Update EMR WP4 Site Specific Studies (July 2025)

ET-EMR: stable course, adaptive power

Towards robust and sustainable feasibility of ET hosting

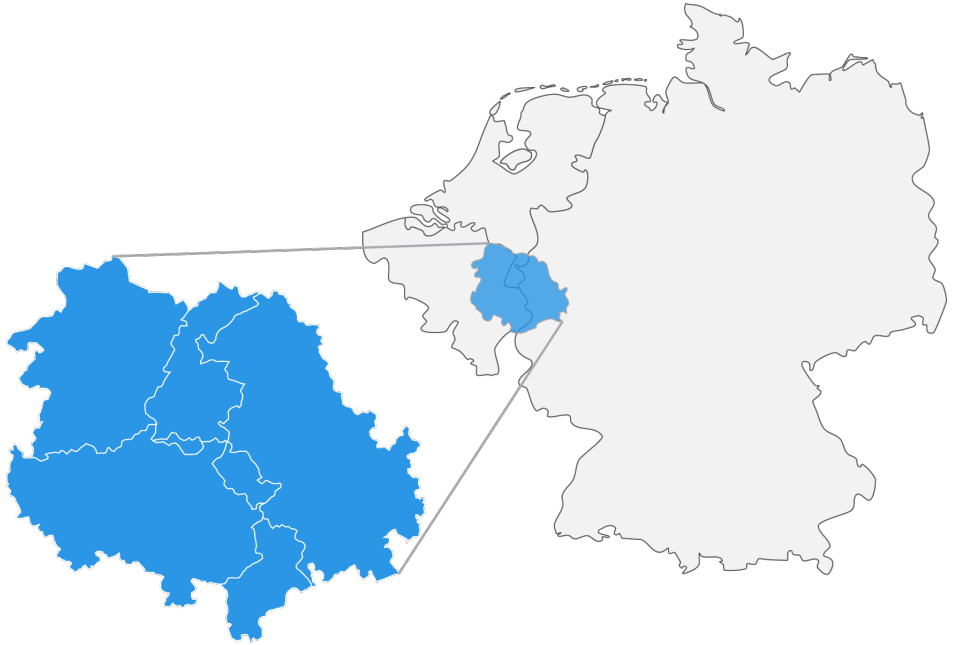
Stan Bentvelsen

on behalf of Wim Walk

22-24 July 2025

EINSTEIN TELESCOPE

EMR Region assets



Subsurface:

- Dampening of vibrations and building in a quiet landscape
- Sufficient and suitable rock masses

Location:

- Ecosystem of renowned research institutes and high-tech industry
- Attractive international living & business climate
- Good connectivity, excellent education, multilingual area

International cooperation:

- Existing strong cooperation internationally
- New elected governments support ET-EMR
- Solid preparation of feasibility studies

ET-EMR Starting points

1: Scientific community is customer

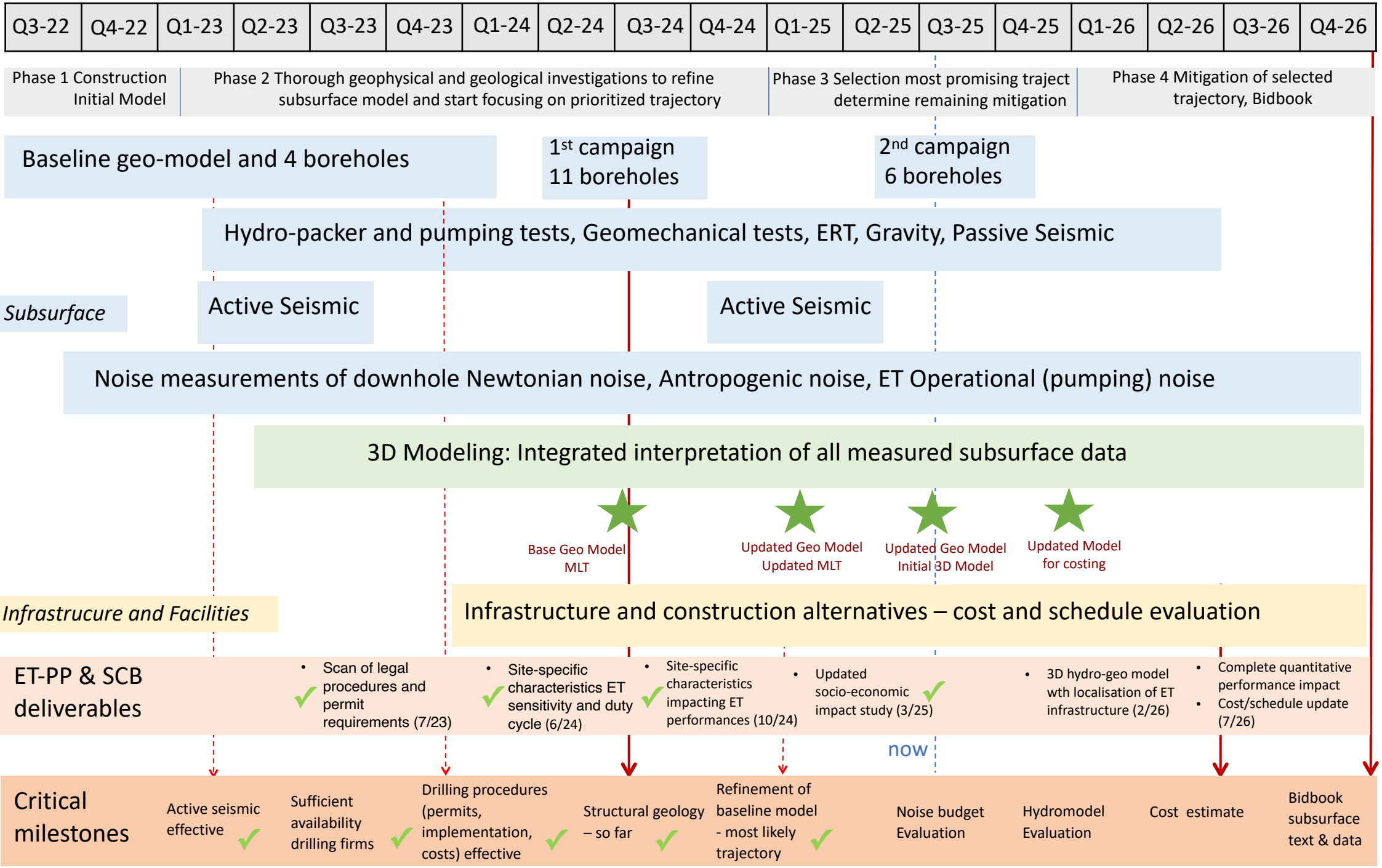
- Adaptive power, to absorb the scientific wishes and requirements

2: Public management

- Public money, public responsibility, public accountability
- Account for choices, costs, and added value; broad socio-economic impact requirement
- Sustainability, circularity, nature, landscape and livability also part of responsibility

3: Synergy as the definition of success

- Integral approach: science, geology, civil engineering, environment and involving society, active R&D network, valorisation, financial commitment



