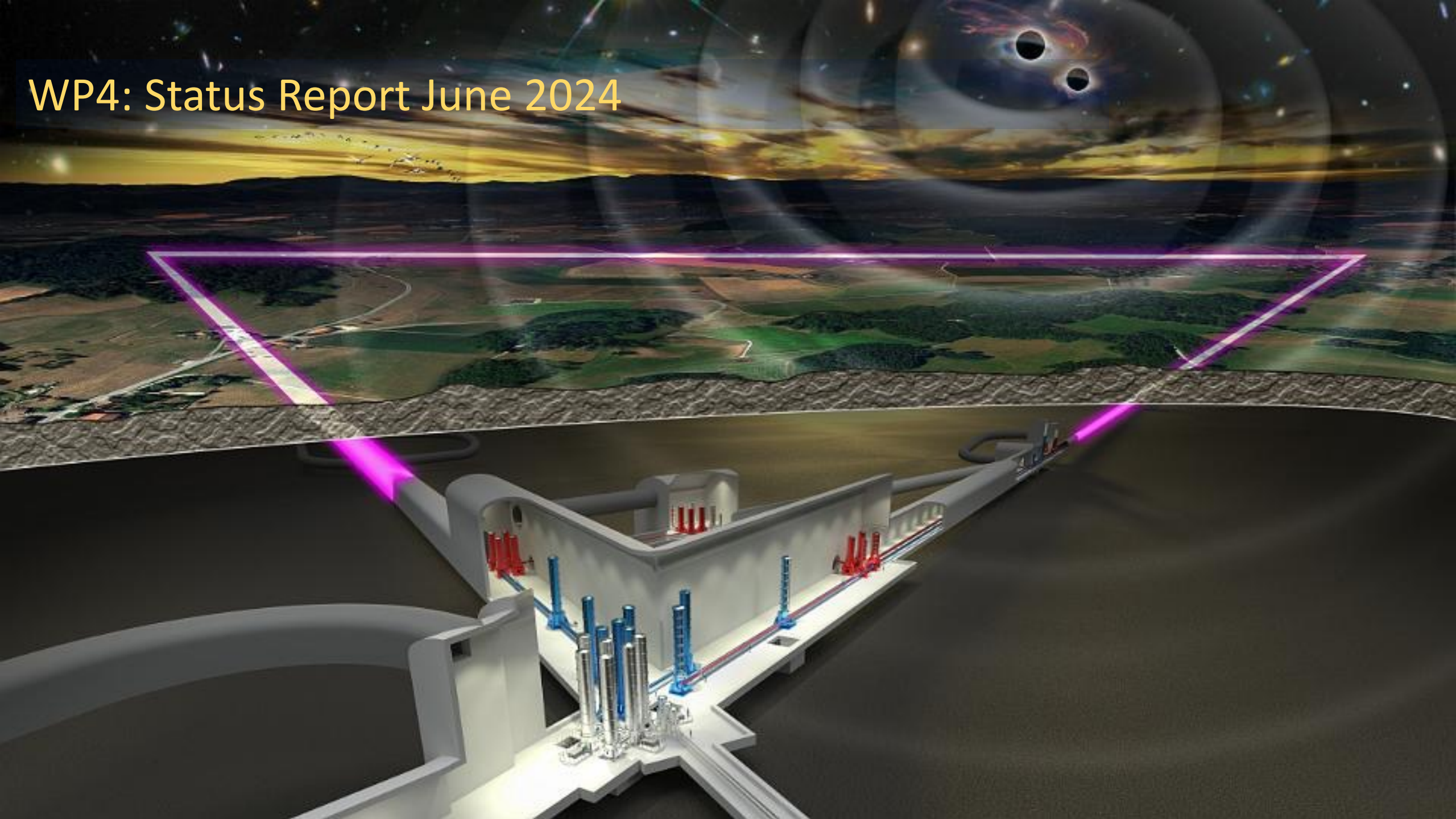
# WP4: Status Report June 2024

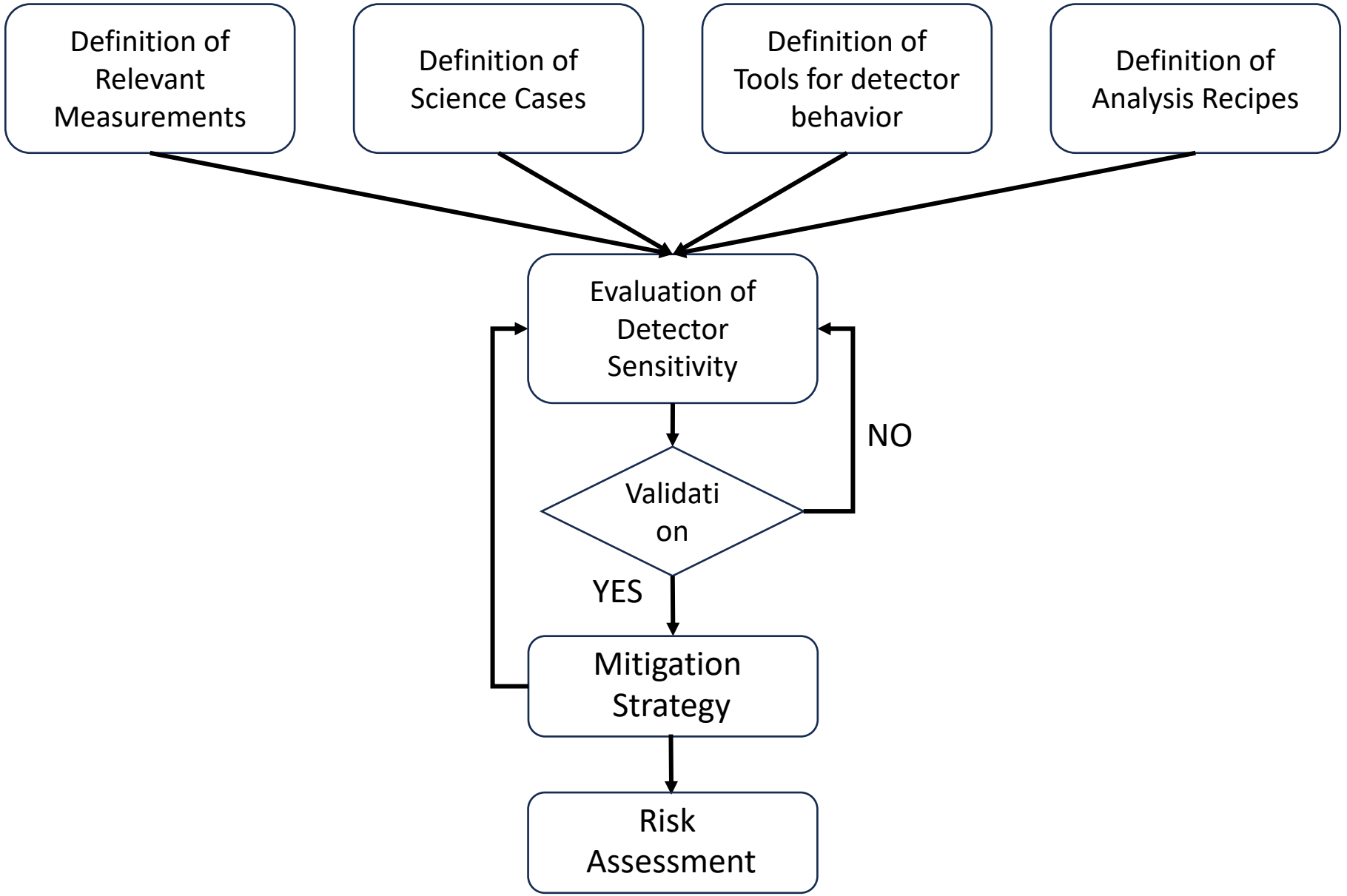


# WP4 – Update June 16th 2024

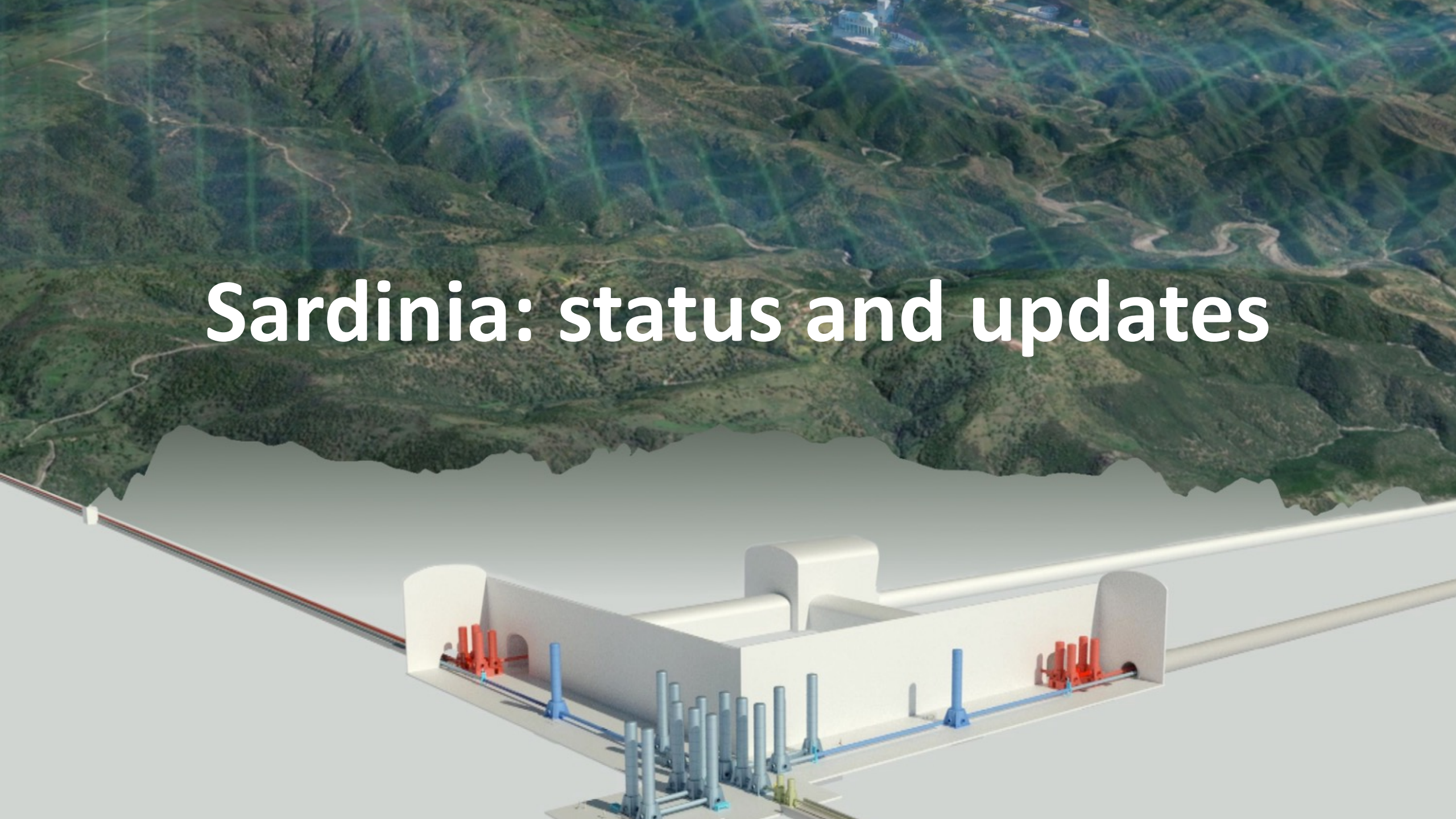
| | Deliverable | Current Status | Mitigation | Estimate |
|---|---|---|---|---|
| M 4.1 | Document detailing site-specific characteristics that impact ET sensitivity and its duty cycle<br>Lead institute: Nikhef, timing: 9/22 + 10 = 7/23 | Report published, was considered not quantitative enough | Will be updated (by inserting referenced documents) and resubmitted. | End 6/24 |
| M 4.2 | Common methodology to estimate impact of site characteristics on ET sensitivity and operation, and if required, a scheme to compensate it<br>Lead institute: INFN, timing 9/22 + 15 = 12/24 | Milestone not yet met. Common methodology is still being developed. Delayed by different site time lines. | Discussion in SPB/WP4, and host sites. Developing a more realistic timeline for individual methodologies to be published 9/24. | 6/24 first draft |
| D 4.1 | Scan of legal procedures, permitting and land acquisitions (steps to be taken prior to starting excavations)<br>Lead institute: Nikhef, timing: 9/22 + 10 = 7/23 | Delivered | | Delivered |
| D 4.2 | Updated socio-economic impact studies. Scan of accessibility, quality of life etc.<br>Lead institute: INFN, timing 9/22 + 15 = 12/23 | Update is being worked by individual local teams, but will still be limited due to incomplete information (localization, subsurface geology, geo-technical understanding). | Maintain an updated view based on new incoming information. | 10/24 for updated view |
| D 4.3 | Complete quantification of all aspects impacting ET performance for both sites<br>Lead institute: UW, timing 9/22 + 28 = 1/25 | Depending somewhat on current work progress, and teams availability, discussions with ETO | Work according to plan and contracts, discussions in SPB, ET Symposium | Expected 12/24<br>9/24 new time line |
| D 4.4 | 3D Geology, hydro-geology and modeling<br>Lead institute: INFN, timing 9/22 + 30 = 3/25 | Work ongoing, main body of activities at both sites. Local site funding and contracting result in different timeline | Work according to plan and contracts. Redefining and optimized workflow and resonsibilities between Sites and ETO | Sardinia: being discussed in contract<br>EMR: expected 1/26 |
