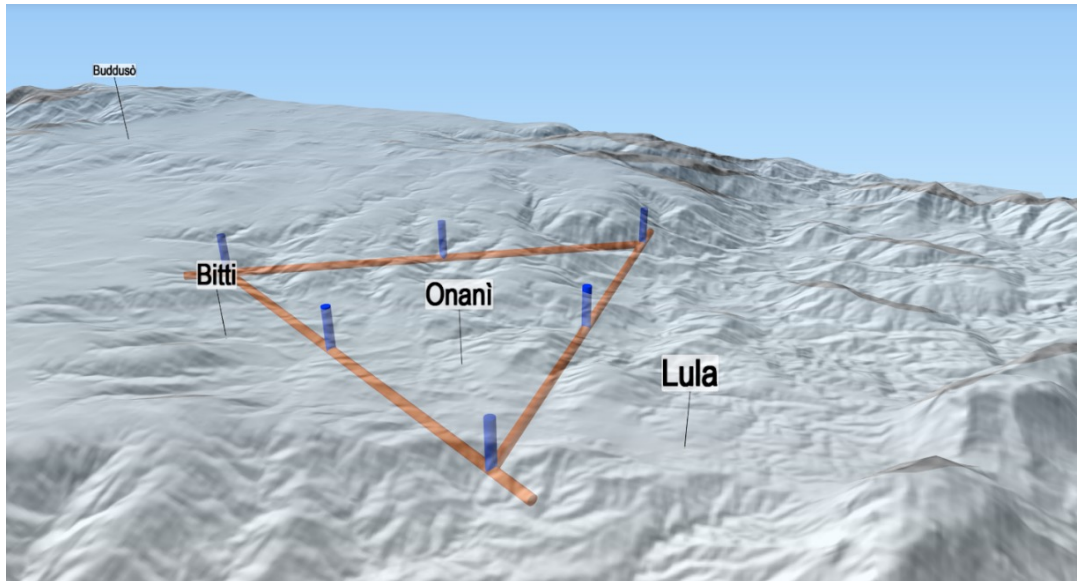
- 3 GNSS permanent stations installed to establish the primary network
- Densification network comprising passive and active geodetic points

UNDERGROUND NETWORK

- Coordinate transfer through shafts
- Installation of several monuments on the floor or walls along the tunnels







Conclusions

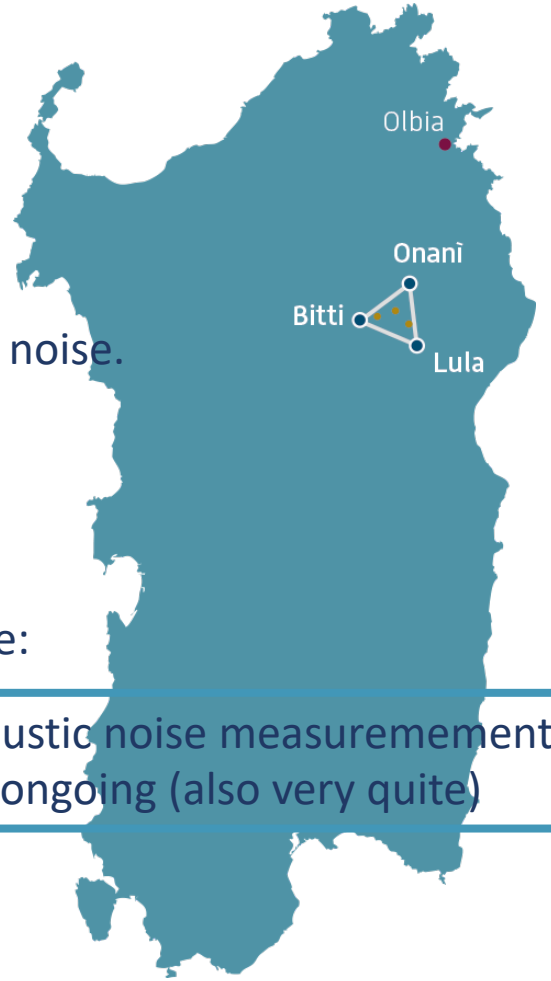
The **geo-physical site characterization** is a task coordinated by SPB of the ET collaboration.

Site characterization is strictly related to the **noise mitigation strategy and detector design**.

LF sources of noise (2-10Hz) affected by **seismic** (→ **Newtonian**) and **magnetic** noise.

Sardinia is **geologically very quiet**, far from active fault lines, and characterized by low anthropic noise.

Since 2019 (and before in 2010-2014), we installed **permanent and temporary arrays** of sensors and **two instrumented boreholes** (operative since 2021).



Measurements show a peculiar **very low level of seismic noise** in the ET-LF band (2-10Hz), where:

Seismic noise match or goes even below the Peterson's NLNM	The projected (seismic) Newtonian noise is also compatible with ET_d	Electromagnetic noise is very low	Acoustic noise measuremement ongoing (also very quite)

Possible **local sources** of noise (e.g. wind farms) are under study.

From the geological and physical point of view, Sardinia is an optimal candidate to host the Einstein Telescope, either in Δ or in L (→ 2 sites) configuration!

The geophysical characterization is a great and fruitful example of **collaboration** between Italian Research Institutes (INFN & INGV), that have brought together **different and complementary skills and expertise** to demonstrate the **extraordinary quality** of the Sardinia candidate site to host ET.

INGV

SARDINIA

FABER

FAR FAULT OBSERVATORY

Seismic events 1985-2022