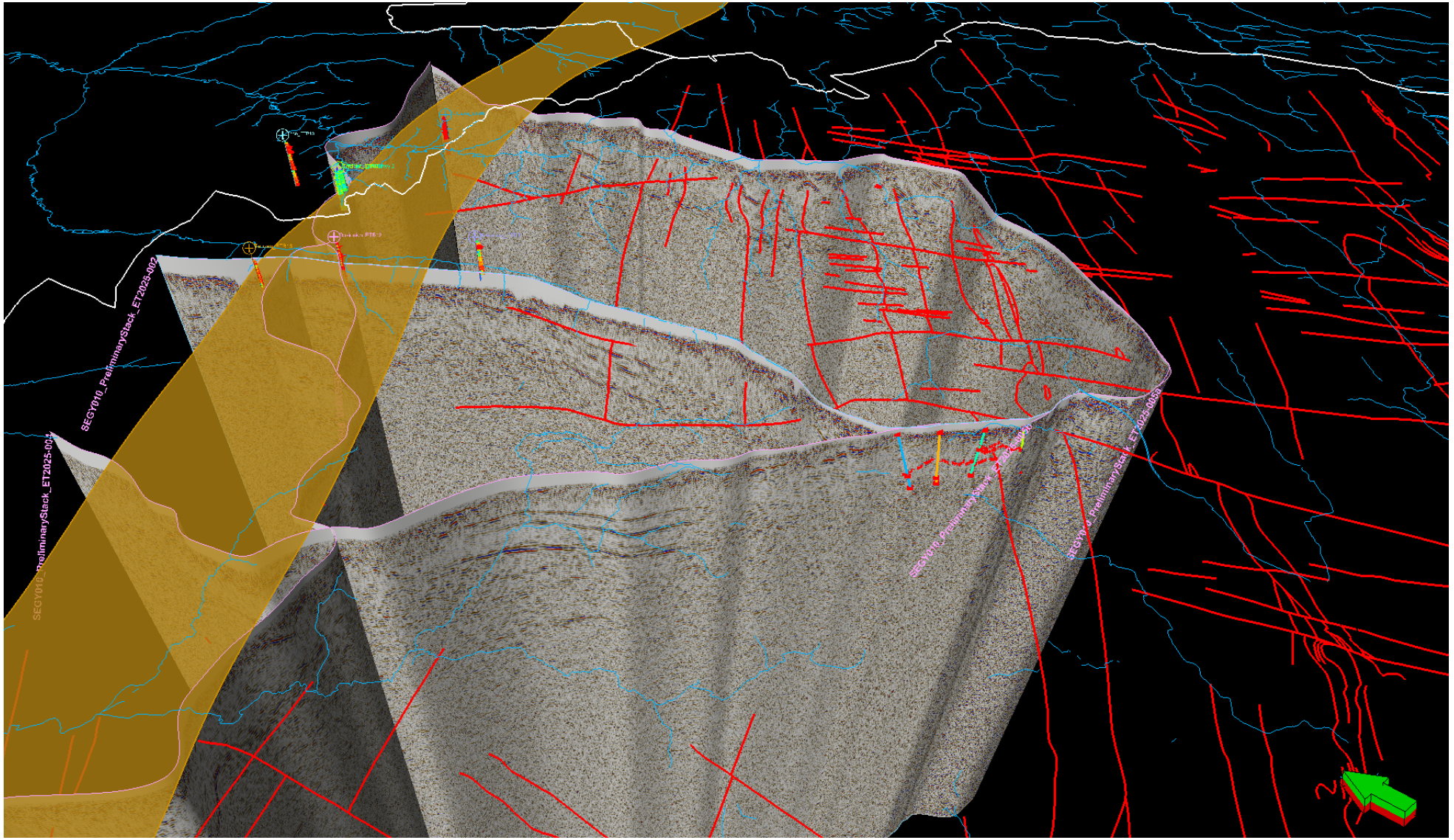
Current Timeline EMR

Subsurface activities only

Schedule does not include potential additional work for L layout

EINSTEIN TELESCOPE

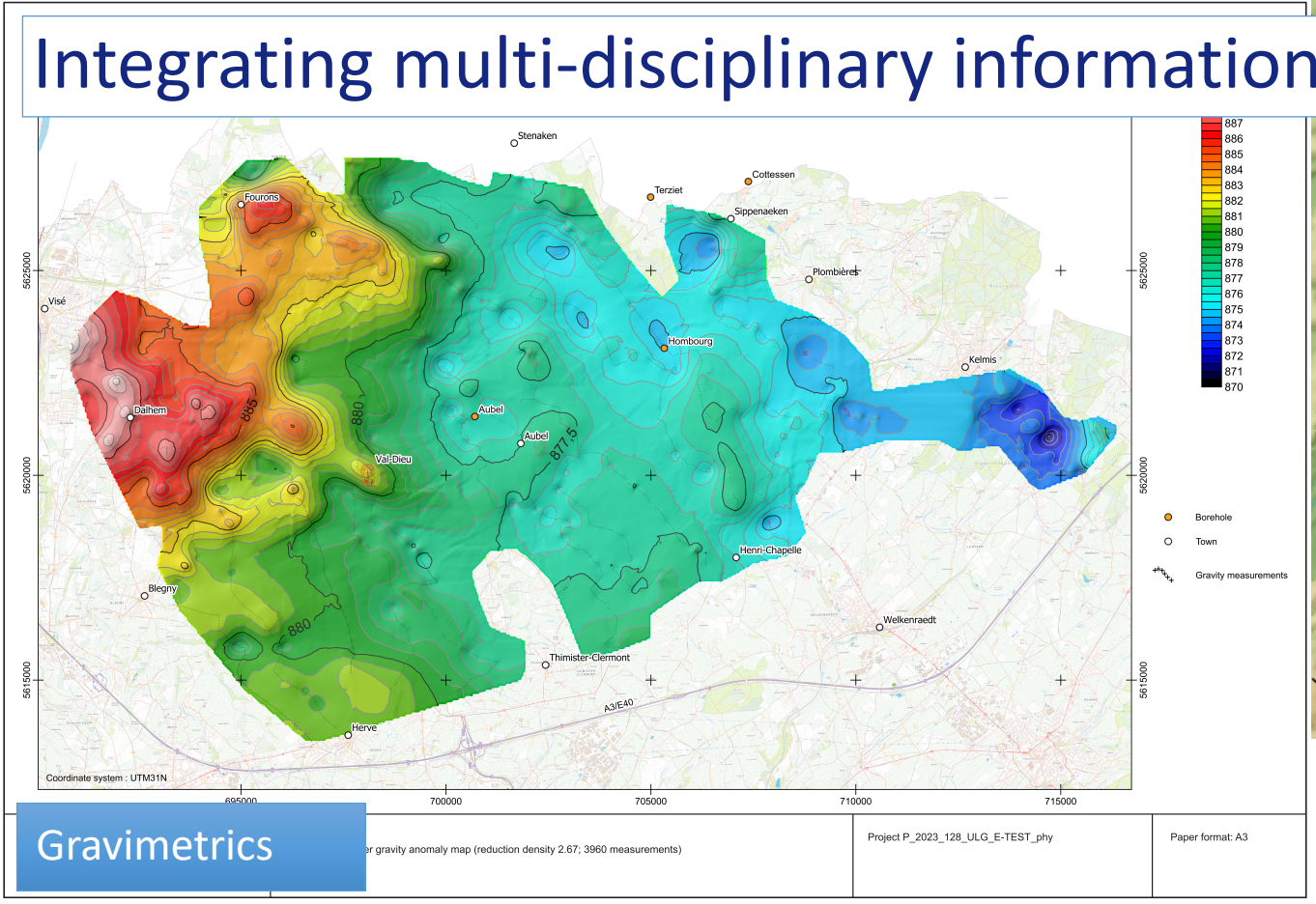
Geology: 3D Model building and interpretation focus:



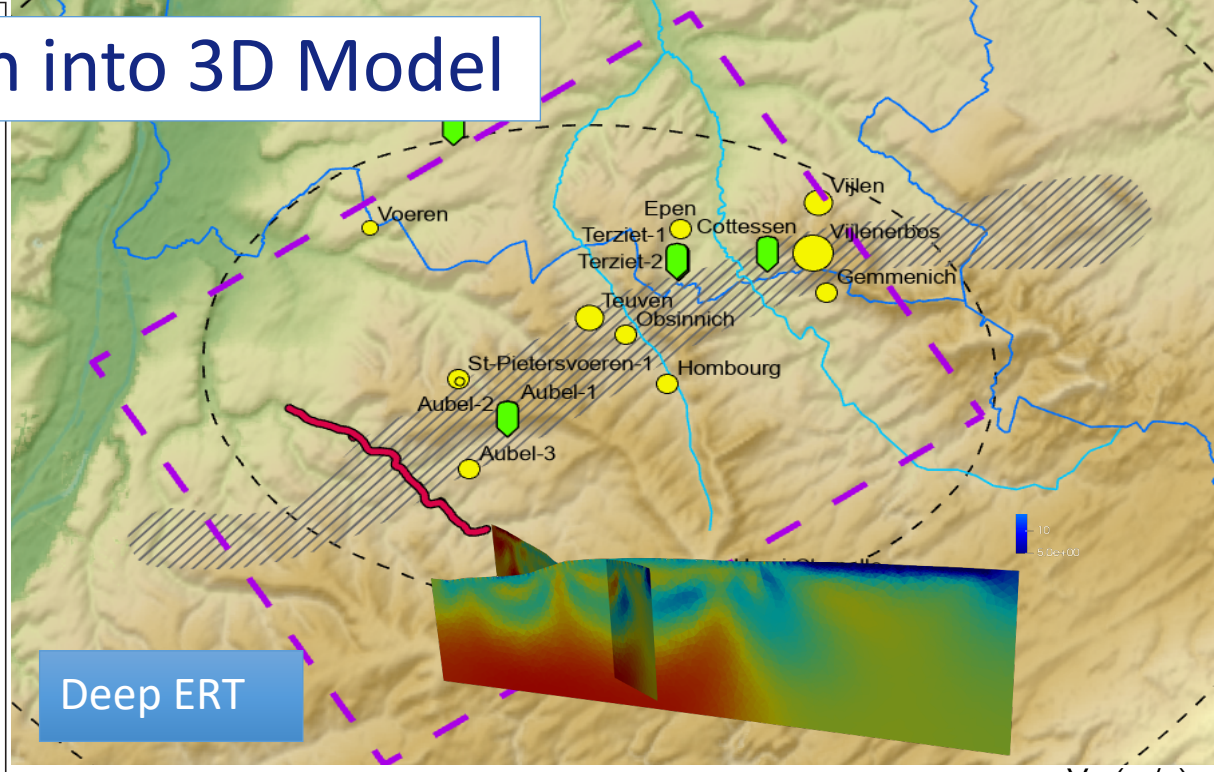
Integrating all data into holistic 3D subsurface model