| D 4.5 | Updated cost and schedule estimates of excavations, including noise cancelation, surface preparation costs (permiting, debris removal, land acquisition etc.)<br>Lead institute: Nikhef, timing 9/22 + 42 = 3/26 | Work ongoing, main body of activities at both sites. Local site fundunding and contracting result in different timeline | Work according to plan and contracts. Redefining and optimized workflow and resonsibilities between Sites and ETO | Sardinia: 6/25<br>EMR: 6/26 |

# ET-PP Milestone M4.2: Methodology

1. Define relevant measurements to be performed, following specific standards
2. Define science cases relevant for site dependent detector performance, likely low frequency scientific targets
3. Define tools to be used to estimated detector behavior, given a specific environmental configuration
4. Define analysis recipes to be followed to evaluate detector potentialities with respect to science cases of point 2
5. Evaluation of detector performance
6. Result validation
7. Define a possible mitigation strategy for environmental noise and evaluate possible additional costs
8. Evaluation of detector performance considering mitigation strategies of point 6
9. Result validation
10. Risk assessment of scientific descoping taking into account results obtained in point 5 and point 8


Definition of Relevant Measurements
Definition of Science Cases
Definition of Tools for detector behavior
Definition of Analysis Recipes
Evaluation of Detector Sensitivity
Validati on
NO
YES
Mitigation Strategy
Risk Assessment

# Sardinia: status and updates



# Action lines

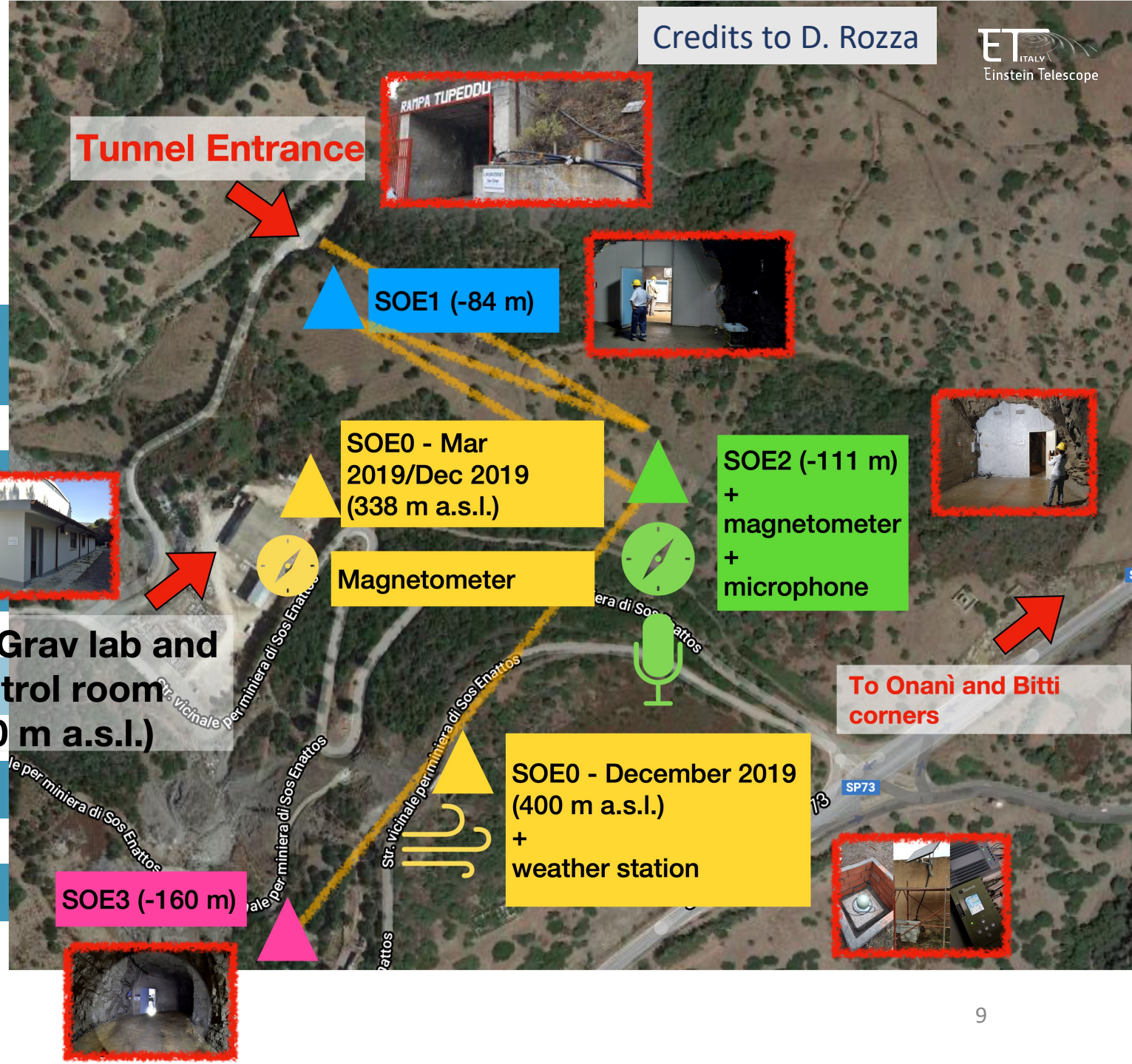
- Site monitoring
  - identification and quantification of local source impact
  - implication for site preservation quality
- Geological studies
  - understanding and characterization of local geology
- Civil and environmental engineering
  - geotechnical investigation
  - optimal placement and environmental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

# 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

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*

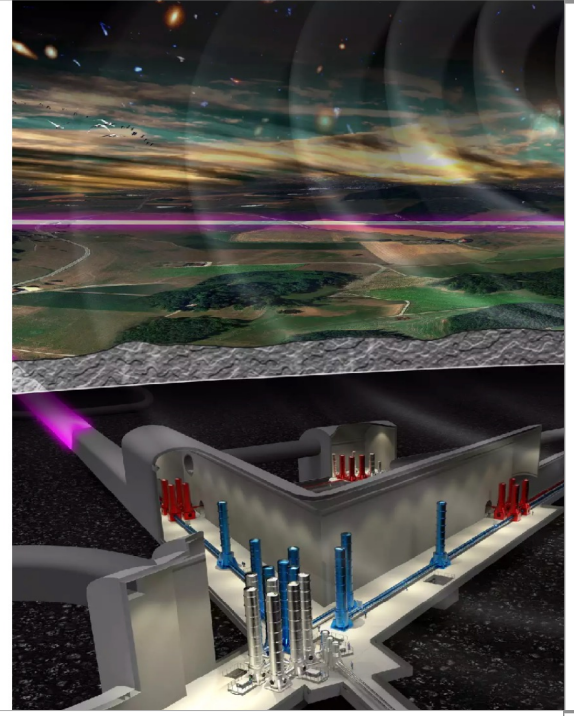
INFN Istituto Nazionale di Fisica Nucleare

uniss UNIVERSITÀ DEGLI STUDI DI SASSARI

ET ITALY Einstein Telescope

INGV

SARDINIA FABER

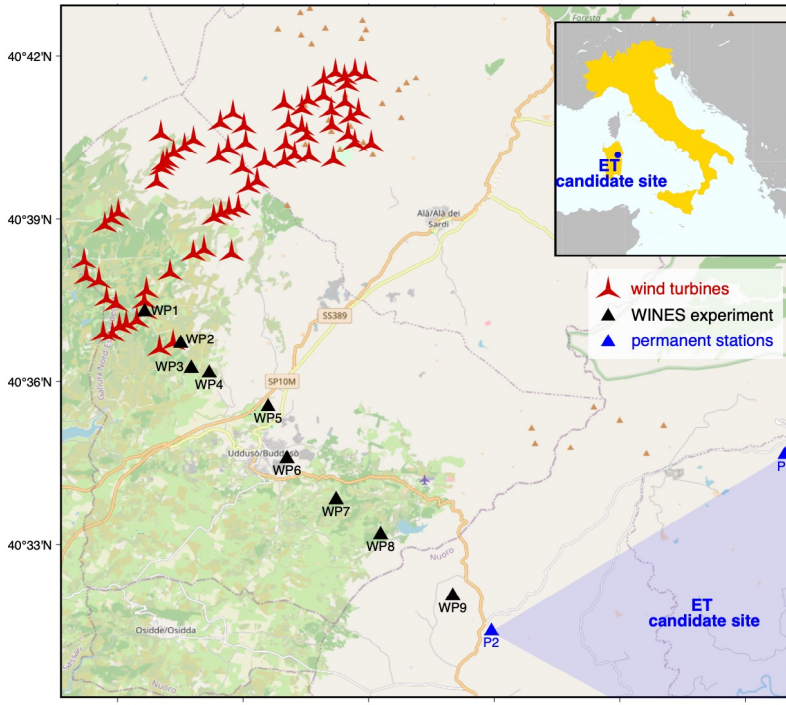


## The Italian candidate site

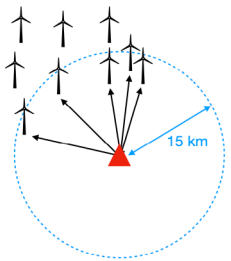
One of the **largest wind park** in Italy is just **15 km** away from the **ET candidate site**

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

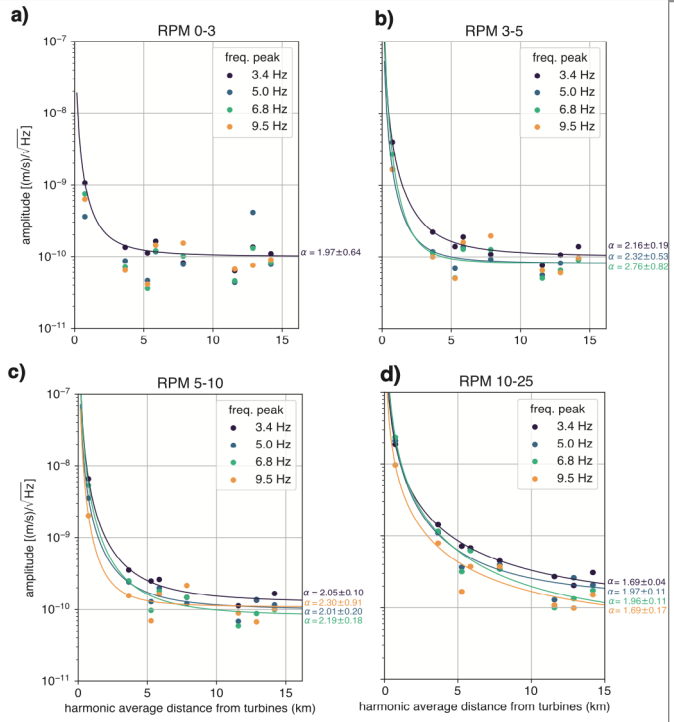
- **9 broad-band** seismic stations
- **~13 km** linear array
- **~2 months** of recording (8/04-30/05/2023)




## amplitude decay



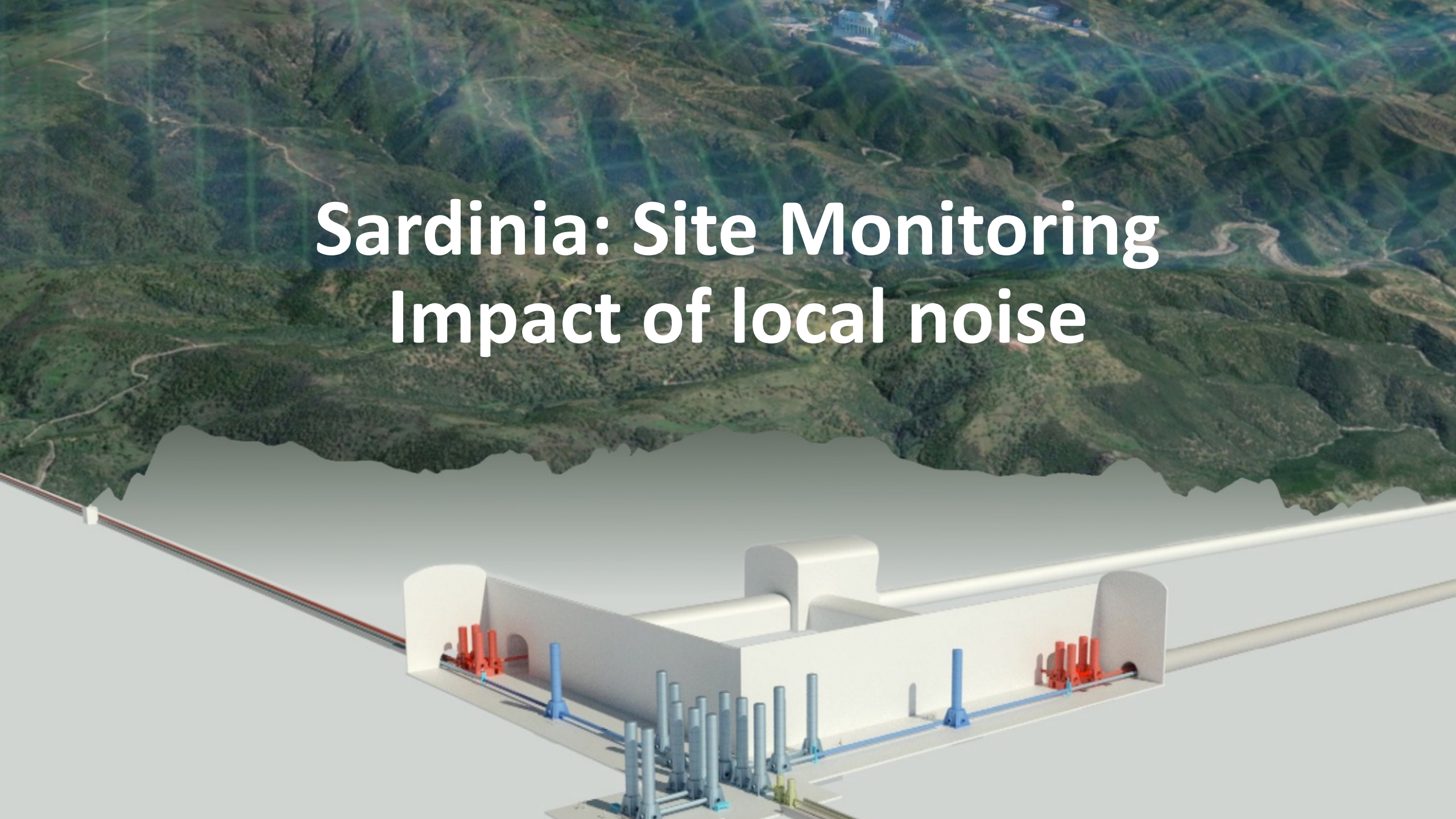

- for each station, we take the **number (N) of turbines within 15 km**
- calculate **harmonic mean distance** of all **N stations**
- **divide** the spectral amplitude by $N^{1/2}$ based on the assumption that turbines are **quasi-random noise source**, **adding in quadrature**
- **fit** with a $1/r^{\alpha}$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

# Sardinia: Site Monitoring
# Impact of local noise



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





ET ITALY Einstein Telescope

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:

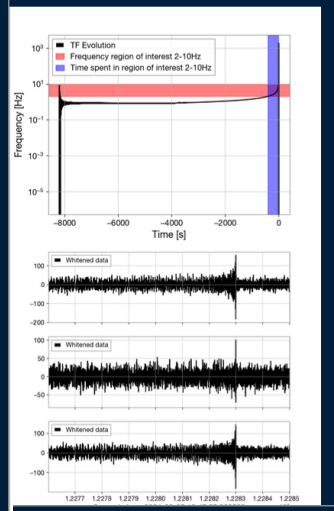
- Low frequency to assess the impact over early warning for BNS mergers (order of KHz)
- Low-mid frequency to assess the impact over IMBH mergers (order of 10 Hz)

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.