Multi-disciplinary interpretation

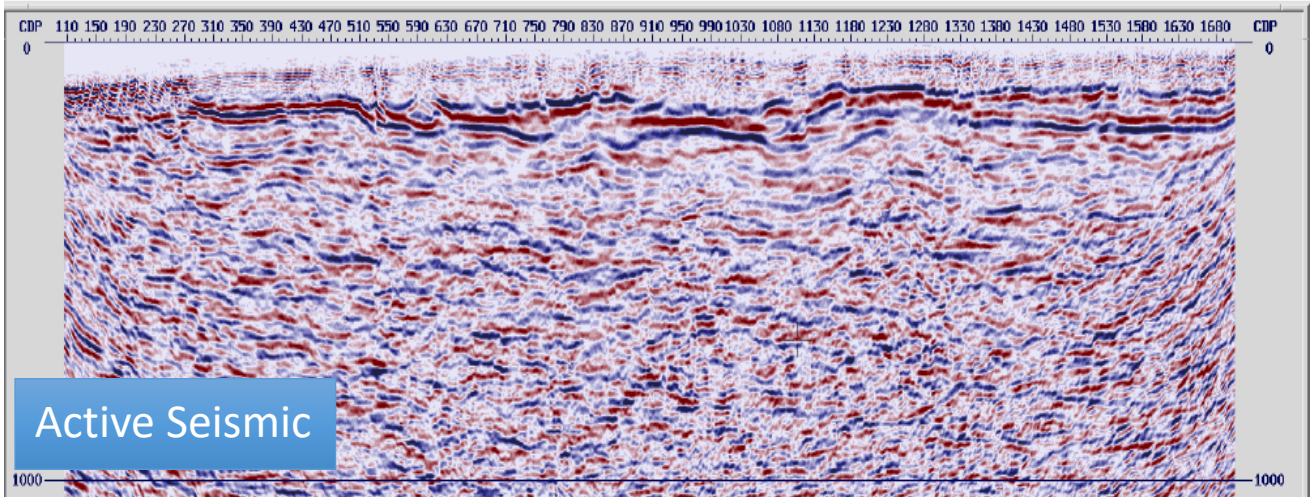
Integrating multi-disciplinary information into 3D Model