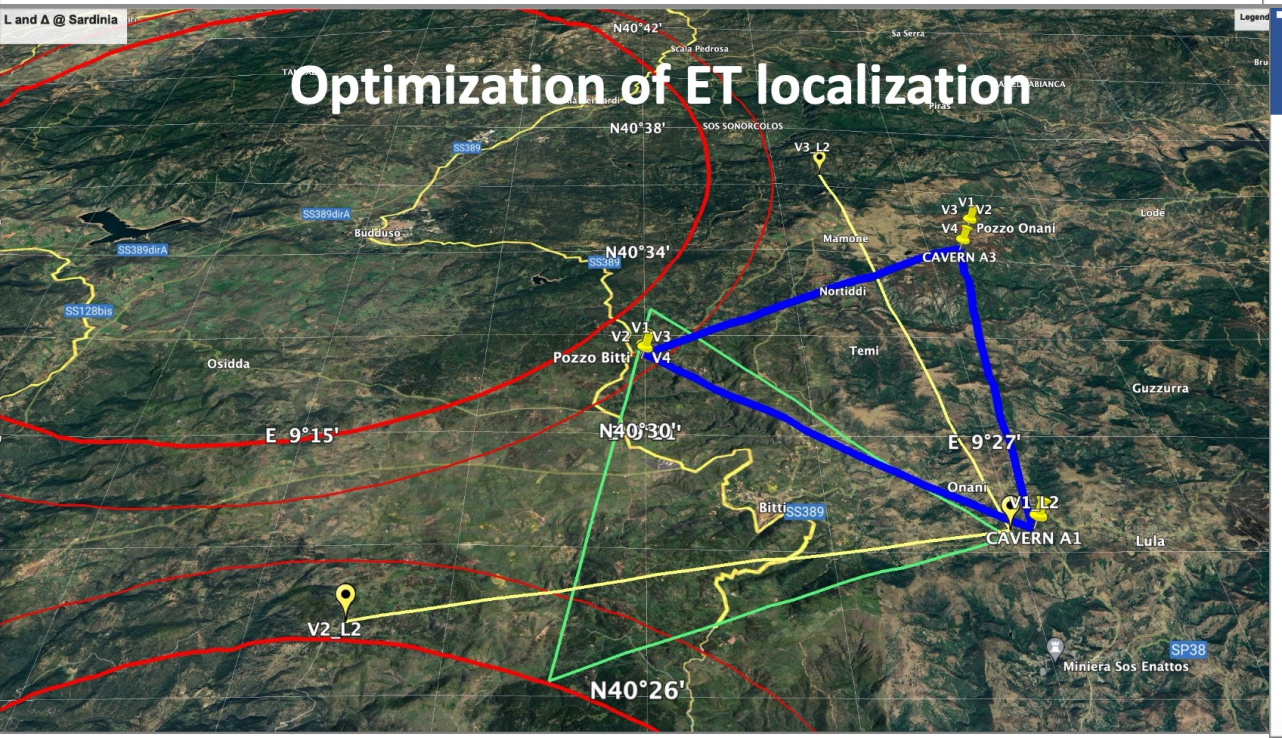
ET ITALY
Einstein Telescope

# 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

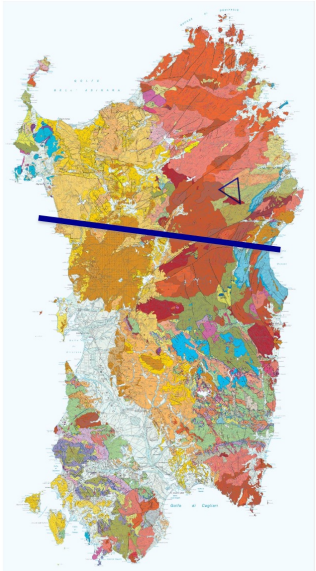


# General remarks

- 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**

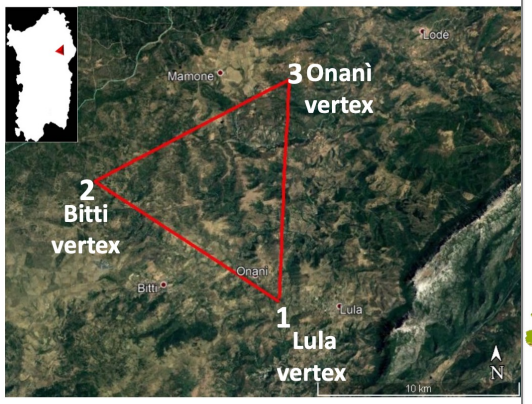
# Sardinia: Geological Studies

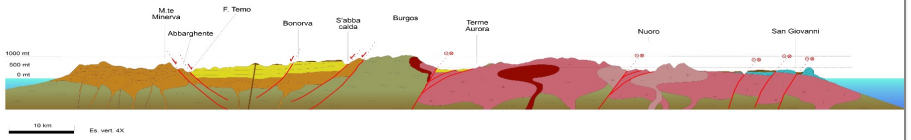
# Geological comparison: the ET Italian candidate



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.

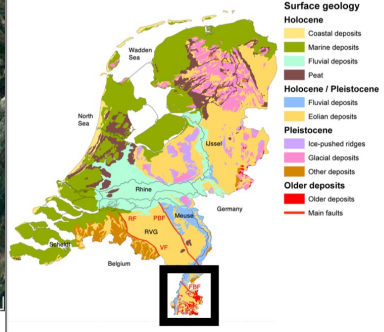
In the last few million years, the island has been essentially tectonically quiet.

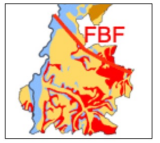


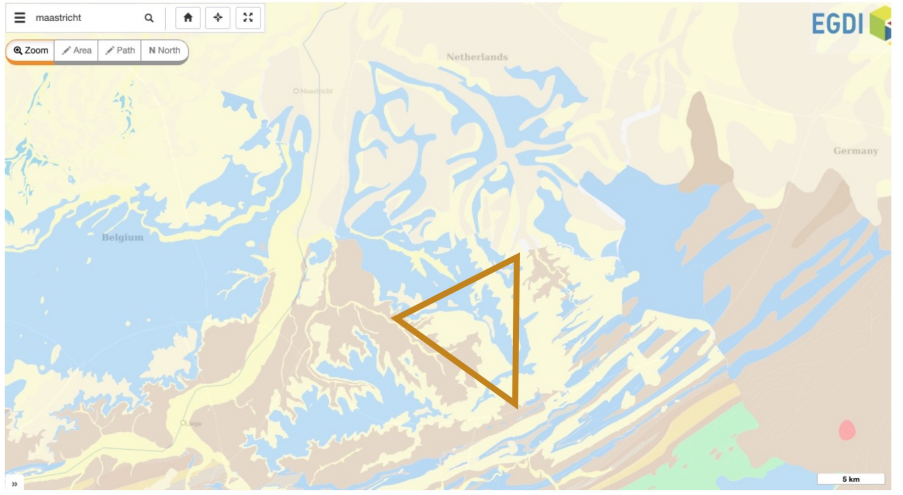




# Geological comparison: the Belgian-Dutch site

**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

# Reference geodetic network

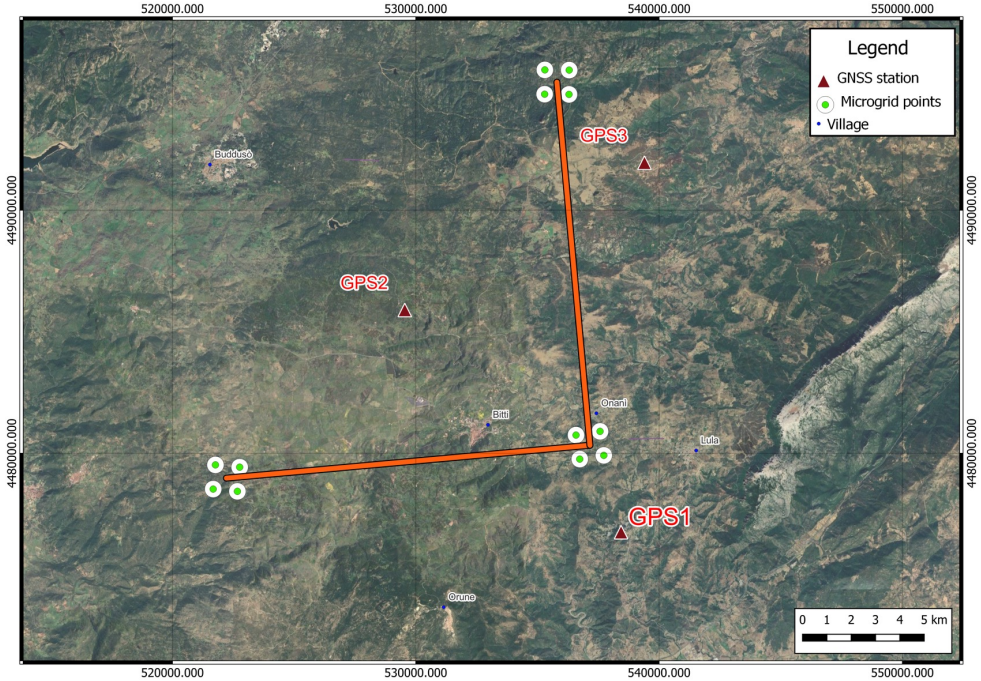
Credits to G. Sappa

## SURFACE NETWORK

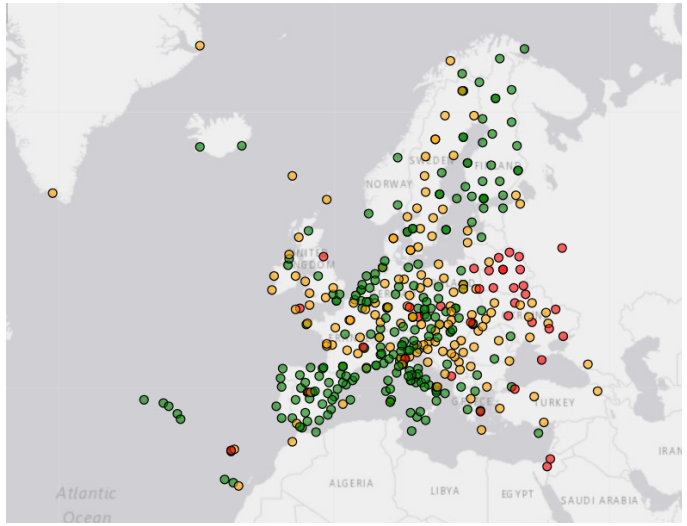
- 3 GNSS permanent stations installed to establish the primary network
- Densification network comprising passive and active geodetic points