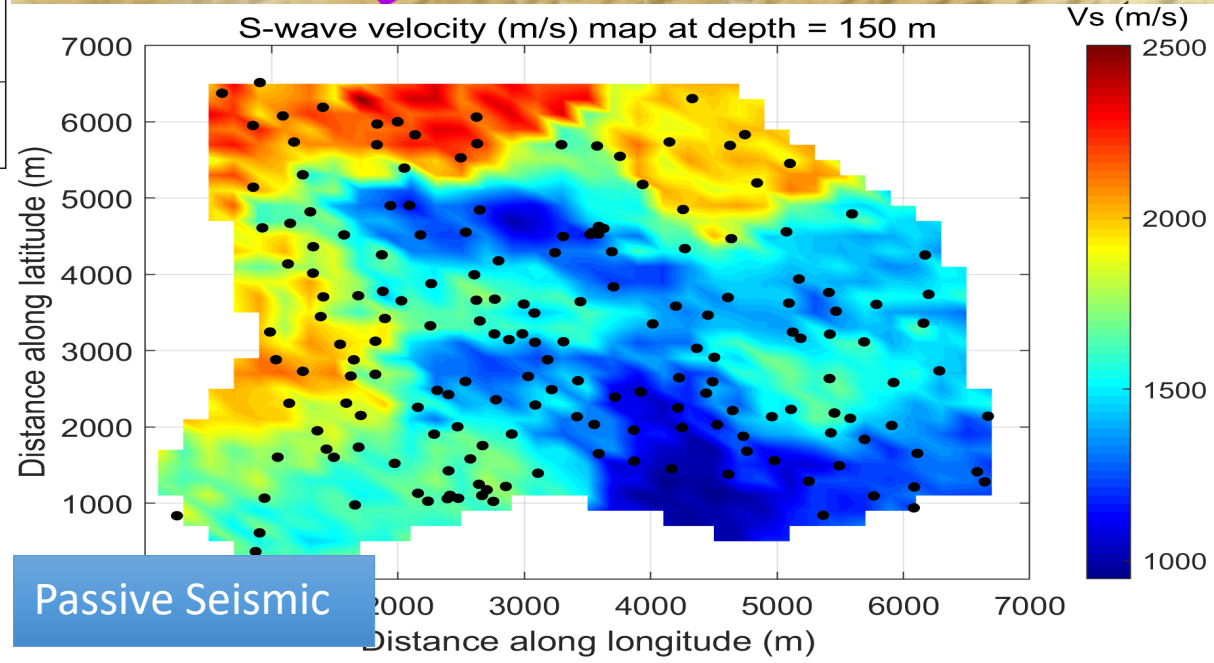
Gravimetrics



Deep ERT

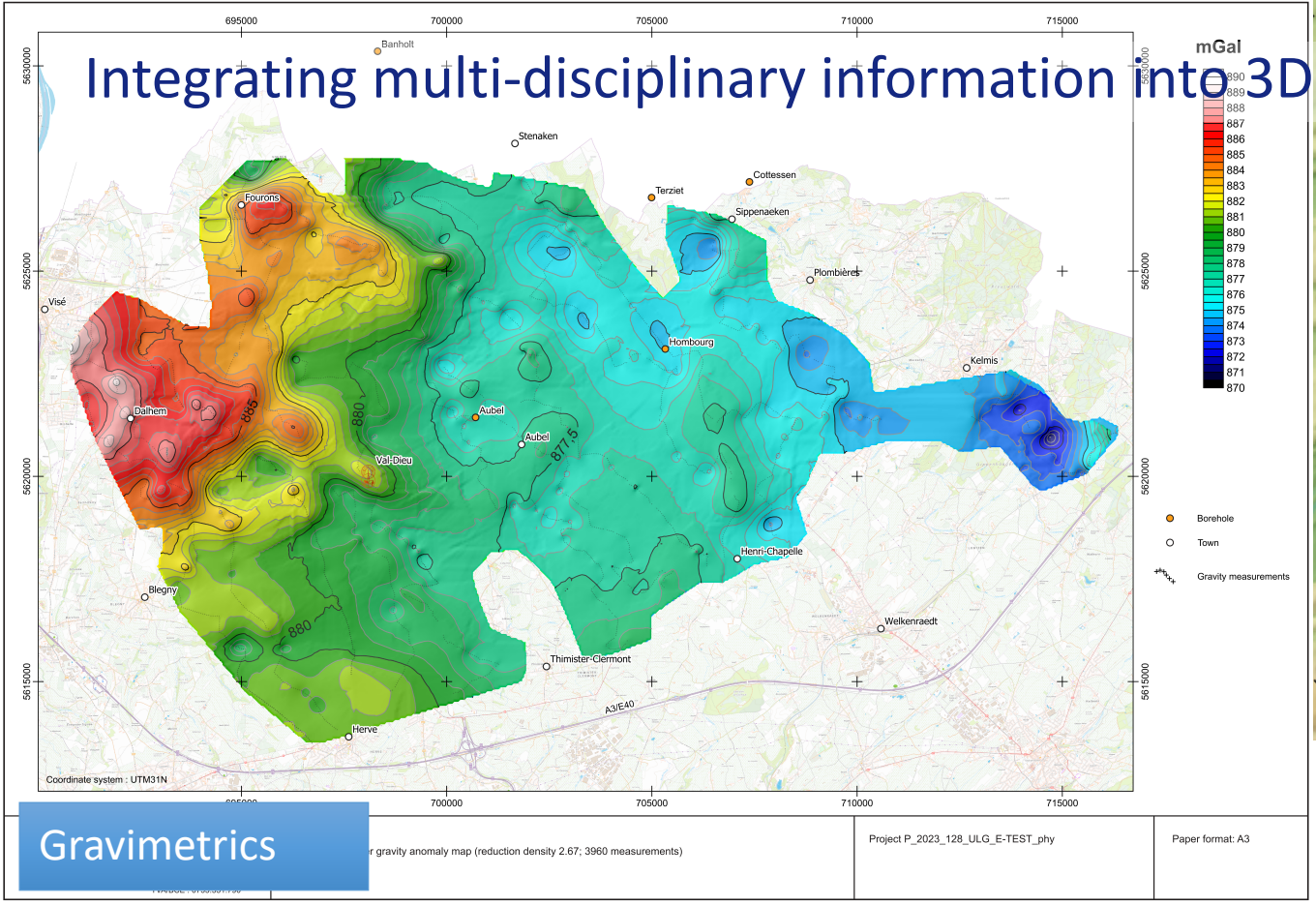


Active Seismic

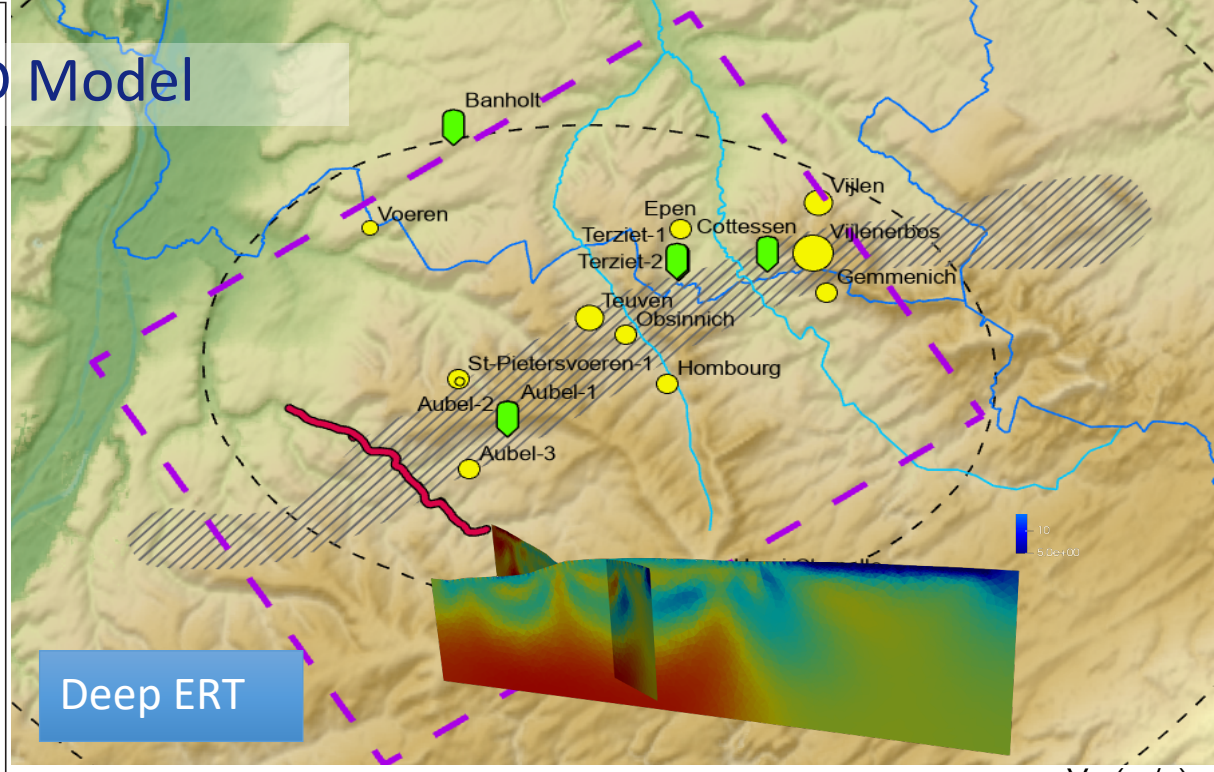


Passive Seismic

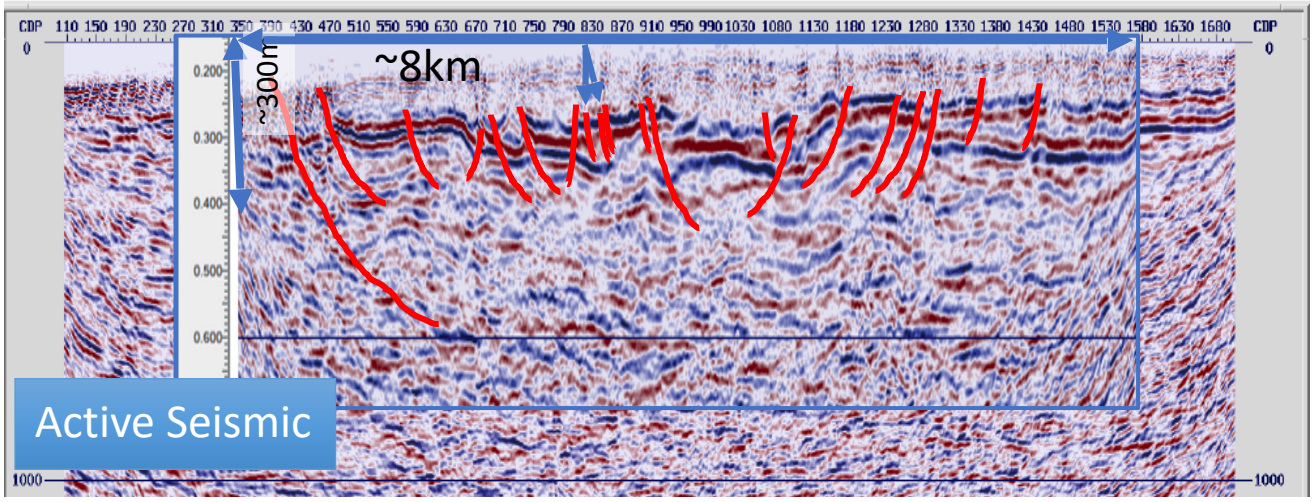
Integrating multi-disciplinary information into 3D Model



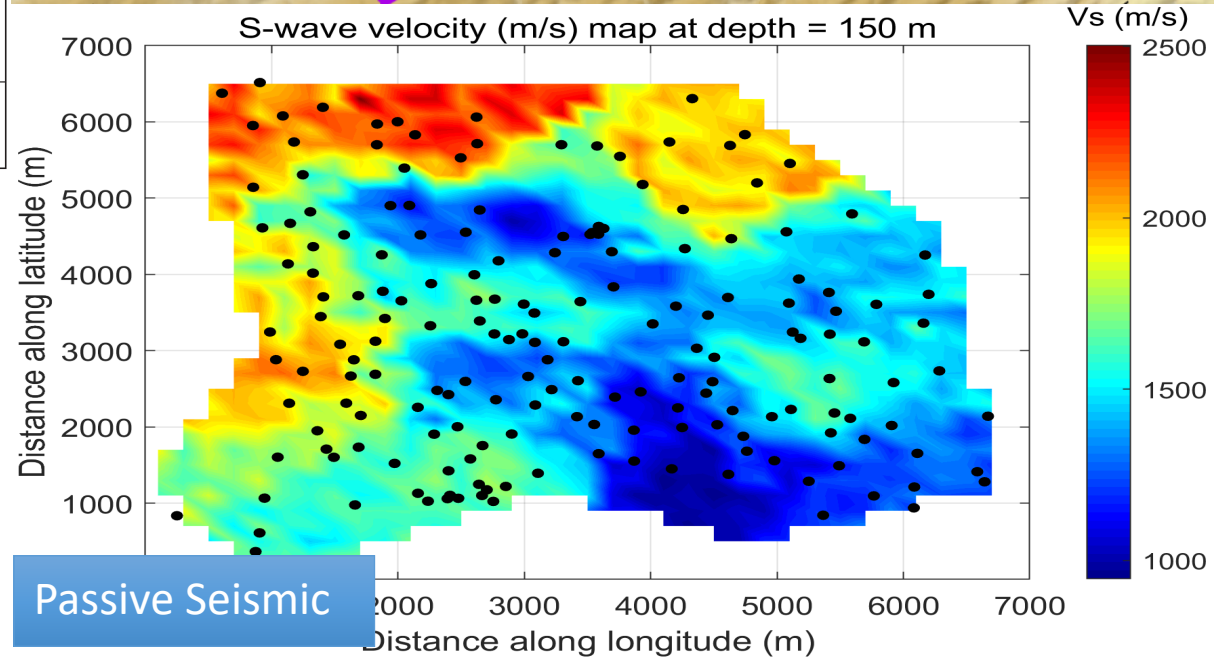
Gravimetrics



Deep ERT



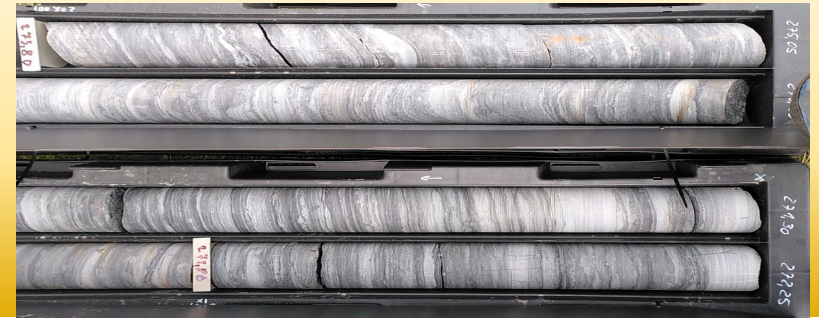
Active Seismic



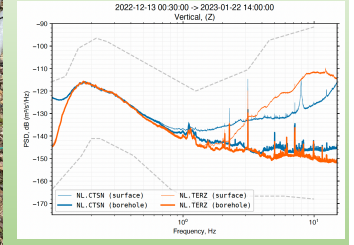
Passive Seismic

Current Status (July 2025):

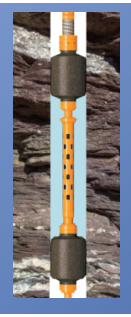
- 11 new boreholes completed 300-400m deep
- Total of 16 boreholes being evaluated
- 2nd borehole campaign started May 19th evaluating geo-mechanics at potential vertices to correct depth, all equipped with seismometers
- Boreholes to derisk L configuration are defined and added but not yet approved

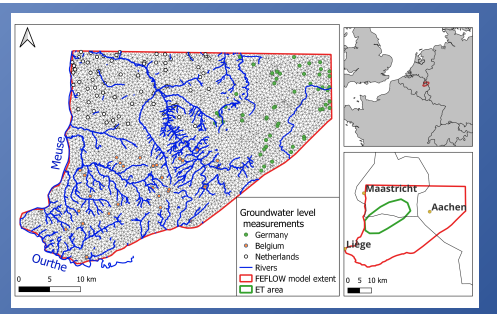


- Subsurface noise network being installed for 10 boreholes, new results Q3-Q4
- All seismometer boreholes also equipped with DAS and VSP
- Noise measurements at surface ongoing
- Dedicated team in place to develop more sophisticated Newtonian Noise modeling
- Noise mitigation schemes starting to be addressed

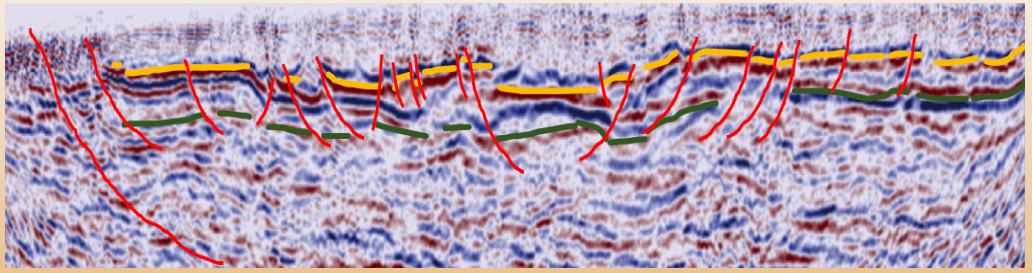


- In total 6 boreholes have been equipped for hydro measurements
- Another 2 will be added during 2nd borehole campaign
- 3D Subsurface Hydro-geological model being constructed
- First significant version ready Q3

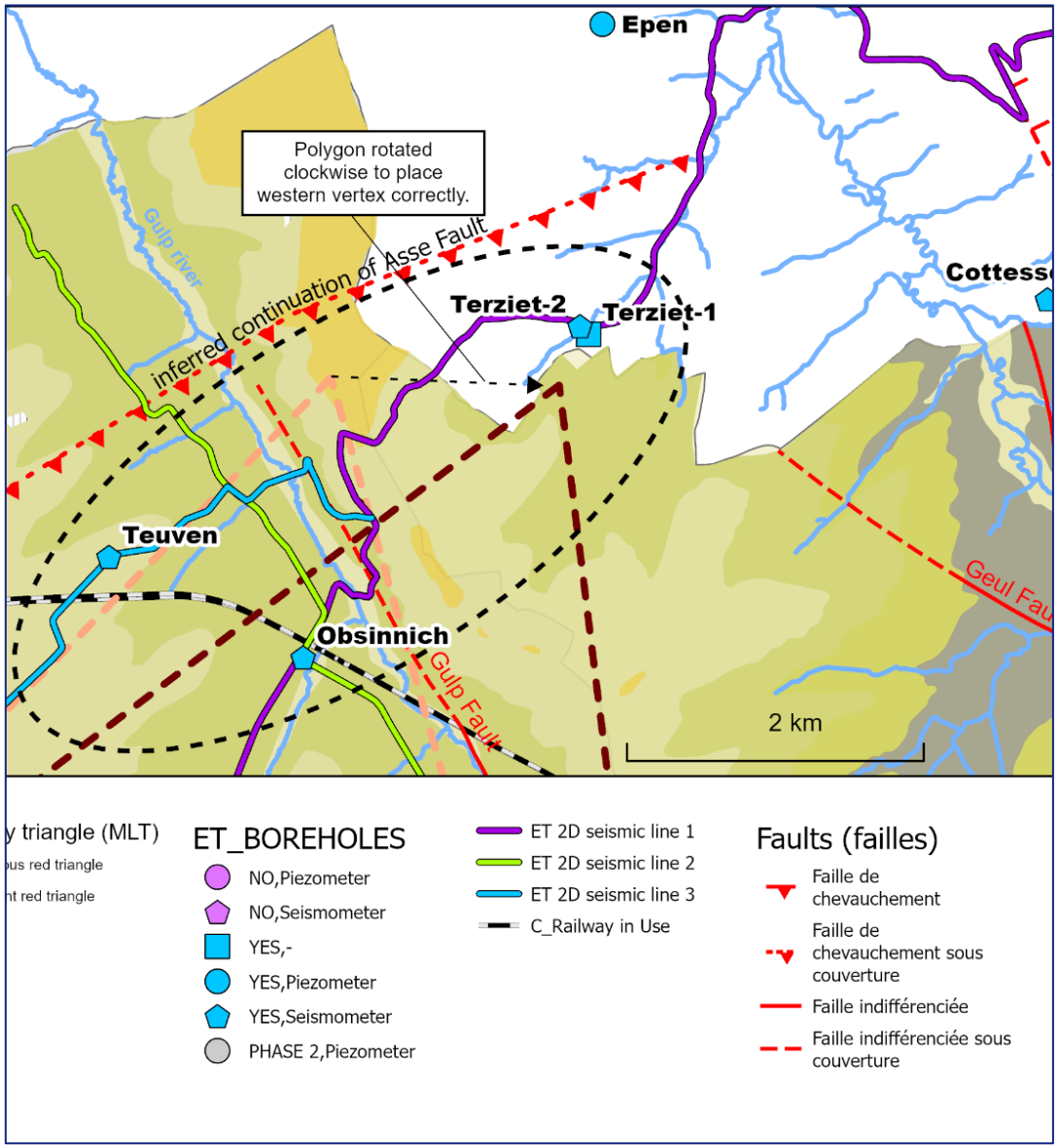




- 100 km seismic completed in April, confirming nice resolution with updated receiver topology
- Seismic being processed and input into 3D subsurface model
- Refining structural geology view in between vertices

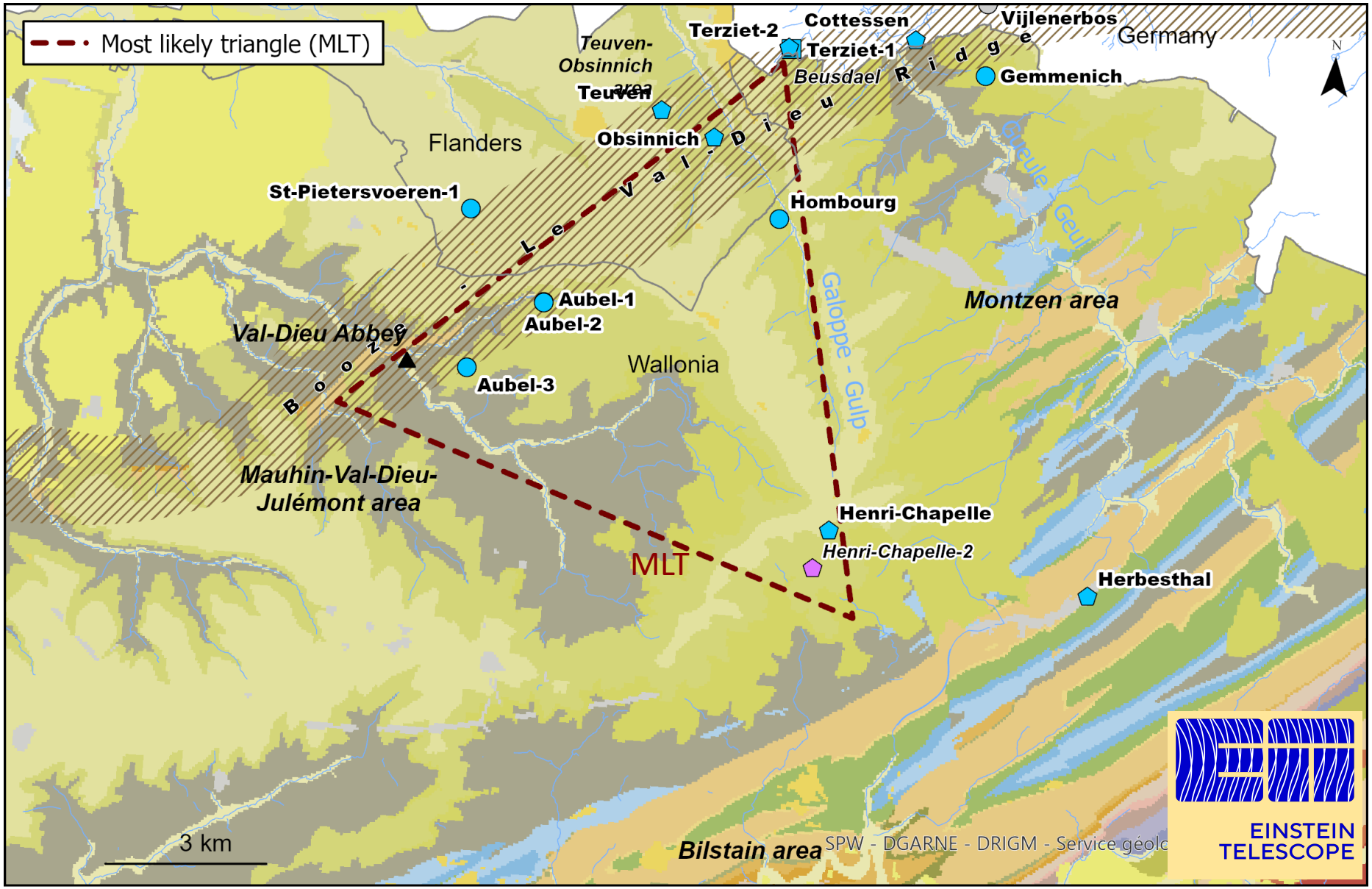


Using structural geological and geomechanical evaluations to optimize location of 2nd campaign boreholes



EINSTEIN TELESCOPE

Most Likely Triangle – based on current knowledge



MLT location convergence based on:

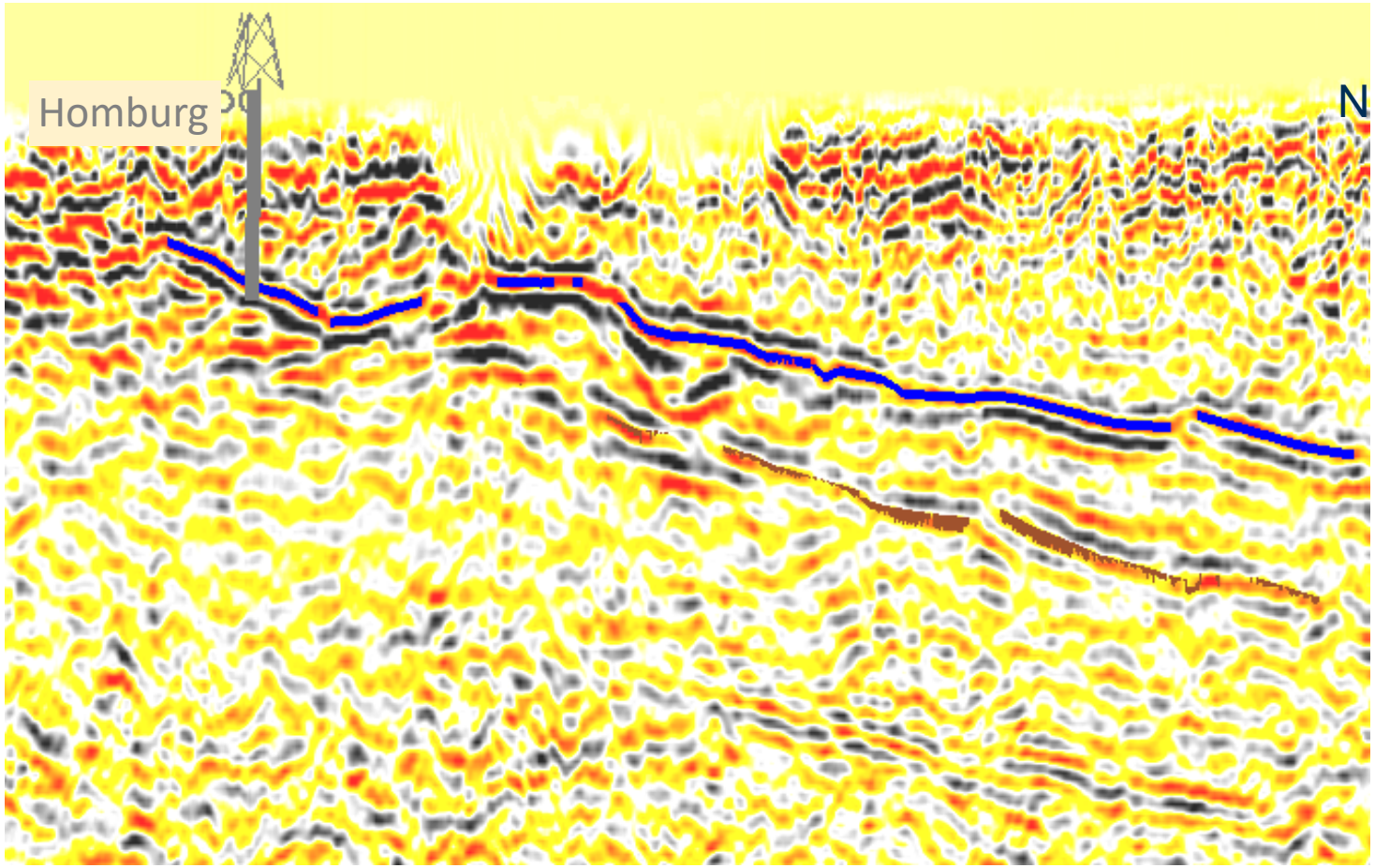
- Structural geology model
- Geomechanical core evaluation
- Available seismic and ERT data

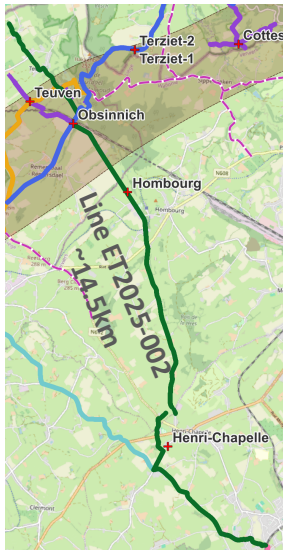
2nd borehole campaign:

- Confirm vertices
- Use recently completed seismic campaign data
- Refine hydro-geological model
- Investigate L (boreholes pending approval)

Preliminary interpretation of ET2025-002 at Hombourg

- Top Dinantian (blue line) ties very well with Hombourg well and good to trace in southern direction
- Thickening in southern direction is consistent with regional knowledge

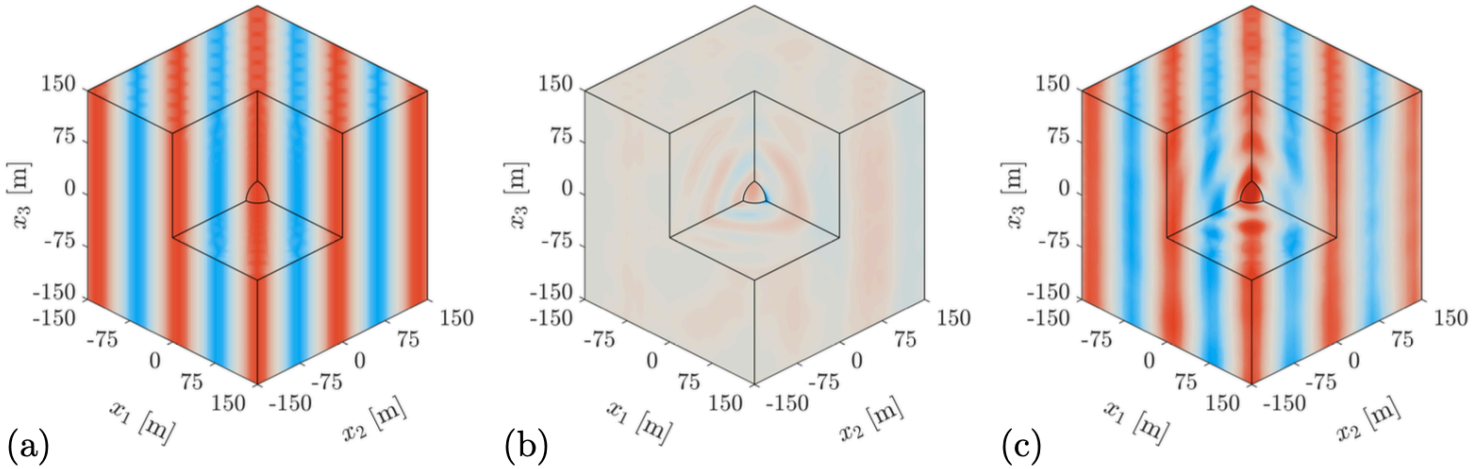




- Excellent seismic depth calibration from boreholes
- Fine tuning of final vertex locations

EINSTEIN TELESCOPE

Newtonian Noise



Evaluate the NN

- We currently do not have an approved model of NN for complex geological settings
- EMR demands, and develops, adequate noise modeling that suits the region

We aim to develop a numerical framework to compute NN to account for arbitrary heterogeneities and sources distribution

- i.e. finite elements for the seismic wavefield and Gaussian quadrature to integrate the NN on FE mesh
- Suitable for any geology - and applicable to EMR
  - So far, NN predictions are based on homogeneous geology
- Suitable for adequate geometries/topographies
  - So far only very simplistic geometries considered (Harms et al. Eur. Phys. J. Plus (2022) 137)
- Suitable for variety of noise sources and mitigation effects
  - So far magnetic and electric disturbance have not been considered

Specific geology

So far EMR has only TERZIET as benchmark

- EMR subsurface measurements are expected late summer 2025
- TERZIET is not on target depth, and hence not representative of EMR

Geology challenges

- EMR has special geological environment where infrastructure is ‘protected’ by soft layers on top
  - Vertical attenuation is much larger compared to other sites

EMR is relatively insensitive to future changes in surface activities

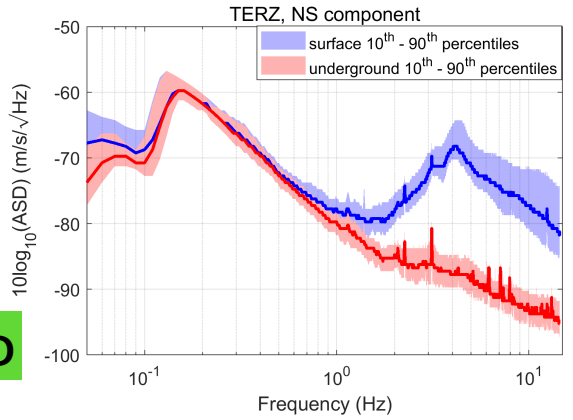
- *This robustness is important for an infrastructure that will run for >50 years!*