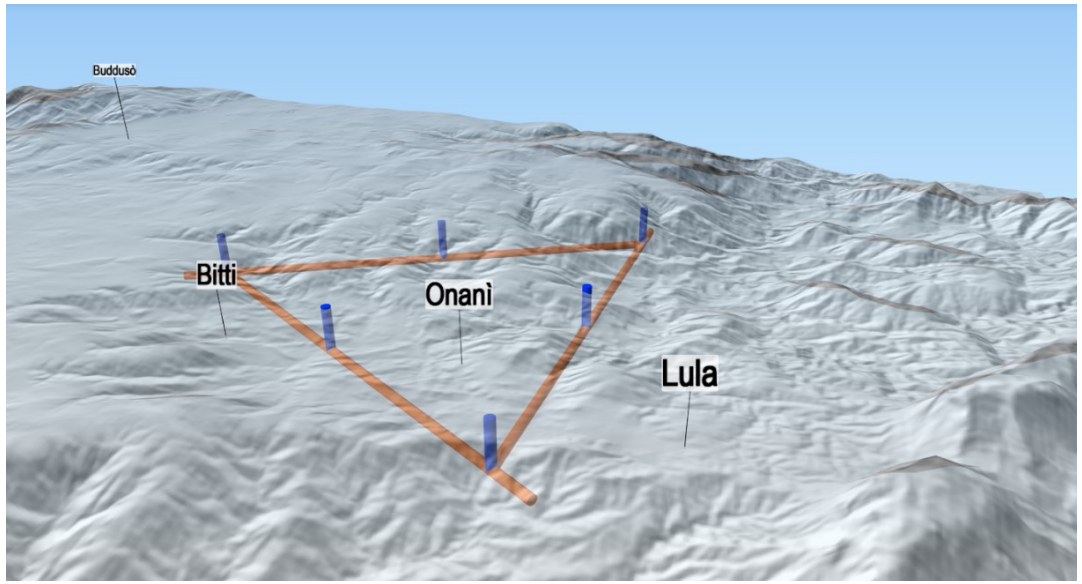
## UNDERGROUND NETWORK

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







# Activity Plan for the Preliminary Site Condition Assessment

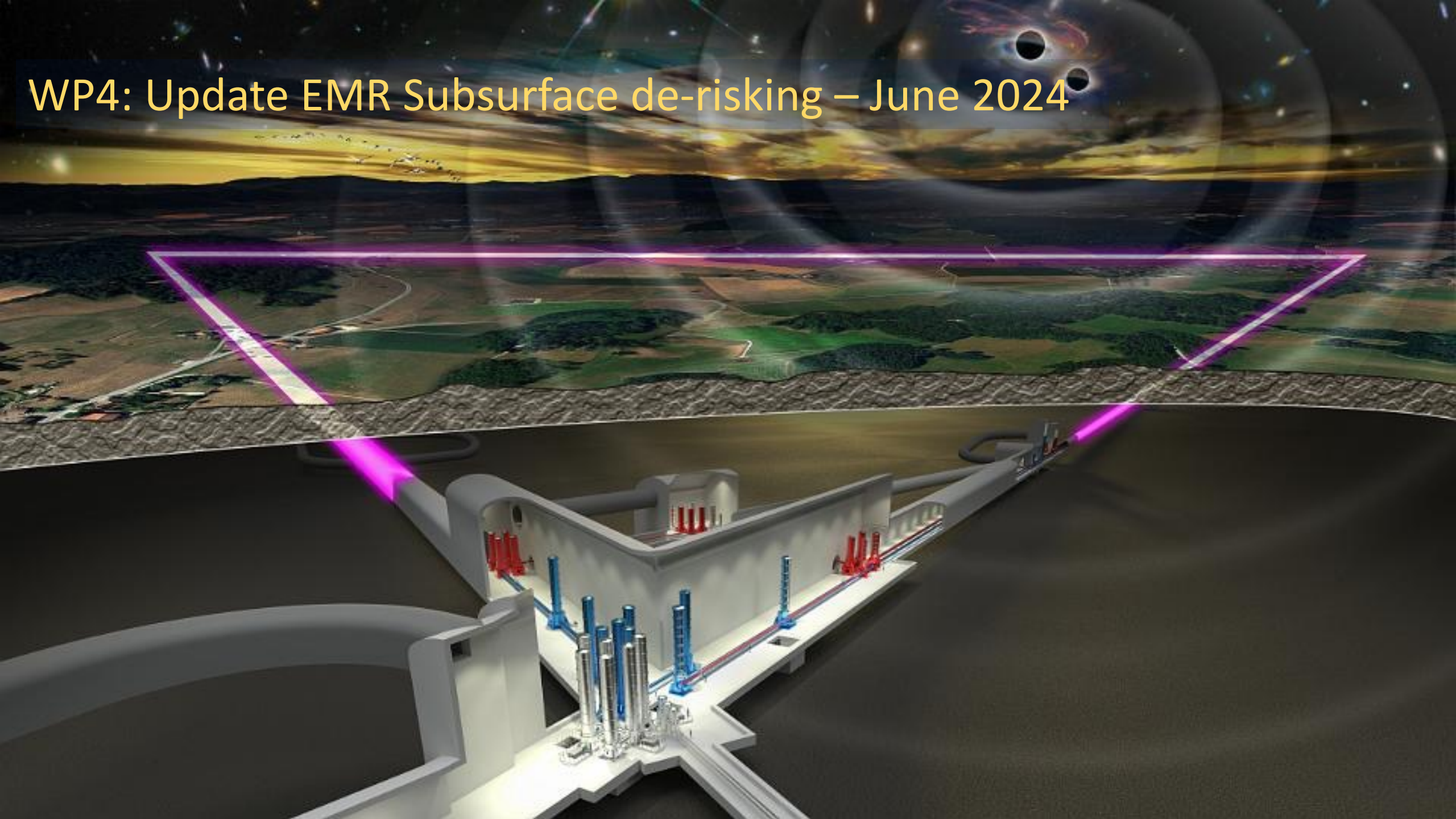
Credits to G. Sappa

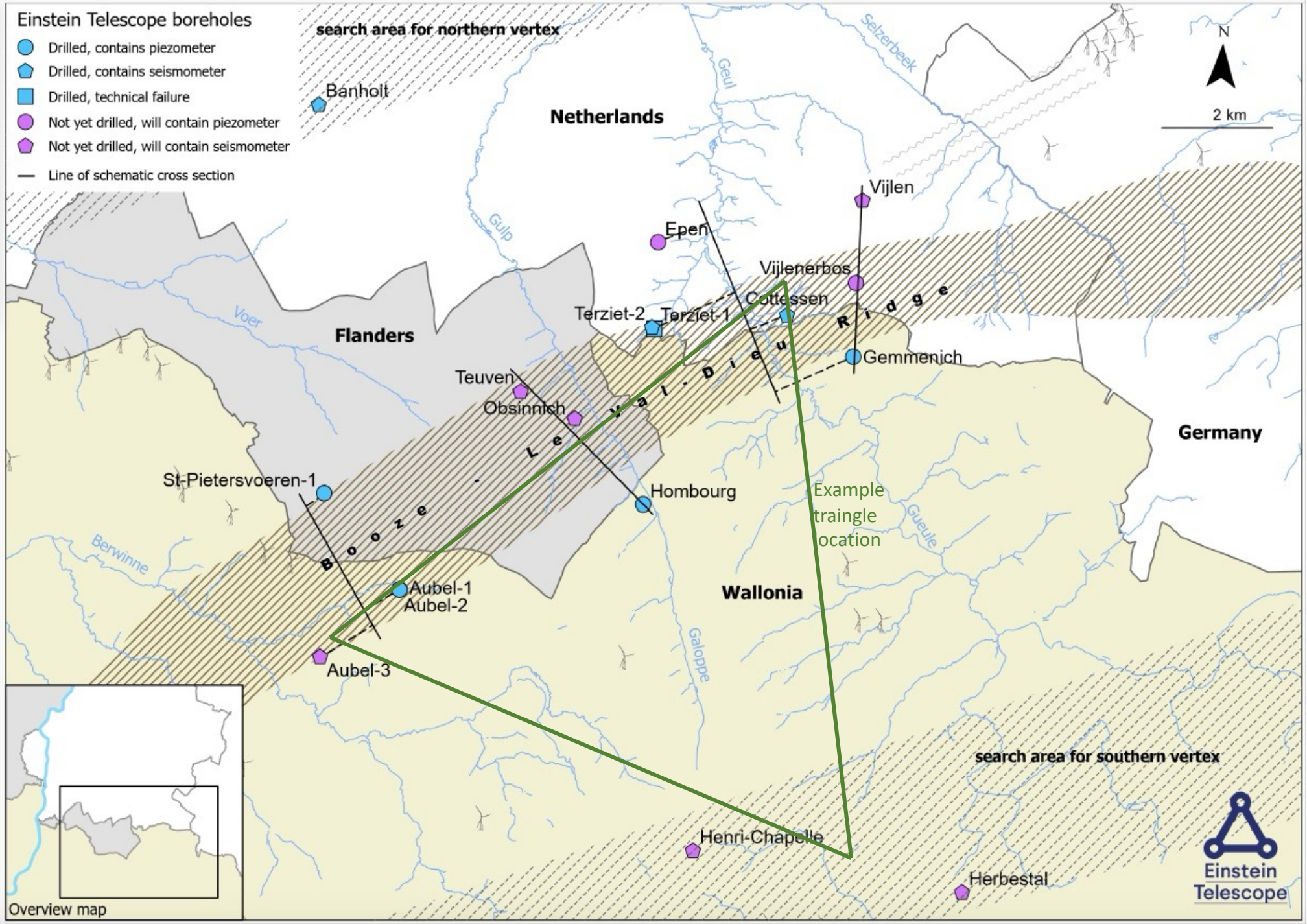
- Lidar survey for scanning the the ET area with 3D restitution
- 80 surveys for the determination of the geostructural characteristics of rocks outcropping
- Geological, geomorphological and hydrogeological surveys for the definition of geological characteristics of the area
- Environmental investigations 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

# News and updates

- **Feb 6th 2024:** Tender of the PNRR ETIC project for the preliminary feasibility study for ET in Sardinia assigned
- **Feb 19th 2024:** Start of activity
- **June 30th 2025**: Deadline activity
- Assumptions: ET located in the area of Sos Enattos (NU, Italy), considering both triangular (six interferometers inserted in a system of tunnels and caverns with an equilateral triangle layout on a side about 11 km) and L shape (two interferometers inserted in a system of tunnels and caverns with an 'L' layout on a side about 16 km) configurations.
  - Modeling and Layouts
  - Preliminary cost estimate (excavation)
  - Evaluation of TBM configuration and tunnel monitoring
  - Preliminary indications on the management of excavated lands and rocks
  - Preliminary strategy on the management of excavated soil and rock
- Site Investigations will start in a few weeks (investigation plan under discussion)

# WP4: Update EMR Subsurface de-risking – June 2024

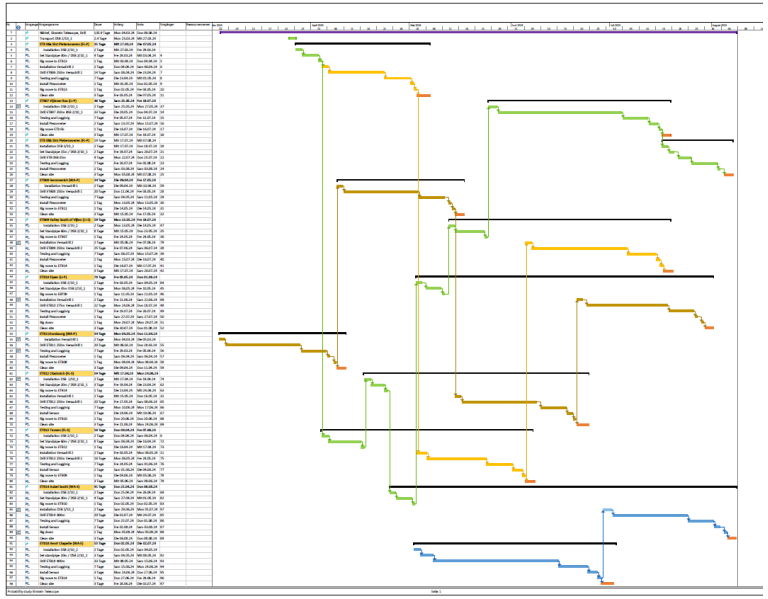





| | |
|---|---|
| Hombourg | ✅ |
| Sint Pieters Voeren | ✅ |
| Gemmenich | ✅ |
| Teuven | Driling at 175m |
| Aubel-2 | Drilling at 120m |
| Vijlen | Drilling at 72m |
| Obsinnich | Pre-drill completed |
| Epen | Pre-drill completed |
| Herbesthal | Pre-drill started |
| Henri Chapelle | Awaiting start June |
| Vijlner Bos | Awaiting start August |

# First Drilling Campagn:

- 11 boreholes:
  3 in NL
  4 in Flanders
  4 in Walloon
- Three completed, now drilling 4, 5 and 6
- Pre-drilling 7 and 8
- Waiting 9, 10 and 11.
- Ending end-August



- Uses 4 drilling rigs in parallel
- Complex Logistics

Core evaluation started

Vijlen, Aubel en Teuven currently drilling

Hombourg, Sint Pieters Voeren and Gemmenich drilling completed on schedule

# Daily Dashboard – 17 June 2024

General Status: No major issues
Schedule: Some site swapping due to permits, slower due to geology
Top Risk: Resources streched. Focus on maintaining control, ensuring safety

Sites currently drilling:

Teuven:
- Completed at 311m
- Very nice and comptent rock
- Image logging now

Aubel:
- Now 225m (of 400m in total)
- Massive, veined sandstone
- Drilling speed increasing
- Dips ~20d

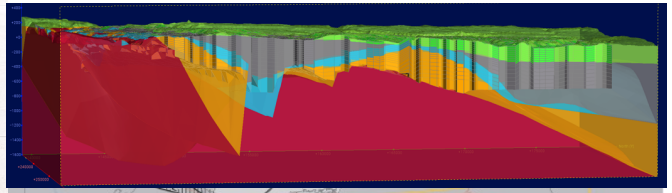
Obsinnich:
- Drilling at 152m
- Some fault zones
- Very competent rock

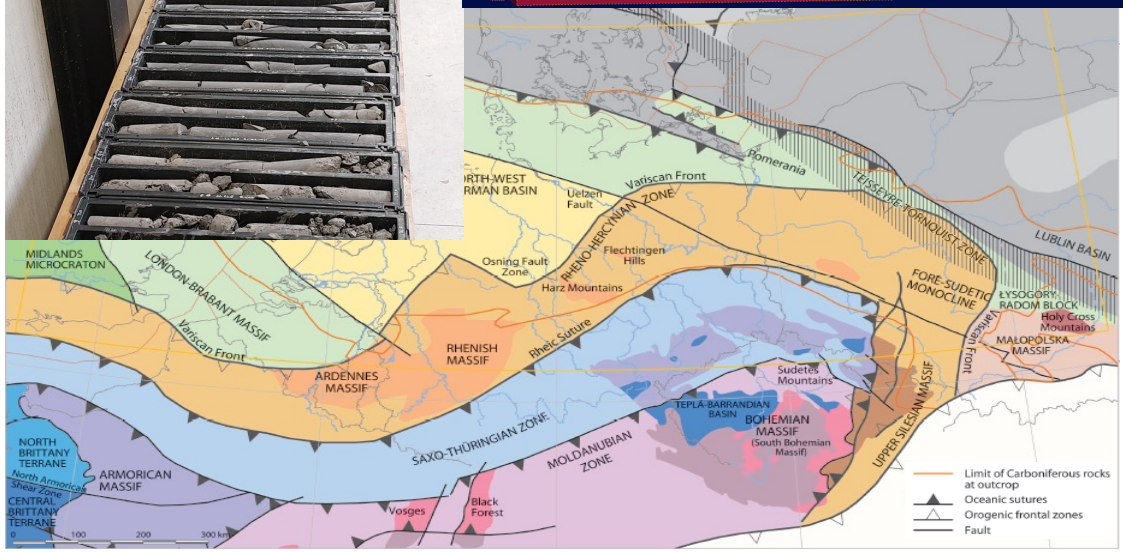
Other Sites:

- Epen: Pre-drill completed at 42m.
- Vijlen: Pre-drill completed at 62m.
- Herbesthal: Pre-drill now at 52m
  Difficult drill, possibly old quarry,
  Checking documents and closely monitoring
- Henri Chapelle: Location fixed, preparing field
  Vijlner bos: Awaiting start in August

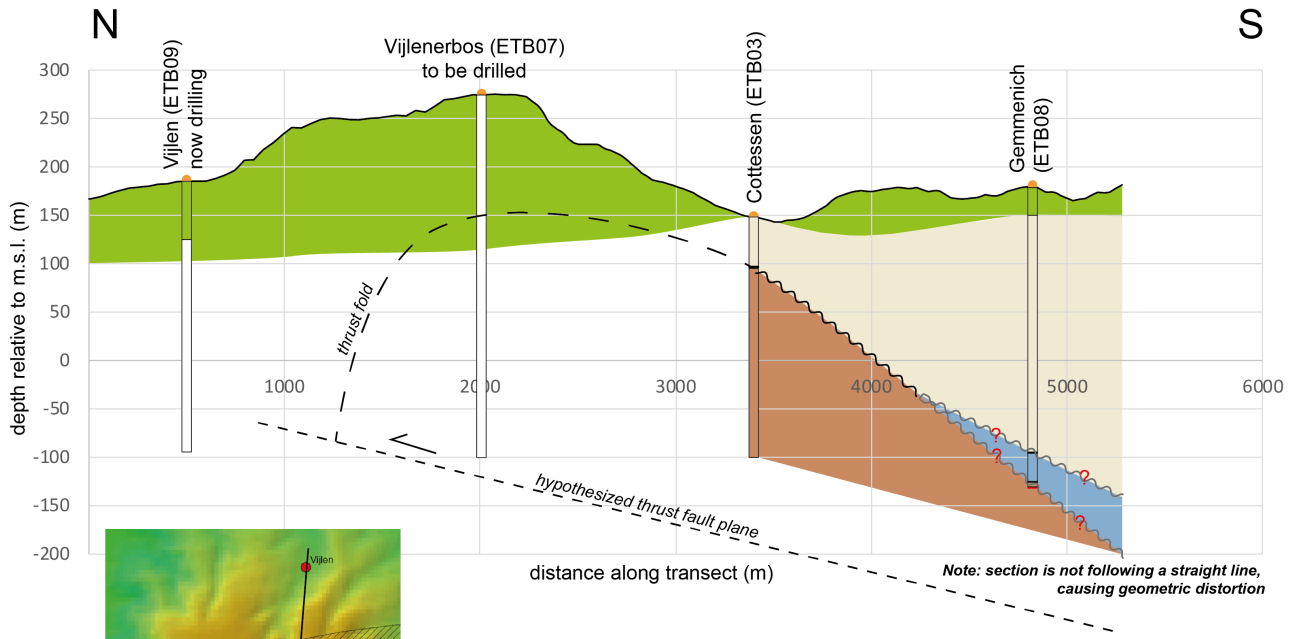
- Gemmenich: 314m completed, site cleaned.
- St P Voeren: 270m completed, site cleaned.
- Hombourg: 251m completed, site cleaned.

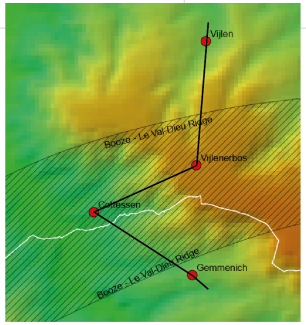
# 3D Integrated Modeling taking off…

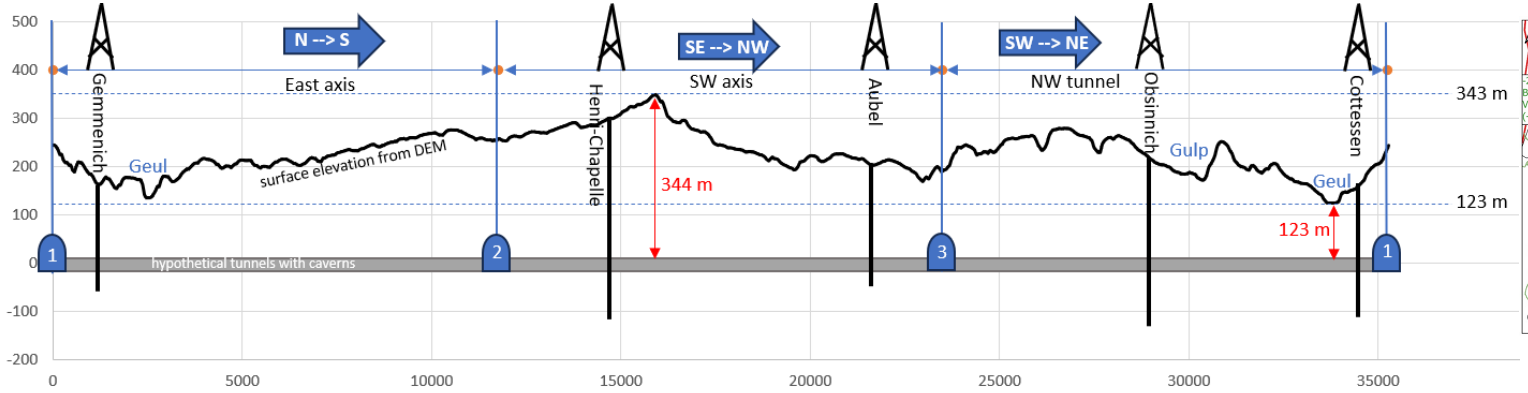


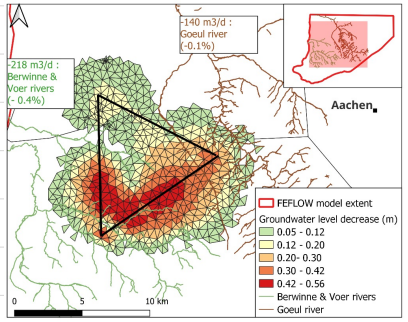


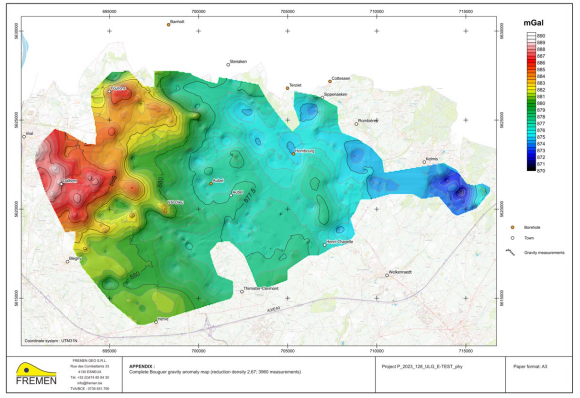

**Synthesis of boreholes across the Booze - Le Val-Dieu Ridge**



# EMR Subsurface Database – current draft of contents

Continuous recording of seismic noise data(MSED2-format?)
- related infra-sound and weather data
- Derived results (PSD's etc, reports)

Seismic Newtonian Noise modelling
- subsurface model calibrated with measurements
- Forward modelling results for predicting noise behavior.
- reports, etc.