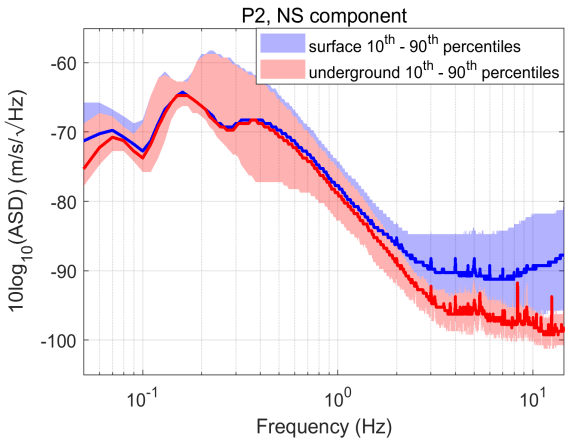
Comparing surface with subsurface

Terziet
- Local depth: 250 m
- Elevation: 150 m

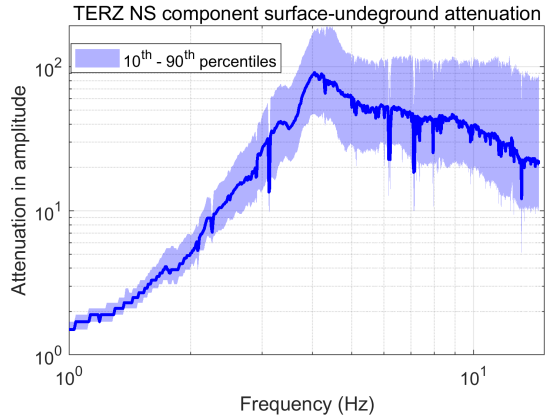
P2 (Bitti)
- Local dept: 264 m
- Elevation: 808 m

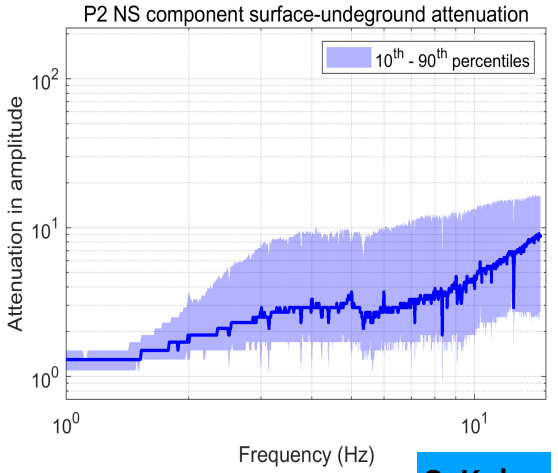
PSD





ratio





S. Koley

Newtonian Noise for EMR

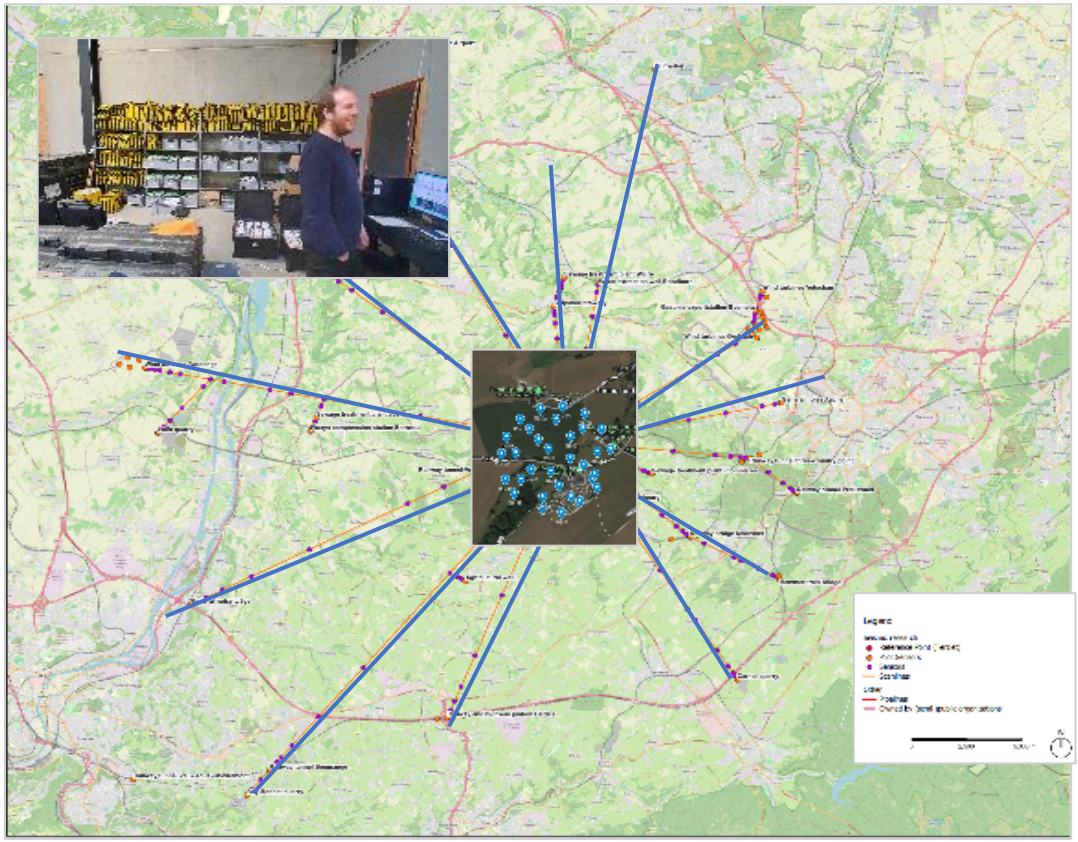
Structured geology provides (additional) opportunity for noise mitigation

- *Requires careful and approved NN modeling for the EMR region*

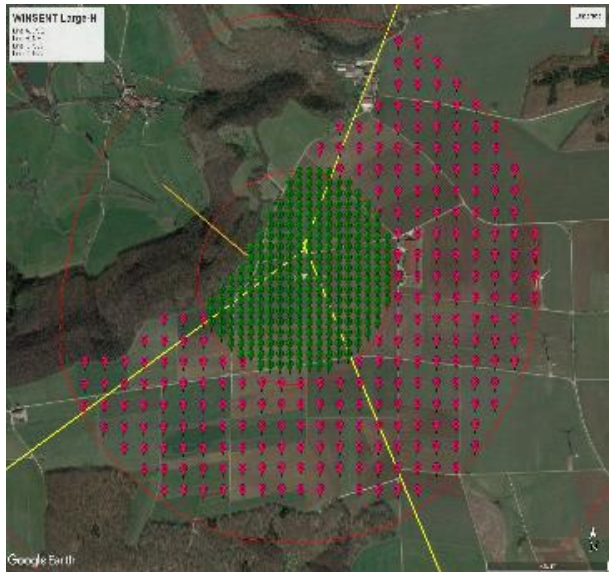
Liège
RWTH
Nikhef
KULeuven
Hamburg
Ghent

- Workshop is active to connect to geology modeling
  1. Measuring the noise at surface and subsurface
     - Quantify attenuation effect for subsurface
  2. Propagation to the corners points
     - Propagation of seismic waves depend on the geology structure and lithology
     - Full account of the complex geology with softer top-layers
  3. Effect of the residual PSD noise on the ET instrument
     - Calculation of NN contribution, using adequate models for geology and sources
  4. Mitigation efforts
     - Active and passive mitigation (e.g. geometry of the caverns)

Seismic & Surface Noise Measurements:



Surface noise measurements using Scan Lines towards noise sources to evaluate impact



4 towers for meterological data
Eddy covariance (vert. turbulent flux)
Lidar (wind monitoring, etc.)
Ceilometer (cloud height, etc.)
Tower movements
- Bending moments
- Torsional moments
- Acceleration

Broadband seismometer (0.05-45Hz)
Rotational geophones on foundation
Dense geophone grid around foundation

Source function of a fully instrumented windturbine recorded

EINSTEIN TELESCOPE

Civil Engineering EMR

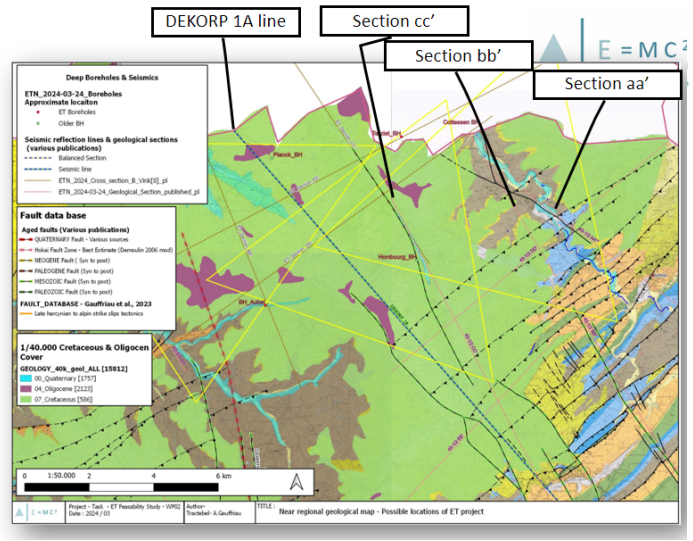
- Review of the geological and geotechnical data
- Dedicated geo-mechanical / civil-engineering team
- Facilities and Infrastructure
- Developing various construction scenarios
- Estimating building cost most likely triangle construction scenario

Einstein Telescope

Conceptual geological model

Geological map.