Passive seismic data
- continuous recording
- Derived results e.g. Vp, Vs, (PSD's etc, reports)
- interpretation: faults

Active seismic data, raw & final results (SEGY)
- acquisition and processing reports
- derived attributes, e.g. Vp, Vs, anisotropy, attenuation?
- interpretation: horizons, faults

DAS and DSTS (strain, temperature, and acoustic digital sensing) data
- VSP's ==> time to depth conversion, attenuation
- Processing results and reports

Magnetic
- In-well logging: Susceptibility, 3D H-field
- long-term measurements of noise

Gravity
- raw data and inversion results

ERT data
- 2D raw data
- inversion results

Heave Monitoring
- InSAR scenes
- GNSS time series

GIS data
- Maps in various forms with different attributes
- topography
- Lidar

3D subsurface static model
- attribute grids: permeability, Poisson's ratio,...
- horizons
- faults
- integrated views of evaluated data

3D dynamic model
- hydrological modelling results
- core evaluations, local space evaluations
- integrated views of evaluated data

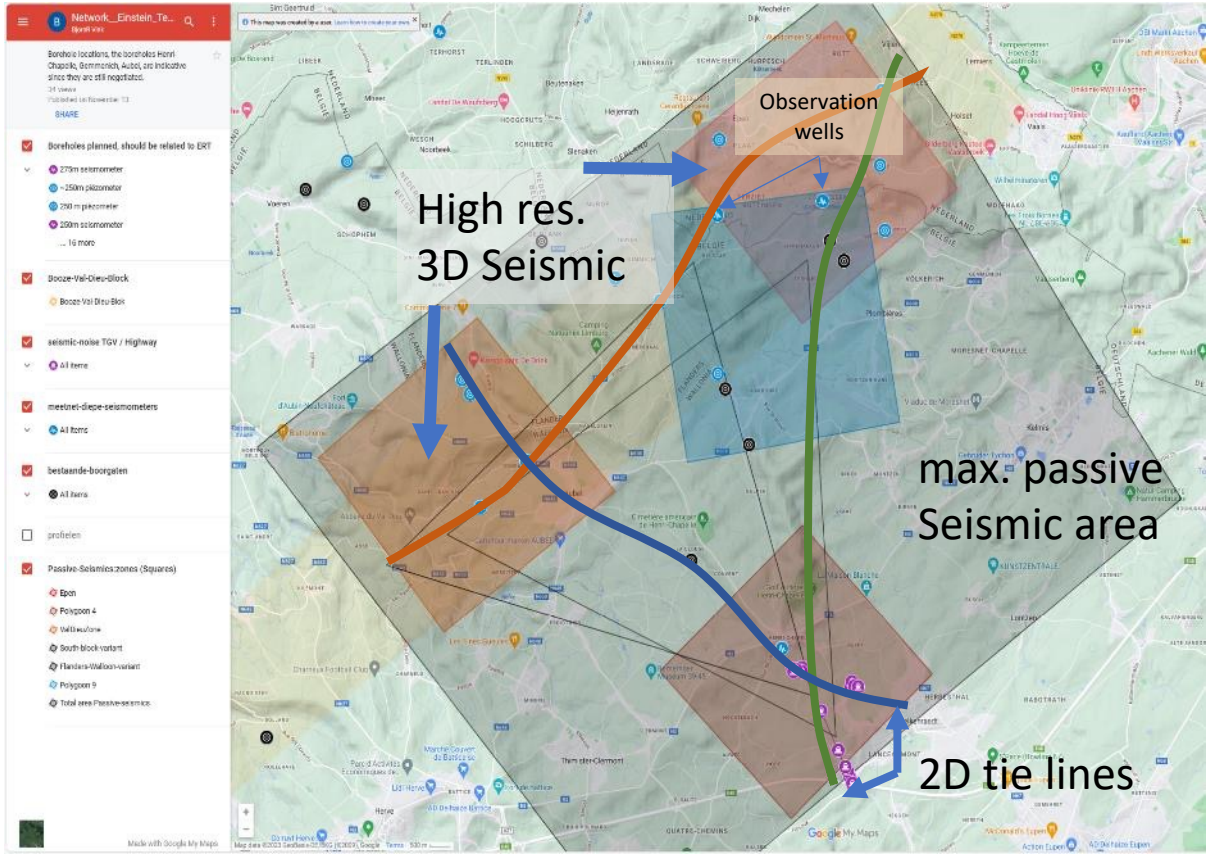
Core logging and measurements
- drilling: daily reports in PDF/image format;
- final bore hole report,
- photos in image formats
- logging: data in raw format, wellcad format, pdf, image format, .txt or .csv;
- packer tests & stress tests: data in excel format -> .txt or .csv possible
- packer tests reports in pdf format

Geomechanical tests:
- reports in .pdf, data in excel (.txt or .csv possible)
- rock characteristics, and expected behavior
- mechanical and chemical properties
- rock classifications: Q-SYSTEM AND RMR
- overall borehole feasibility assessment report

Separate:
- permits, risks and mitigation, cost estimates, updated planning forecasts

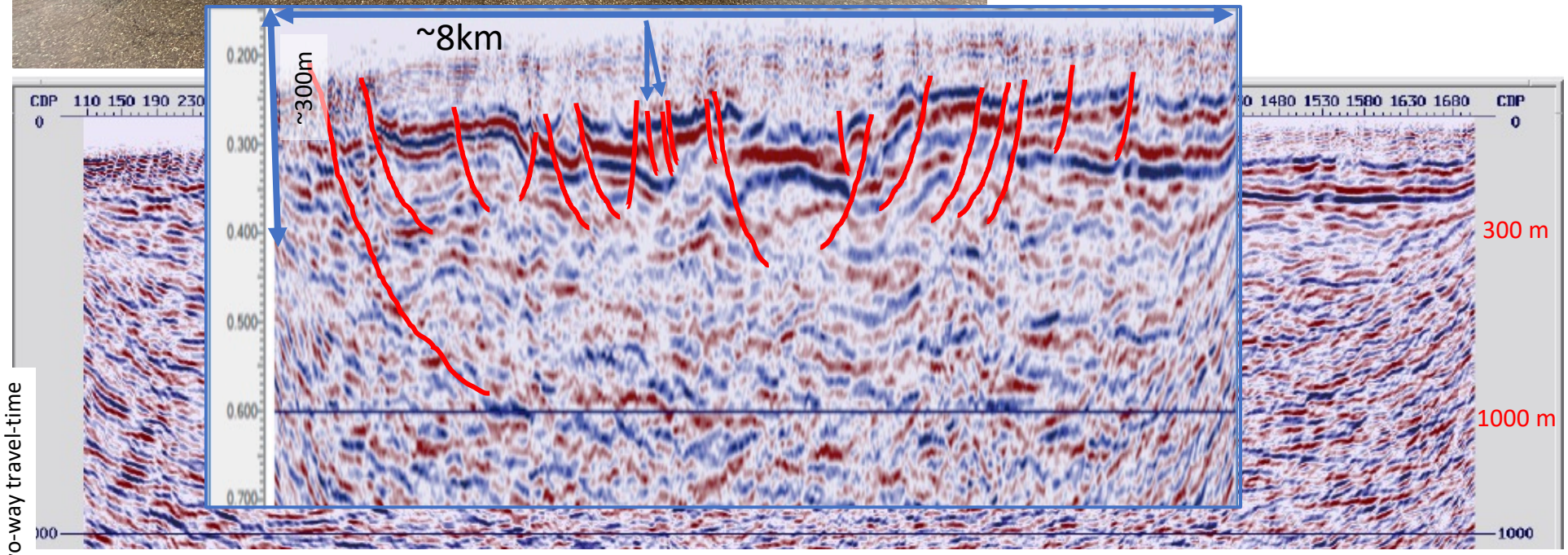
# Active seismic campaign 2024 starting this Fall

- 3+ high res. 2D seismic tie-lines between envisioned corner-points
  - Tying into most instrumented wells
  - ➔ crooked lines, total of ~ 50-60km. single vibe (1-100Hz), 5m source, 5m receiver, offset ~1000m, image depth range 0-600m
- 3 high res. 3D seismic surveys (cross-spread based) at potential corner points
  - Each ~1km*1km, 50m source/receiver line spacing, 10m source spacing, 10m receiver spacing ➔ 10k source & receiver positions, 20-line km
- Simultaneously acquire 2D/3D DAS-VSP's at instrumented wells
- 3D passive seismic to delineate Booze Val-Dieu block with Vp, Vs
  - Cover the area (~100 - 225km2) encompassed by the corner-points

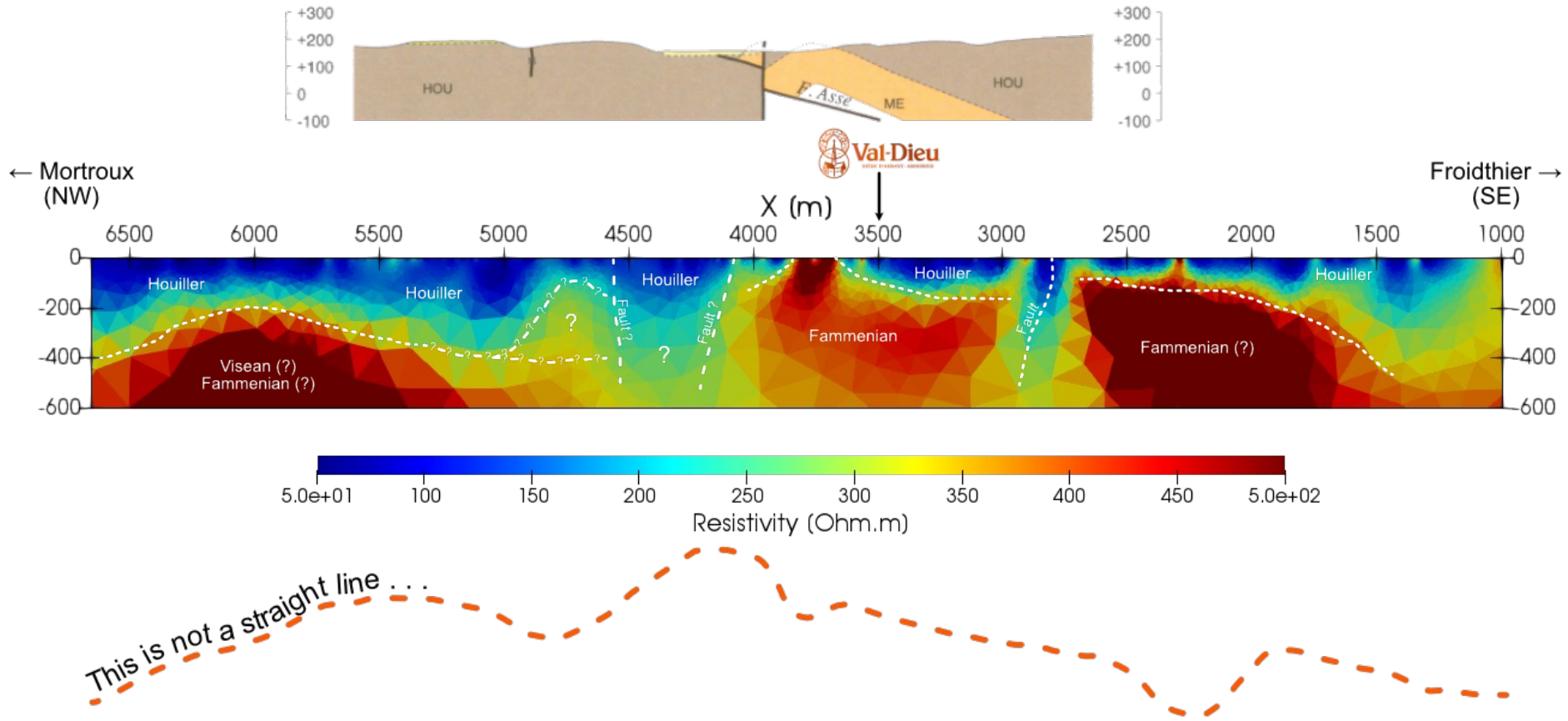


# Active Seismic appears to be more effective than expected


- Electrical Source effective, environmentally friendly
- Strong reflection layers visible and traceable
- Valuable info between and around corner points
- Deeper structures visible
- Clear indication of fractures



# Interpolate in between bore holes using ERT and, soon, Active Seismic




Example of ERT and seismic calibration using Aubel boreholes

# De-risking Activities

Boreholes: two sets of ~10

Geomechanical Evaluation Cores vs Shafts

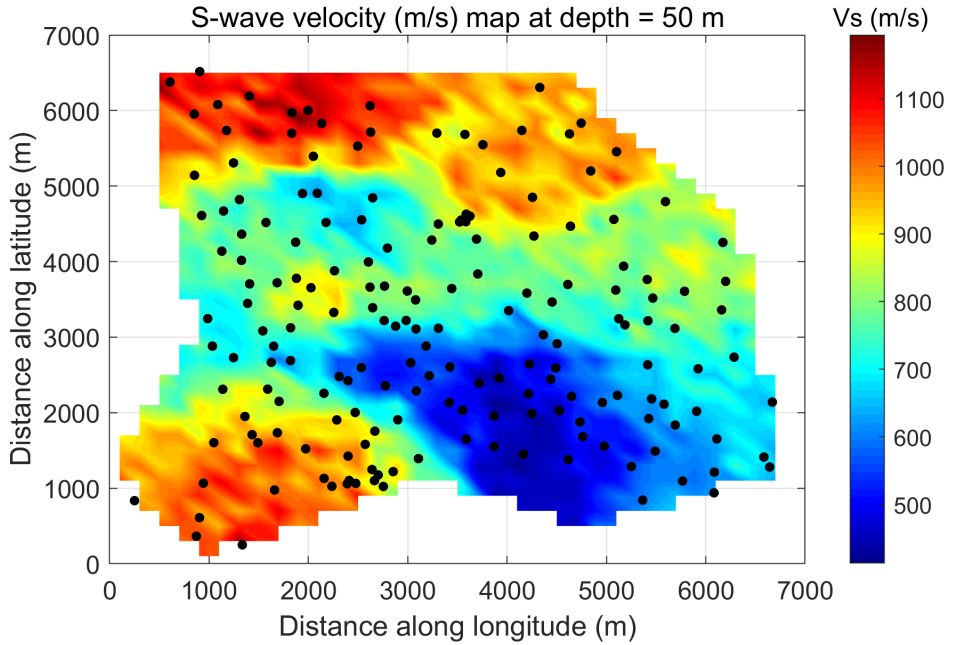
Hydro-geology

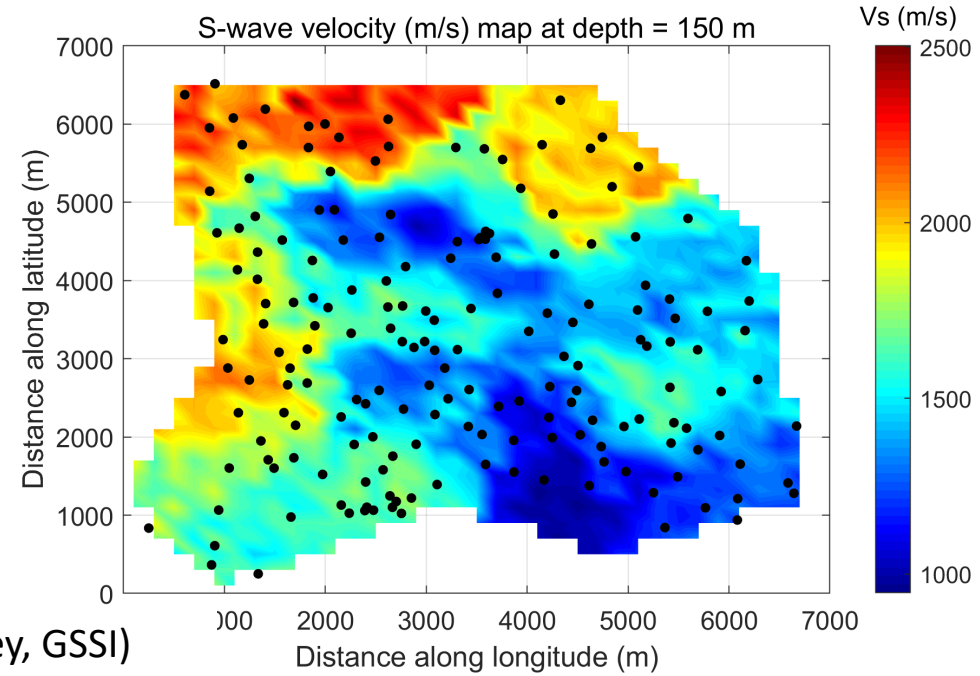
Active seismic campaign

Passive seismic campaigns

ERT, Magnetic, Gravimetric surveys

Anthropogenic Noise Studies

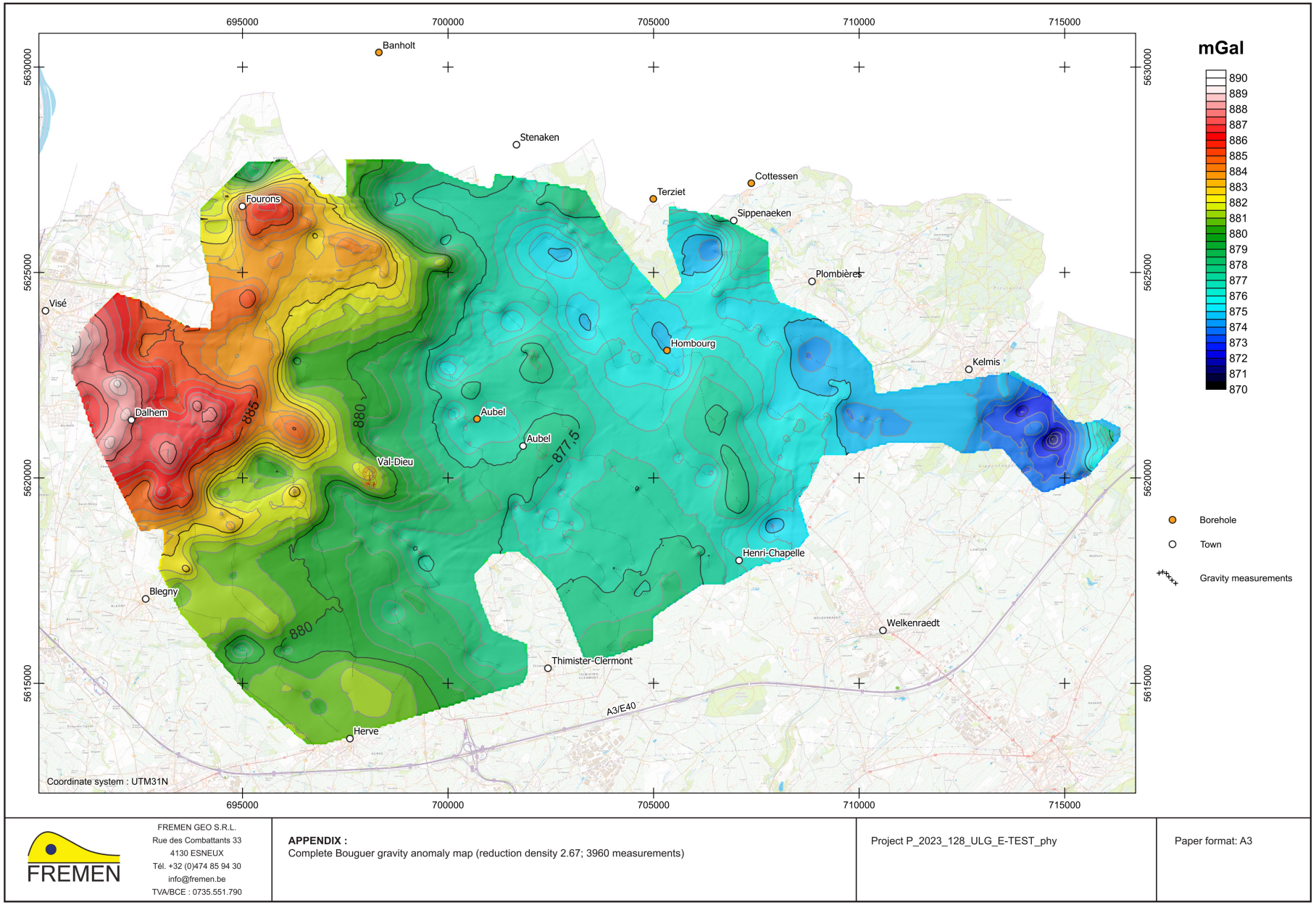



(Soumen Koley, GSSI)

# Gravimetrics

- Complement 3D Integrated Model
- Joint inversion



# Seismic and Magnetic Noise Measuring Network

- Extensive network of seismic sensors and magnetometers
- ~20 broadband permanent seismic stations on surface
- ~10 broadband borehole seismometers: three installed and next 5 starting August
- Moving flexible seismic sensor network (400 Multi-Component)
- Magnetometers, first installation mid July
- First, preliminary noise results along region expected:  Q1-2025.