DEKORP 1A seismic line and 1:25000 geological cross sections are shown on the map.




laminated black CLAYSTONE

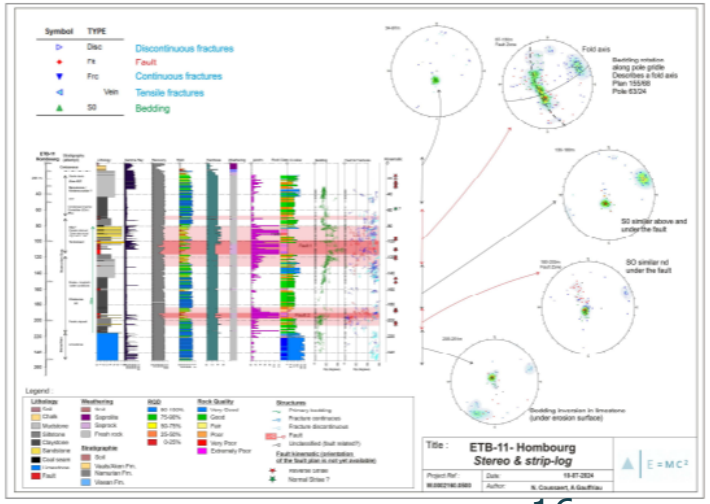


Figure 5 : Structural patterns of each tectonic domains towards depth

Socio-economic (updated)

The EMR region offers strong research institutes and high-tech industry.

- Since 2018:
  Strong science and innovation potential for both the Einstein Telescope and impact to the EMR region and Europe.

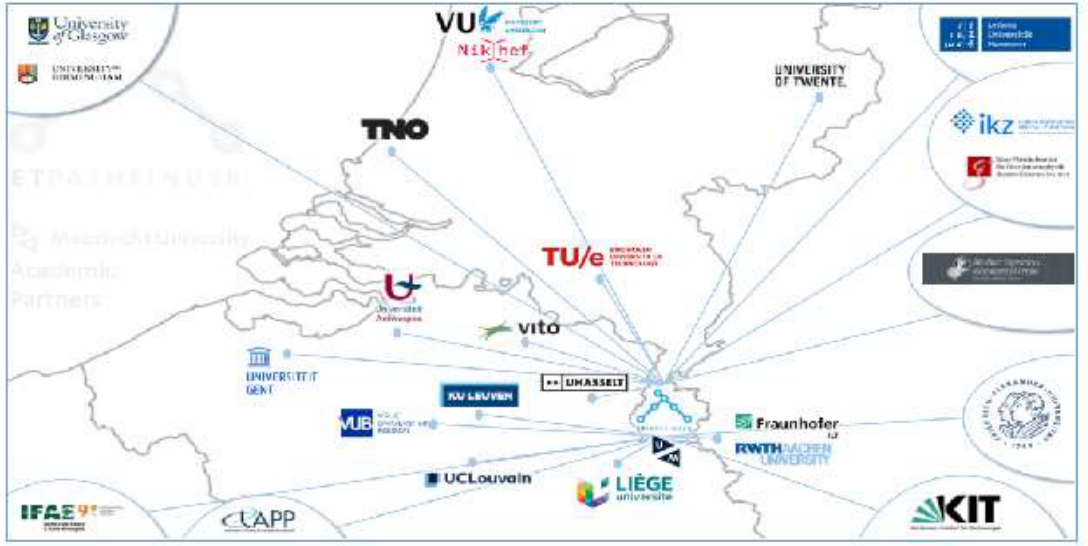
Pillar R&D infrastructures that drive key enabling technologies and deliver innovation

- ETpathfinder and ET-CRISTAL; Innovation projects like ET2SMEs, ET4business and the Einstein Telescope Education Center.

Socio-economic (updated)

The overal investment in research and development projects for the Einstein Telescope is already over €100 million.

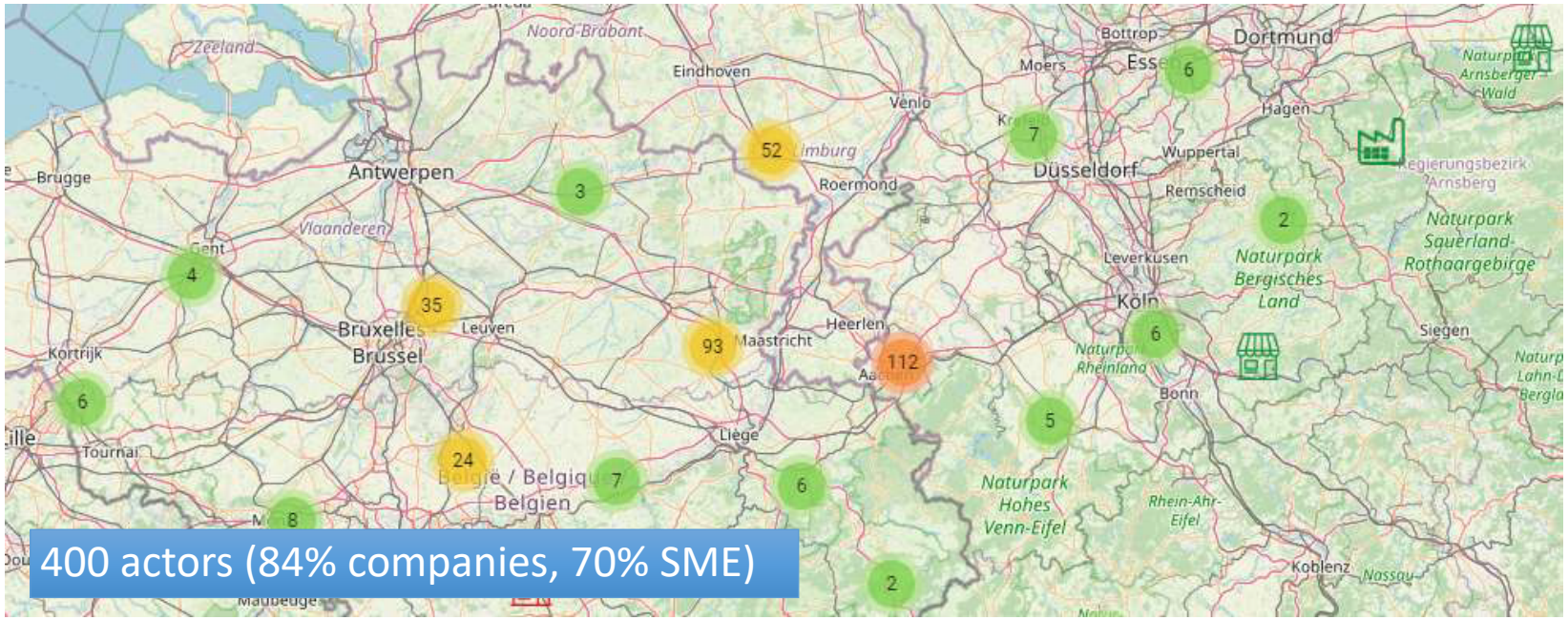
- Around 400 relevant industry actors with technologies relevant to ET in the EMR are recorded that they can contribute.

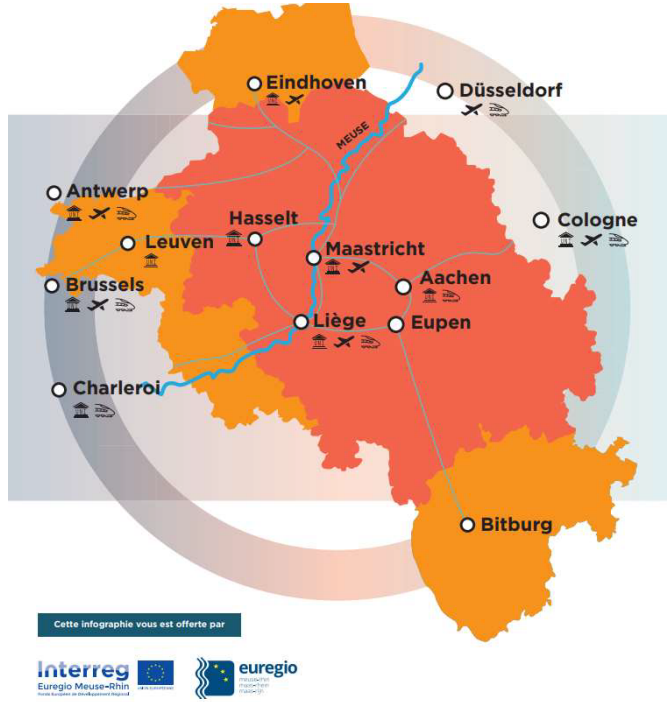


There are already plenty of examples.

- NL: New vibration-free cooling systems that may be useful for future quantum computers.
- Belgian research on mirror coatings may be applicable in chip technology, or in UV filters for construction or solar cells.
- Germany laser research is of interest to the automotive industry, in LIDAR systems to measure distances.
  - RWTH: two currently running projects (BeamPipes4ET and UHV.NRW) represent together a volume of Euro 5.04 mln. and are furthermore excellent examples for euregional business involvement

Socio-economic (updated)





Economic studies have been delivered and are in progress also showing the economic impact.

- Already visible for the preparatory phase and the technology development.
- Also the case for the direct return that comes from the construction and operation of the Einstein Telescope.
- Science and innovation ecosystem act as an ecosystem magnet for talent, innovation and knowledge development.

This shows the sense of Europe investing in the Einstein Telescope, not only for science but also for the economic and societal impact.